Historic England

Heat Pumps in Historic Buildings

Air Source Heat Pump Case Studies – Small-scale Buildings

Summary

Electrifying heat is key to reducing reliance on fossil fuels for historic buildings. No technology is better placed for space heating than heat pumps. If the whole heating system is well designed, it will deliver comparable running costs to natural gas systems. Air source heat pump (ASHP) technology can be installed quickly and has lower capital costs than other heat pump technologies. This makes air source a key technology in the decarbonisation of space heating.

There are many examples of ASHPs performing well in historic buildings in England. However, there are also instances where new ASHPs have not met expectations. When poorly performing systems are reported openly without exploring the underlying issues, people may conclude that heat pumps are not a suitable replacement for fossil fuel heating systems in older buildings.

In 2021, we commissioned environmental building services engineers specialising in net zero technology, Max Fordham LLP to review the performance of ASHPs in 10 properties: homes, offices, shops and two small churches across England to inform our on-going advisory work. The key findings were:

- ASHPs work well in a range of different historic building types and uses.
- The type of ASHP and the heat emitters selected must complement the building and its occupancy.
- Building occupants need briefing on how to make best use of their ASHPs and reduce running costs. The user demonstration should include how to optimise the heating system and adjust setpoints and schedules.
- The visual and noise impact of ASHP external units and the cold air plume discharges were not an issue in any of the case studies. However, it is good practice to carefully consider the positioning of units to minimise impacts whether or not the building is historic.
- Four out of 10 of the case studies would have benefited from an alternative type of ASHP or heat emitters.

This publication has been prepared by Max Fordham LLP and reviewed by Caroline Cattini-Dow and Dan McNaughton (Historic England).

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Contents

1 Introduction

Figure 1:
Location of the 10 case studies and types of ASHPs. Monobloc ASHPs are shown in blue. DX ASHPs are shown in red.

Ten case studies were commissioned to help understand factors underlying good or poor system performance in air source heat pumps (ASHPs). These case studies span homes, offices and shops, and churches in Cheshire, Cornwall, Cumbria, Gloucestershire and London. The case studies were mostly 18th and 19th century buildings and included a range of building construction types, and six were listed buildings. All of the properties had ASHPs installed as their primary space heating. Five of the properties use monobloc (air-to-water) ASHPs, and five had some type of direct expansion (air-to-air) ASHP.

Case studies evaluation parameters

The ASHP at each site was evaluated to assess its efficacy. The building services engineers considered:

- visual appearance
- noise
- electrical design
- manufacturer's guidance
- hydraulic design, including heat emitter
- maintenance
- defrost cycles
- controls
- performance
- thermal improvements to the building
- refrigerant used
- running costs
- occupants' experience.

In order to do this evaluation, the building services engineers did a non-intrusive site survey with the occupant, visually checked the ASHP and:

- took photographs
- measured the free area around the ASHP
- measured the distance to the closest noise-sensitive location
- measured noise levels, with and without the ASHP running
- measured flow speeds at the ASHP air exit
- took thermal images
- checked for the presence and quality of key installation components, such as anti-vibration mounts and pipework insulation
- measured radiator and pipe size
- measured the glycol content of the system's fluid.

Each building occupant was asked a prepared set of questions about their experience living with the ASHP heating system including:

- Have you found the building comfortable since the ASHP was installed?
- How have you found the noise levels coming from the ASHP?
- Has the cold air emitted from the ASHP caused any problems?
- How have the running costs changed, if at all?
- Do you know how to use the controller for the heating system?
- Do you understand the maintenance requirements of the ASHP?
- Have you noticed the defrost function causing any drop in comfort?

The ASHP installations were graded for technology choice, user comfort and system design/installation quality:

System details key

Technology choice

☆☆	Poor	An alternative technology would offer significant or multiple advantages to the installed system.
★☆	Good	The installed system is not detrimental to energy use/running costs, but an alternative technology may offer other advantages.
★★	Excellent	Optimal technology match for the type of building and its use.

User comfort

☆☆	Worse	Users expressed dissatisfaction with their thermal comfort compared with their previous heating system.
★☆	Neutral	Users reported no change in thermal comfort after installing an ASHP.
★★	Improved	Users expressed an improvement in thermal comfort compared with their previous heating system.

System design/installation quality

☆☆	Poor	Specific design choices or poor quality installation could be contributing to suboptimal efficiency.
★☆	Good	Aspects of system design or install quality could be improved, but are unlikely to impact system efficiency.
★★	Excellent	Optimally designed and installed system.

Measures and abbreviations

°C — temperature in Celsius
CO_2 — carbon dioxide
COP — coefficient of performance, SCOP — seasonal COP
F-Gas — fluorinated gases
GWP — global warming potential
kWh — electrical energy used in kilowatts per hour
l/s — flow rate in litres/second
ΔT — temperature difference
Pa — pressure measured in Pascals
W — power measured in Watts

Case studies limitations

There was no intrusive system testing.

Where available, energy bills were used to assess the running costs, however some were estimates or did not cover the appropriate time periods. It was often not possible to separate heating and hot water use from other household electrical consumption, such as cooking, lighting and domestic appliances. This made it challenging to make quantitative comparisons before and after the ASHP was installed. The users' perceptions of running costs have been reported but the information is highly subjective to each individual's expectations.

Users' views were sought about the look of their ASHP and external and indoor units, noise and cold air discharge plumes. However, structured surveys of views from others such as neighbours, passers-by, historic building conservation advisers in local authorities or Historic England were not carried out.

The case study findings are based on a single visit to each site and dependent on the weather that day. The site visits were carried out between December 2021 and February 2022.

Although each case study survey was thorough, it was not possible to inspect those parts of the property that were covered or inaccessible at the time of the visit.

2 ASHP types: monobloc and direct expansion

In an ASHP, the evaporator extracts heat from the outside air. It does this by dropping the pressure in the evaporator so that the refrigerant begins to boil at a lower temperature than the ambient air temperature. This allows heat to be extracted from the air, even on the coldest days. The condenser is the part of the ASHP that delivers the heat into the building.

There are two types of ASHPs: monobloc and direct expansion (DX). All ASHPs house the evaporator (heat exchanger and fans) in an external unit. The difference between the two types of ASHPs is the location of the condenser. In a monobloc ASHP, the condenser is located within the external unit. In a DX ASHP, it is located away from the external unit.

A monobloc air-to-water ASHP connects directly to the building's heating system. The pipes connecting the external unit and the building are filled with heating system water. This wet heating system can then use traditional heat emitters, such as underfloor heating, radiators or fan convectors, to deliver heat to the space.

ASHP external unit dimensions and colours

Single ASHP external units are typically 1,200mm tall, 1,000mm wide and 400mm deep. In keeping with permittted development rights, the units have to be no larger $0.6m^3$.

Permitted development rights do not apply for listed buildings and scheduled monuments, or where there are Article 4 directions for Conservation Areas or World Heritage Sites.

Standard colours for units are off-white to grey. Although it is possible to specify other colours, changing the unit may undermine the manufacturer's warranty.

For more information about planning permissions see www.planningportal.co.uk/permission/common-projects/heat-pumps/planning-permission-air-source-heat-pump

DX systems transfer heat into the building using refrigerant rather than water. The pipework connecting the external unit with the building will be two different diameters. This diameter difference is often the easiest way of telling a monobloc and DX system apart. The remote condenser in a DX system can either interface with a wet heating system via a heat exchanger or directly with the individual room heat emitters or indoor units. Systems that use indoor units to deliver warmth are referred to as air-to-air heat pumps. Most DX systems also allow the unit to run in a cooling mode. Care is needed to ensure overall energy consumption does not inadvertently increase by operating in cooling mode in summer.

There are three main DX types: split system, multi-split system and variable refrigerant system. The split system is the simplest. One indoor unit connects directly to one external unit. A separate external unit is, therefore, required to extend the system.

The multi-split system allows multiple indoor units to be connected directly to a single external unit. Each indoor unit can be set to an individual temperature, but all the indoor units must be in either heating or cooling mode at the same time.

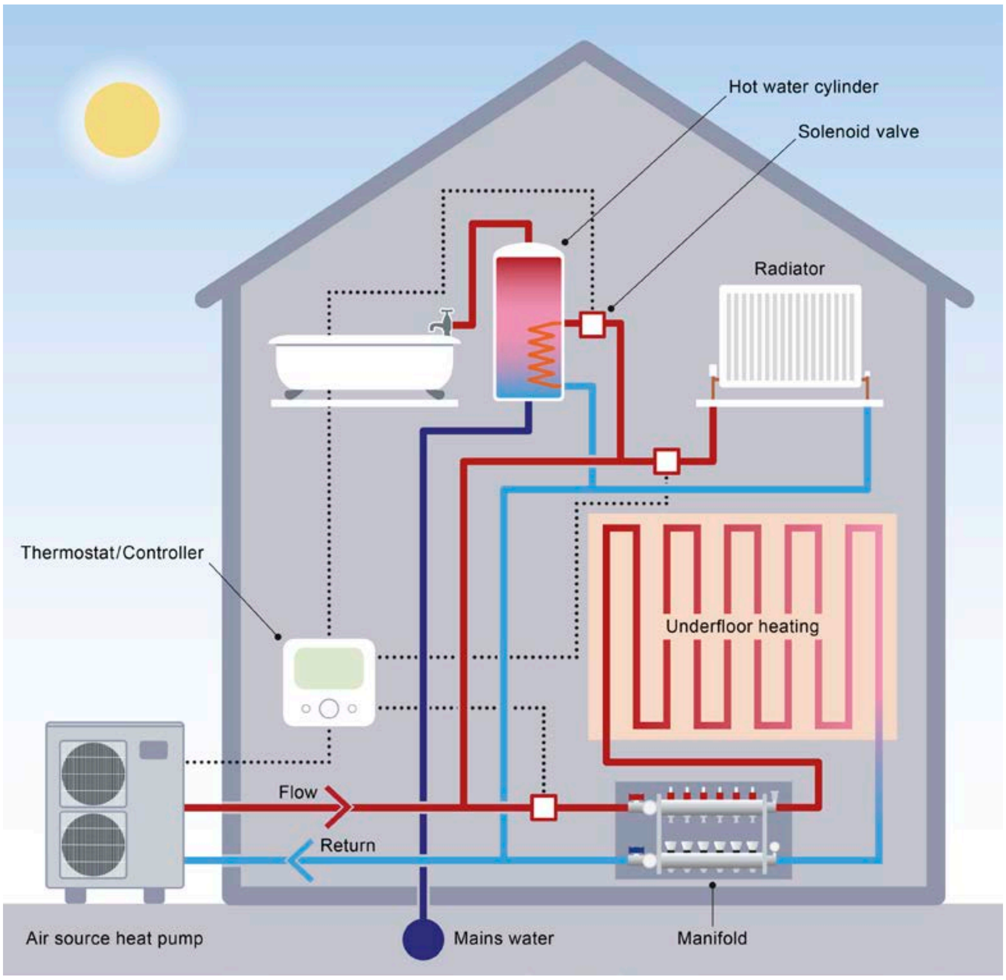
The most efficient and flexible system is the variable refrigerant system, but it comes with the highest initial outlay. This system allows multiple indoor units to be connected to a single external unit, and it can facilitate simultaneous heating and cooling. To enable this functionality, additional equipment is required between the external unit and the indoor emitters. Traditional variable refrigerant systems have high refrigerant charges, which can leak over time. Hybrid variable refrigerant systems that significantly reduce the amount of refrigerant required are now available.

Figure 2:
An example of a typical wall-mounted indoor condenser often used with DX ASHPs for both heating and cooling. The indoor condenser has been colour-matched to blend with the decor.

Monobloc ASHPs

- have a hermetically sealed refrigeration circuit so there is no on-site refrigeration pipework, reduced chance of refrigerant leaks, and installers do not need to be fluorinated gas (F-Gas) qualified
- can utilise natural refrigerants which have a low environmental impact
- work with traditional heating systems (radiators, fan convectors and underfloor heating
- generate hot water via a storage tank,
- the maximum distance between the external unit and cylinder/ connection to the heating system is around 20m.

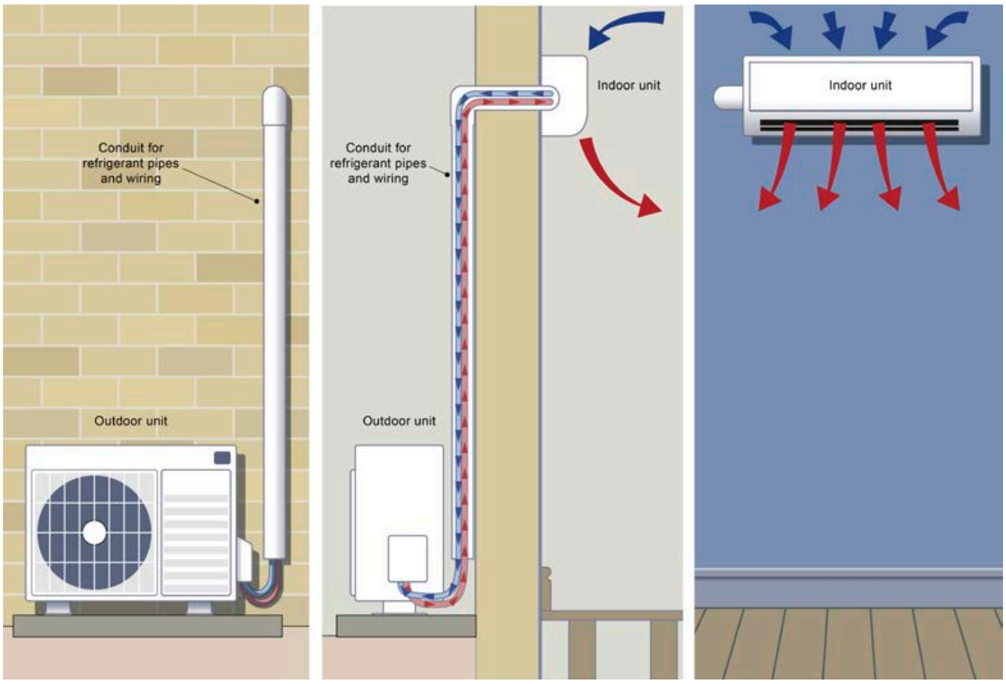
Figure 3:
Monobloc (air-to-water) ASHP.



DX ASHPs

- have refrigerant pipework between indoor and external units so there is an increased risk of refrigerant leaks via damage to pipework or installation error, and installers need to be fluorinated gas (F-Gas) registered
- there are no systems currently available that utilise low environmental impact refrigerants
- heat is delivered directly from the ASHP condenser to the building air using forced convection, and indoor units always incorporate a fan and therefore make noise when heating or cooling so they are less suitable for residential applications
- incorporate high-capacity heat emitters so these systems are suitable where quick warm-up times are required.

Figure 4:
Direct expansion (air-to-air) ASHP.



3 Observations and findings

The observations and findings drawn from the case studies cover:

- noise
- cold air discharging
- defrosting
- drainage
- visual impacts
- electrical installation
- glycol
- buffer vessels
- heat pump capacity – monobloc and DX ASHP systems
- refrigerants
- user experience
- system optimisation.

Noise

The noise from external ASHP units was not reported as an issue at any property. Given that the public discussion around ASHPs often focuses on the noise generated by external units, this was unexpected. The occupants at one property reported being aware when the external unit first started up but could not hear it when it was running. In this case, the ASHP was mounted to the house using a wall bracket with little anti-vibration dampening. This may have allowed the vibration from the initial compressor start-up to be transferred into the building's structure.

Cold air

No occupants reported an issue with the cold air discharged from the external unit. ASHPs discharge a plume of cold air while running. This cold air movement can be felt up to 3m from the unit. Walking briskly through the discharge plume is unlikely to cause discomfort. However, positioning the ASHP where someone might be required to linger in front of it – when unlocking a front door, for example – would be uncomfortable and should be avoided.

Defrosting

Nine out of ten users did not notice the short interruption to their heating system that occurs when the ASHP is required to defrost and were, in fact, unaware of the defrost function. During certain external weather conditions, frost will form on an ASHP's external evaporator. The frost must be periodically melted to allow the ASHP to continue to operate. This is known as a defrost cycle. Defrost times for modern ASHPs are between two and 10 minutes. While the ASHP pump is defrosting, it is normally unable to deliver heat to the building. The heavyweight construction of some historic buildings makes them resilient to short interruptions in heat.

Drainage

Generally, condensation water from external units is allowed to run over the ground to a nearby drain. This water will freeze in winter and become potentially hazardous. In all the studied properties, pedestrians did not need to walk between the ASHP and drain. Therefore, ice caused by condensate water was not reported as an issue by any participant, but it was noted as a potential slip hazard at some properties. In two properties, condensate water dissipated through a gravel/slate bed that surrounded the base of the external unit, thus eliminating any potential hazard.

Figure 5:
A slate bed at the base of the ASHP allows condensate and defrost water to dissipate safely.

Visual impacts

Given that all the case studies involved historic buildings, it was assumed that most of the ASHP external units would be hidden from view. This was not the case. Only one property attempted to conceal the external unit. None of the occupants in the houses were dissatisfied with how the external unit looked, despite the fact that it was visible from their private gardens.

The only property that had attempted to conceal the ASHP external unit experienced unintended consequences. To reduce the visual impact of the unit, the base had been sunk 500mm below the ground level so that the top of the unit was below the level of the garden boundary wall. However, from the street, this slight drop in level made little difference. On the garden side, a hurdle fence had been erected to screen the unit although part of this screen had been blown down by winds. Dropping the level of the unit has caused issues with snow building-up around the ASHP in winter and leaf litter build-up in autumn. The snow and leaves must be removed manually for the ASHP to operate without fault. Although no issues were reported at this property, dropping the level in this way could also leave the ASHP vulnerable to damage from flooding.

Electrical installation

The quality of the electrical installations appeared to be high in all cases. Cables were routed safely and neatly. This is a likely consequence of the prescriptive and regulated nature of the electrical industry in the UK.

Glycol

Glycol is an antifreeze and relatively expensive and so may be omitted from systems to reduce installation costs. All the monobloc ASHPs in the case studies had some level of glycol in their systems.

Monobloc ASHPs need protection against freezing because they contain water. If an ASHP is connected to an electrical supply, the internal controls will guard against freezing by activating the pump when the temperature of the water inside the unit drops below a defined value. In the event of a power cut, the unit will be exposed to freezing. Most manufacturers require glycol to be added to the heating system water to stop it from freezing and damaging the ASHP. System designers need to consider this addition because it reduces the water's ability to carry heat and makes the liquid more viscous. This has an impact on heat emitter design, pipe sizing and pump sizing.

If the volume of system water is greater than about 220 litres or 20kW of ASHP capacity, it may be more cost-effective to install a plate heat exchanger. This will physically separate the heating water that travels outside and the water that remains in the building.

Buffer vessels

Buffer vessels are only used with monobloc ASHPs. Buffer vessels are insulated tanks designed to provide additional water volume to the system. None of the case study properties with these ASHPs had a buffer vessel installed. Buffer vessels can serve several functions:

- They can increase heating system volume to provide energy for defrost cycles without removing energy from the building.

- They can increase system inertia to maximise ASHP run times, which will, in turn, maximise efficiency.

If piped to provide hydraulic separation between the ASHP circuit and the building circuit, the buffer vessel will ensure that the minimum system flow rates will be met. A guaranteed minimum system flow rate can also be achieved via the heating system design. For example, leaving thermostatic radiator valves off radiators or control heads off underfloor heating manifolds in zones where the heating thermostat is located.

The decision on whether to include a buffer vessel must be made on a project-by-project basis, following any design considerations and recommendations from the chosen ASHP manufacturer. In some of the case studies, installing a buffer vessel may help improve short ASHP run times:

- Site 1. A buffer vessel may help to improve short heat pump run times.
- Site 2. A buffer vessel may help to improve short heat pump run times.
- Site 3. A buffer vessel could provide hydraulic separation to protect the heat pump from highly variable system flow rates.
- Site 4. A buffer vessel was not required. The large thermal mass of the church's underfloor heating system provided adequate thermal buffering to the heat pump.
- Site 9. A large buffer vessel could be beneficial in this church, but it is unlikely to solve the system's specific issues.
- Site 10. There was no evidence that a buffer would improve system efficiency.

ASHP capacity

Bigger is not better when it comes to installed ASHP capacity. When ASHPs start up, it takes time for them to reach their peak operating efficiency. Good system design and an appropriate size will allow the ASHP to operate at this peak efficiency for long periods of time. For this to happen, the ASHP's heat output should match the building's heat demand. Modern ASHPs can adjust their output down to about one-third of their peak output. The larger the installed ASHP, the more often the minimum ASHP output will exceed the building's heat demand. In this scenario, the ASHP will turn off for a period of time to stop the building from overheating. The larger the ASHP, the more often it will have to switch off, resulting in the ASHP spending more time operating in the inefficient start-up mode. This is known as 'cycling'.

System designers need to consider the system's running cost, the initial capital cost and any space constraints that exist in and around the building. In 2021, a monobloc AHSP external unit cost around £550/kW. In contrast, new gas boilers cost £43/kW. To achieve affordable installation costs, it is, therefore, important not to oversize the ASHP. The same argument is true for selecting heat emitters. Radiators that allow an ASHP to work at 35°C rather than 50°C could be up to five times more expensive and will take up more wall space. There is a balance to be struck here, and a good system designer will help select the best solution on a case-by-case basis.

Figure 6:
Installed capacities of the monobloc ASHPs per m^2 of floor area.

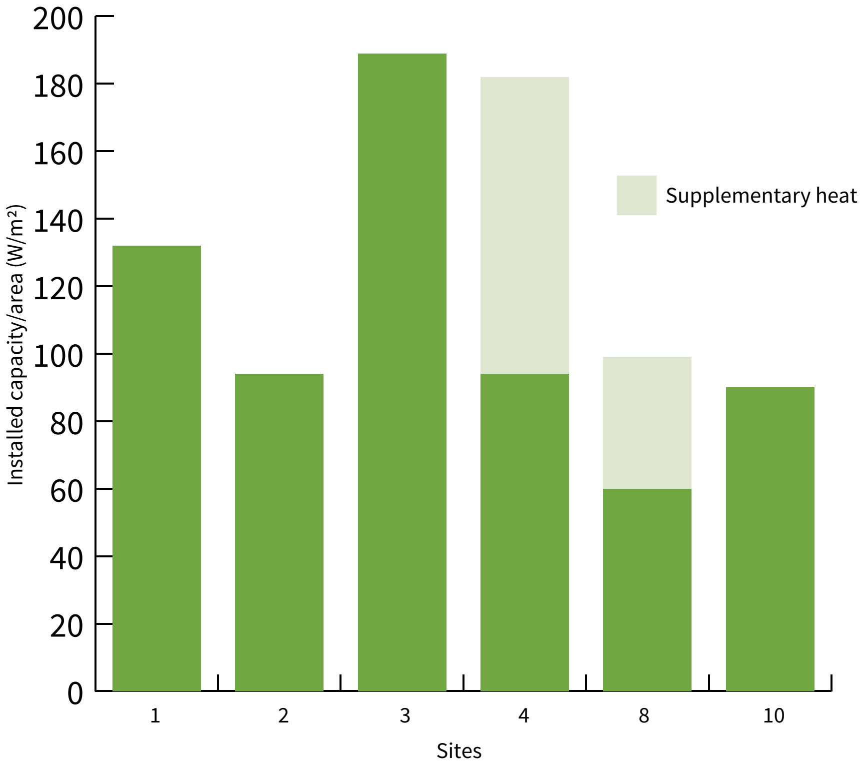
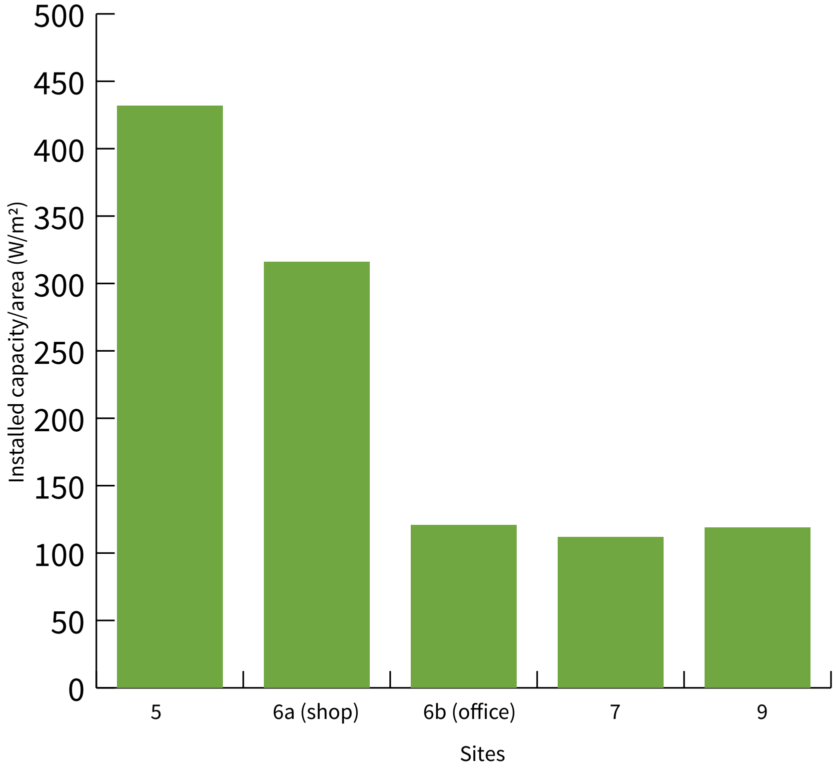


Figure 7:
Installed capacities of DX ASHPs per m^2 of floor area.



Monobloc systems

There was a significant variation between the case studies (see Fig. 6). A high installed capacity did not always correspond to a comfortable or efficient building.

Table 1 compares the installed ASHP capacity with the expected ASHP size, given what was known about the thermal upgrades made to each building.

The steady state heat loss from a solid wall building with single-glazed windows and no loft insulation should not exceed 110W/m². The average capacity of the three renovated residential projects is 105W/m². This suggests there is a tendency to oversize ASHPs.

Table 1: Monobloc ASHPs – installed capacity vs expected capacity.

	Installed capacity W/m²	Expected range W/m²	Comment
Site 1	132	30 – 65	Oversized heat pump installed for a property that has undergone extensive insulation improvements.
Site 2	94	30 – 65	Potentially oversized heat pump for a property that has undergone recent refurbishment.
Site 3	189	95 – 110	Oversized heat pump for the size of building, despite limited thermal upgrades to the building fabric.
Site 4	94 (182 with wall panels)	95 – 110	Heat pump is well sized. Radiant panels are an ideal top-up as they are fast acting.
Site 8	60 (99 with electric boiler)	95 – 125	Undersized heat pump for size of heating load. Direct inline electric boiler brings the total installed capacity in line with the expected capacity. It is, however, expensive to run.
Site 10	90	30 – 65	Potentially oversized, but exact thermal performance details of fabric are unknown.

The results (see Figs. 6 and 7) for the monobloc and DX systems have been separated when comparing the installed capacities of heat pumps against the area of the building. This is because the W/m² installed capacity of DX systems tend to be larger than monobloc systems because of the sizes of units available to purchase.

Site 2 has been included in the monobloc section, despite having a DX ASHP, because it delivers heat through a traditional wet heating system.

DX systems

The capacities of DX systems tend to be larger because they are often sized to provide large summer cooling capacities. As the heating and cooling is provided by the same unit, this artificially pushes up the installed heating capacity.

Table 2:
DX ASHPs – installed capacity vs expected capacity.

	Installed capacity W/m²	Expected range W/m²	Comment
Site 5	432	95 – 110	Cooling capacity dominant, driven by large shop windows.
Site 6a (shop)	316	95 – 110	Cooling capacity dominant, driven by large shop windows
Site 6b (office)	121	65 – 85	Cooling capacity dominant, driven by office heat gains in summer (lighting, IT equipment and people).
Site 7	112	65 – 85	Cooling capacity dominant, driven by office heat gains in summer (lighting, IT equipment and people).
Site 9	119	95 – 110	Correct sizing; lower capacity split units are not available.

Refrigerants

There are several refrigerants available on the market today. European manufacturers no longer use refrigerants that damage the ozone layer. However, many of the commonly used refrigerants are potent greenhouse gases. If the refrigerant were released into the atmosphere, its global warming potential (GWP) allows you to calculate the equivalent effect on global warming compared to carbon dioxide (CO_2). Although the overall environmental impact depends on more than GWP, for this discussion the refrigerant's GWP will suffice. Table 3 sets out the GWP associated with a selection of common refrigerants.

Table 3:
Common refrigerant properties.

Refrigerant	R-410A	R-32	R-290 (propane)	R-744 (CO_2)
Global warming potential (GWP)	2088	675	3	1
Typical charge (kg)	2	2.2	0.9	2.3
Carbon dioxide equivalent of full leakage ($kgCO_2$)	4176	1485	27	2.3
Number of case study sites	6	4	0	0
Fluorinated gases (F-gas) regulations	phasing out in small systems from 2025	Phasing down	n/a	n/a

Replacing a natural gas boiler with an ASHP will reduce the CO_2 emissions associated with the heating system for a typical UK home by around 3000kg per year. However, if there were to be a complete gas leak from a typical domestic ASHP that uses R-410A that would be the equivalent of 1.4 years of carbon savings associated with the running of that ASHP system. A key goal of Fluorinated gases (F-gas) regulations (www.gov.uk/guidance/fluorinated-gases-f-gases) is to phase down using refrigerants that have significant GWP when released into the atmosphere such as R-410A or R-32 refrigerant which is used in all the case studies. These high GWP refrigerants will, therefore, have a more constrained supply, meaning the price is likely to rise unless demand reduces. This is important because it means that the costs of maintaining existing R-410A ASHPs will likely increase. R-32 has a much lower GWP than R-410A, and so is less likely to be limited in the short term. However, R-32 is not a long-term solution. Natural refrigerants such as R-290 can achieve a much lower GWP and are now becoming commonly available in consumer ASHPs. The F-Gas regulations are due to be reviewed and may recommend R-32 be phased out.

As seen in Table 3, using natural refrigerants such as R-290 (propane) or R-744 (CO_2) reduces the danger of unintended global warming impacts from refrigerant leaks. However, their use introduces other design challenges, such as R-290 has higher flammability and that R-290 and R-744 cannot be used with DX systems, summarised in Table 4.

Table 4: Flammability of refrigerants used in monobloc and DX ASHPs.

Refrigerant	R-410A	R-32	R-290 (propane)	R-744 (CO_2)
Flammability (as defined in Refrigerants — Designation and safety classification) (ISO 817: 2014)	A1 (non-flammable)	A2L (lower flammability)	A3 (higher flammability)	A1 (non-flammable)
Monobloc	yes	yes	yes	yes
DX	yes	yes	no	no

At the time of the case studies were carried out, there were no low GWP DX ASHPs on the market. The advantages associated with DX systems in commercial properties, principally the ability to deliver cooling, make them key decarbonisation technologies, despite the higher GWP of the refrigerants they use. Each case should, however, be assessed on its merits: a badly specified low GWP monobloc ASHP may not deliver the desired user outcomes, and a DX system may be more appropriate.

Occupants' experience

The ASHP's outlet water temperature dominates the ratio between electricity in and free heat out. For example, on a cold (2°C) day, a modern ASHP can deliver heat at approximately 8.0p/kWh when the water leaving the ASHP is at 35°C. This 35°C water would be warm enough for an underfloor heating system or a generously sized radiator system. If the same ASHP were required to provide 50°C water, for example, to serve smaller radiators, the efficiency would drop and deliver heat at approximately 11.8p/kWh. For comparison, a modern mains gas boiler will provide heat at between 7.4 and 8.1p/kWh, depending on the system design and how well it has been commissioned. Costs are only applicable at the time of the surveys being carried out.

Increasing the heat emitter sizes is not the only way to allow the ASHP flow temperature to be lowered. Improving building insulation should always be considered as the first step to reducing energy consumption and running costs. When insulation is added to a property, the existing heat emitter can deliver the required heat at a lower temperature, thus improving ASHP efficiency.

Another way to ensure the system runs at the lowest possible temperature is to enable heating for extended periods. It is generally cost-effective for a building occupied throughout the week to run the heating continuously at a low temperature. When buildings are intermittently occupied (holiday homes, churches and so on), running the heating when the building is unoccupied may not be the cheapest option. Each case would need to be assessed.

When an ASHP starts, it takes time to settle down and begin working at its peak efficiency. Long run times reduce the number of inefficient start-up periods, which improves the average ASHP efficiency. There are also benefits regarding the wear and tear of the compressor. However, modern inverter-driven ASHPs will slowly bring the compressor up to speed, which reduces the impact of the stop/start cycles.

Key findings from occupants' experiences

- The ASHPs deliver cost-effective heating at low temperatures when allowed to run for long periods without interruption.
- Occupants who operated their ASHPs continuously had the best perception of thermal comfort and were generally happy with their heating system.
- Occupants who were unsatisfied with the temperatures of their properties in the morning did not have the necessary knowledge to extend their system run times and would benefit from additional training.

System optimisation

The radiators in a room are sized to keep the room warm when it is very cold outside (-3°C is a common design temperature). For the majority of the year, the outside temperature is much warmer. The implication is that radiators can run cooler for much of the year while still maintaining comfortable room temperatures. Most modern ASHP control systems adjust the output temperature automatically, using the outside temperature to determine a suitable flow temperature. This type of control is known as 'weather compensated control'. The controller will change the flow temperature between a maximum and minimum value, as defined by the commissioning engineer. This process is known as 'setting the heating curve'.

Lowering the heating curve will reduce energy use and therefore cost. However, lowering it too far will mean the property does not reach the desired comfort temperature. Often the person commissioning the system will set the heating curve slightly too high to avoid complaints. The person who is optimising the system needs to consider the heating system specification, building insulation values and user expectations. Consequently, striking the correct balance between comfort and running costs is best done by the user. The settings to optimise the heating curve often require the user to be familiar with the controller's advanced features. In the case studies with this type of system, users typically did not understand how to optimise the heating curve to reduce running costs.

4 Case studies

Each of the 10 case studies cover:

- system details
- system and other observations
- occupant interview notes
- a discussion including potential improvements.

Site 1 – residential, monobloc ASHP

Site 1 is a stone two-storey, two-bedroom terraced home in Cheshire. Although not listed, the row of cottages are part of a 19th century estate village.

Significant renovations were carried out in October 2020 to improve its energy efficiency. The works included adding internal mineral wool wall insulation to all external walls and installing a monobloc 8kW Hitachi RASM-3VRE ASHP that distributed heat through a radiator central heating system. The ASHP also provided all the domestic hot water for the property, which was stored in a hot water cylinder. There was a wood-burning stove in the living room, which serves as an additional or back-up heat source. Previously, the property was heated by electric storage heaters, which did not achieve comfortable temperatures.

Figure 8: Site 1

System details

Technology choice	★★	Monobloc heat pump is ideal for residential application where the unit can be located close to the domestic hot water cylinder.
Thermal comfort	★★	Comfort much improved over previous electric storage heaters.
System design/ installation quality	☆☆	Large heat pump capacity (132W/m², expected range for a renovated property of this size 30–65W/m²) coupled with low loss header and 10mm small heating system pipework size may be contributing to short cycle times and suboptimal heat pump efficiency. A low loss header is a means of hydraulically separating the primary side of a system from the secondary.

Property type	Residential
Heat pump technology	8kW monobloc
Heating system	Wet radiator system, no buffer vessel, low loss header installed
Hot water system	Domestic hot water storage cylinder
Use pattern	Semi-continual occupation, occupant in full-time employment

System observations

- 8kW monobloc ASHP installed.
- The ASHP used R-32 refrigerant.
- The installed ASHP capacity equated to 132W/m². This is higher than would be expected in a non-refurbished solid wall property.
- The installer's heat loss calculations which were used to size the ASHP resulted in a 4.4kW peak heat loss. This equates to 73W/m². This is higher than the 30–65W/m² that would be expected for a fully renovated property.
- The large ASHP capacity contributed to cycling (that is to say operating for short periods of time and then switching off).
- The ASHP appeared to be short cycling on the day of the visit. This can be a common issue at milder temperatures when the heating load of the building is below the minimum output of the ASHP, causing it to cycle on and off. On the day of the visit, the outside temperature was approximately 12°C.
- The ASHP was installed at the rear of the property on a wall-mounted bracket.
- The ASHP had a low impact on the external appearance of the property and the unit was installed against a similarly coloured wall.

- The raised mounting provided sufficient clearance from heavy snowfall or flooding.
- The location met all the manufacturer's installation requirements for access and airflow.
- There are some small anti-vibration dampers between the ASHP and the mounting bracket, and between the mounting bracket and the wall.
- Condensate drainage had been addressed and there was no risk of freezing over walkways.
- Pipework was well insulated.
- During operation, noise levels were within the expected range.
- During operation, the air speed at the ASHP outlet was within the manufacturer's recommendations.

The sizes of the radiators were consistent with best practice design. The radiators were large enough to deliver adequate heat to the rooms at temperatures that allowed the ASHP to operate efficiently.

Most of the pipework seen at Site 1 was 10mm microbore copper. This is smaller than would be expected in best practice design for a property of this type. While sub-15mm pipework can form part of a modern low-energy house system, it is unlikely to provide a sufficient flow rate for a retrofitted building.

ASHP manufacturers specify minimum water flow rates through their systems. These rates are typically two to four times higher than those for an equivalent fossil fuel boiler. The system's pipework should be designed so that the ASHPs integrated circulation pump can achieve this minimum flow rate without any additional pumps.

Figure 9:
Site 1: ASHP installed at the rear of the house

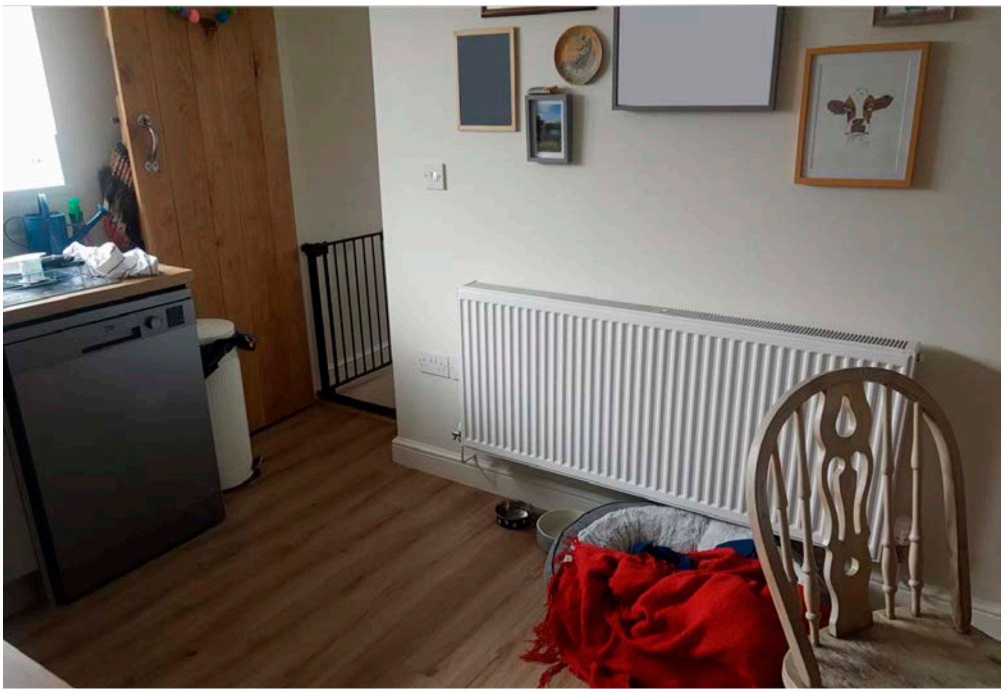


Figure 10:
Site 1: Kitchen radiator with 10mm connecting pipework.

To guarantee minimum system flow rates, the installation at Site 1 incorporates a low loss header between the ASHP and the heating system, and a secondary pump on the radiator circuit. This arrangement adds additional costs and complexity to the system and, in this instance, may contribute to suboptimal ASHP performance.

During the site visit, the ASHP was running in short (sub 4-minute) cycles. The short cycling is probably caused by a discrepancy between the flow rates on the ASHP side of the low loss header and the heating system side. It should be noted that the site survey took place during mild weather, and this may have contributed to the very short cycle time.

ASHP manufacturers also specify a minimum system volume. The system volume has two effects: the first impacts ASHP run times. In a system with a large water volume, it takes more time for the water to complete a cycle through the pipework, radiators and back to the ASHP. The longer the journey time for the water, the longer the ASHP will be able to run. This maximises run time and, therefore, overall efficiency. If these minimum volumes are not achieved, water will circulate around the system quickly, resulting in short cycle times and reduced efficiency.

At Site 1, the minimum system volume recommended by the manufacturer is 28 litres. The estimated water volume of the installed heating system was 50 litres. If the system volume is too low, larger bore pipework could be installed, and a small buffer would help to increase the overall system volume.

Further observations

- The radiators appear to be well sized, reflecting the larger sizes required for a 5°C ΔT system.
- Most of the radiators are connected to the heating circuit with 10mm microbore pipework. This is not advised for ASHP systems, because the high flow rates required in such systems lead to excessive pressure drop in smaller pipes.
- The system's glycol concentration was measured and should prevent freezing down to -10°C.
- Plant room pipework is well insulated to minimise heat loss.
- The use of a secondary circulation pump and associated low loss header was unexpected. The ASHP contains a circulation pump that can provide approximately 70kPa of external pressure, which should be sufficient for most home heating systems. However, the system uses an additional external pump and a low loss header, which allows the circulation pump in the ASHP and the external pump to operate separately without interference. This low loss header may distort the flow and return temperatures, thus reducing efficiency. The building services engineers concluded that the low loss header is not necessary and is, in fact, detrimental to the efficiency of the ASHP.

To evaluate whether the secondary circulation pump and the associated low loss header are required, a closed circuit pressure drop calculation was carried out. The precise details of the pipework layout and sizes are unknown due to the observational nature of the study. Consequently, the calculations are an estimate, based on the available floor plans and the visible pipework.

Based on a design ΔT of 5°C, a mean fluid temperature of 42.5°C and a heating load of 4.4kW (as calculated by the installer), the index run pressure drop was calculated to be approximately 70kPa, at a flow rate of 0.2l/s. From the ASHP manufacturer's specifications, the available external pressure at this flow rate is approximately 55kPa, thus indicating that the installed secondary pump and low loss header are required. Doing the same calculation with larger pipe sizes gives a pressure drop of approximately 31kPa. A secondary pump and low loss header would not, therefore, have been required if 15mm pipework were used in the system.

Installing 15mm pipework would have reduced the overall system costs and improved the system efficiency.

Figure 11:
Site 1: The low loss header was not felt to be necessary and was, in fact, detrimental to the efficiency of the ASHP system.

Occupant interview

The tenant reported:

- They had no issues with the ASHP.
- The system was set to target a constant temperature of 16°C. This is lower than the usual target temperature, but the tenant found it comfortable.
- The house could feel a bit too hot in the summer, so the windows are open most of the time. It is unclear if this is due to the improved insulation at the property or an overactive ASHP.
- The noise of the ASHP was not an issue.
- The cold air emitted from the ASHP was not a problem.
- They did not know how to use the programmable thermostat, so the temperature is always set to 16°C and manually adjusted when required.
- Originally, the legionella cycle was occurring every day, which meant the ASHP was working hard on raising the temperature of the stored domestic hot water. As a result, the radiators were not getting up to temperature. The legionella cycle has now been set to occur once a week and the issue has been resolved.
- It was not noticeable when the ASHP goes into defrost mode.

Energy consumption

The ASHP was installed with a sub-meter. This allows the electrical consumption of the heating system to be measured separately from the rest of the electrical demand at the property. It is an important feature and allows the occupant to understand where their energy demand is coming from. Figure 12 shows the meter reading on 18 November 2021. The total demand of the property from October 2020 to November 2020 was 4183.6kWh. The ASHP accounts for 73% of the total. The bills provided by the occupant had significant time gaps so did not allow for an analysis of the real costs for this report.

Figure 12:
Site 1: Electricity meter showing ASHP kWh in the top display.

Discussion

The heating system had been installed to a high technical standard, with good insulation and layout, but the system design is suboptimal.

The internal circulation pump and low loss header are needed because of the undersized radiator pipework. However, these additions reduce the efficiency of the system and have increased the capital cost of the installation. If appropriately sized pipes had been used, the internal pump of the ASHP would provided sufficient pressure and the additional pump would not be needed. This highlights the importance of whole system design, optimised for low temperature ASHP systems. The low loss header may be part of the reason why the ASHP was cycling on and off during the visit, but this could also have been due to the mild outdoor temperatures.

From the occupant's perspective, the system was working well and they were pleased with the performance. However, the occupant stated they did not know how to time program the thermostat. Showing the occupant how to operate the time control would allow them to make more energy savings, for example by establishing a lower setback target temperature at night or when away from home.

Site 2 – residential, DX ASHP

Site 2 is a Grade II listed thatched cottage in Cheshire thought to date from the mid-17th century but much altered in the 19th century. The oak small-panel frame, partly replaced in brick, sits on a sandstone plinth. The house is single storey with attic bedrooms.

The property had undergone renovations, including secondary glazing and internal wall insulation, to improve energy efficiency. The 10kW Hitachi RAS-4WHVNPE split unit DX ASHP is paired with the Hitachi RWM4.0NE internal unit, was installed in 2019, replacing a smaller ASHP that did not provide enough heating for the space. The new ASHP provides domestic hot water via a hot water cylinder. There is also a wood-burning stove in the living room, which serves as an additional or back-up heat source.

System details

Property type	Residential
Heat pump technology	10kW DX split
Heating system	Wet radiator system
Hot water system	Domestic hot water storage cylinder
Use pattern	Continual occupation – retired occupants

Technology choice	★★	Extended run of external pipework required. DX unit selected to enable a distance greater than 20m between external unit and indoor interface, with traditional radiator heating system and hot water storage tank.
Thermal comfort	★☆	Users reported the kitchen being cold first thing in the morning and using an electric heater to warm the space. They were unaware of how to change heat pump system time settings.
System design/ installation quality	☆☆	Heat pump capacity 94W/m² (expected range for a renovated property of this size 30–65W/m²). Low loss header should not be necessary for a property of this size that has been renovated. Poor attention paid to airtightness where refrigerant pipes enter/exit the building.

- DX ASHPs can accommodate distances of up to 50m between the external unit and the domestic hot water cylinder. Monobloc heat pumps are limited to a maximum distance of around 20m between the external unit and the domestic hot water cylinder.

- Installing a DX ASHP means that pipework leading to the outside unit is hydraulically separate from the radiator circuit, so the circulation pump only needs to provide pressure for the radiator circuit.

- Interfacing the DX system with a hydraulic unit allows a traditional wet radiator system to be used for space heating and a hot water cylinder for domestic hot water.

System observations

- A 10kW DX ASHP was installed.
- The refrigerant was R-410A, which is being phased out.
- The ASHP was installed at the rear of the property on a wall-mounted bracket. It was neatly contained in an existing low-walled area.
- The external evaporator was piped with refrigerant to the internal condenser.
- Installing a DX split system allowed the external unit to be located far away from the main living spaces without the potential for the water to freeze in a long external pipe run.
- The ASHP was only visible from part of the rear garden. The impact on the building's appearance was minimised.
- The location met all of the manufacturer's installation requirements for access and airflow.
- There were no anti-vibration mounts between the ASHP and the building. Occasionally, vibration from the compressor starting or stopping could be heard within the property.
- Condensate drainage has been addressed. The ASHP was installed above an existing drain, so there is no risk of freezing water over walkways.
- External pipework insulation has been severely damaged by birds, exposing the bare pipework in many places.
- The external unit was sub-metered, allowing the energy consumption of the heating system to be separated from the rest of the property.
- The ASHP appeared to be cycling on the day of the visit. This can be a common issue at milder temperatures, when the heating load of the building is below the minimum output of the ASHP, causing it to cycle on and off. On the day of the visit, the outside temperature was approximately 12°C.
- The mean air speed at the ASHP air outlet was within the manufacturer's recommendations.

Further observations

- The radiators appeared to be well sized, reflecting the larger sizes required for a 5–10°C ΔT system.

- There was no glycol in the heating circuit to provide anti-freeze. Given that the water piping was entirely indoors this was not a problem.

- Poor installation practices were observed where refrigerant pipework enters the house. For example, an oversized hole was not sealed around the pipework and daylight was clearly visible.

- The use of a secondary circulation pump and the associated low loss header was unexpected.

Occupant interview

The tenant reported:

- Most of the time, the property was warm enough. However, in winter, in the early morning (around 7am), the occupant used an electric heater to supplement the ASHP.
- One of the bedrooms was too hot to sleep comfortably. Although a window was left open the sleeping temperature was still not comfortable. The tenant had been told not to use the thermostatic radiator valve to adjust the radiator output.
- The noise of the ASHP was barely perceptible from indoors. One of the occupants could hear it switching on and off when they were in the kitchen — the room closest to the ASHP.
- There had been no complaints from neighbours about the noise.
- Cold air emitted by the ASHP had not been a problem.
- They did not know how to use the controller. They knew the ASHP came on at 6am and went off at 10pm but did not know how to change the timer.
- The ASHP pump performs the domestic hot water legionella cycle once a week. The occupant noticed an increased hot water temperature in the morning.
- The occupant noted that the property landlord had a limited number of staff with the knowledge necessary to help with operating the ASHP.

Discussion

The system appeared to be well installed, except for the hole in the wall where the pipework enters the building. As with Site 1, a secondary circulation pump and low loss header should not be necessary given the size of the property.

As large portions of the external pipework insulation have been destroyed by birds, these needed reinstating with mechanical protection. The current lack of insulation would have been causing significant losses in efficiency.

The occupants did not have a good understanding of how to control their heating system, which is important to get the best performance from the ASHP. More information on how to control the timing of the ASHP would help alleviate the problem of the property being too cold in the mornings. Additionally, the advice not to use the thermostatic radiator valve to reduce the bedroom temperature was probably unhelpful. It is likely that this advice was given with the aim of maintaining minimum system flow rates. Without thermostatic radiator valve control, an occupant had been leaving the bedroom window open to reduce the room temperature. This would have added to energy consumption and the running costs. It is very likely that any efficiency gained by reducing the cycling of the ASHP was overshadowed by the heat wasted from having a window open. This again, indicates the need for clear and quality advice for occupants on how to use their heating system. Bedrooms are sensitive locations that need additional temperature control.

Site 3 – commercial, monobloc ASHP

Site 3 is a converted 19th century coach house in Cheshire. It is a commercial property and current let out for a sports massage therapy business.

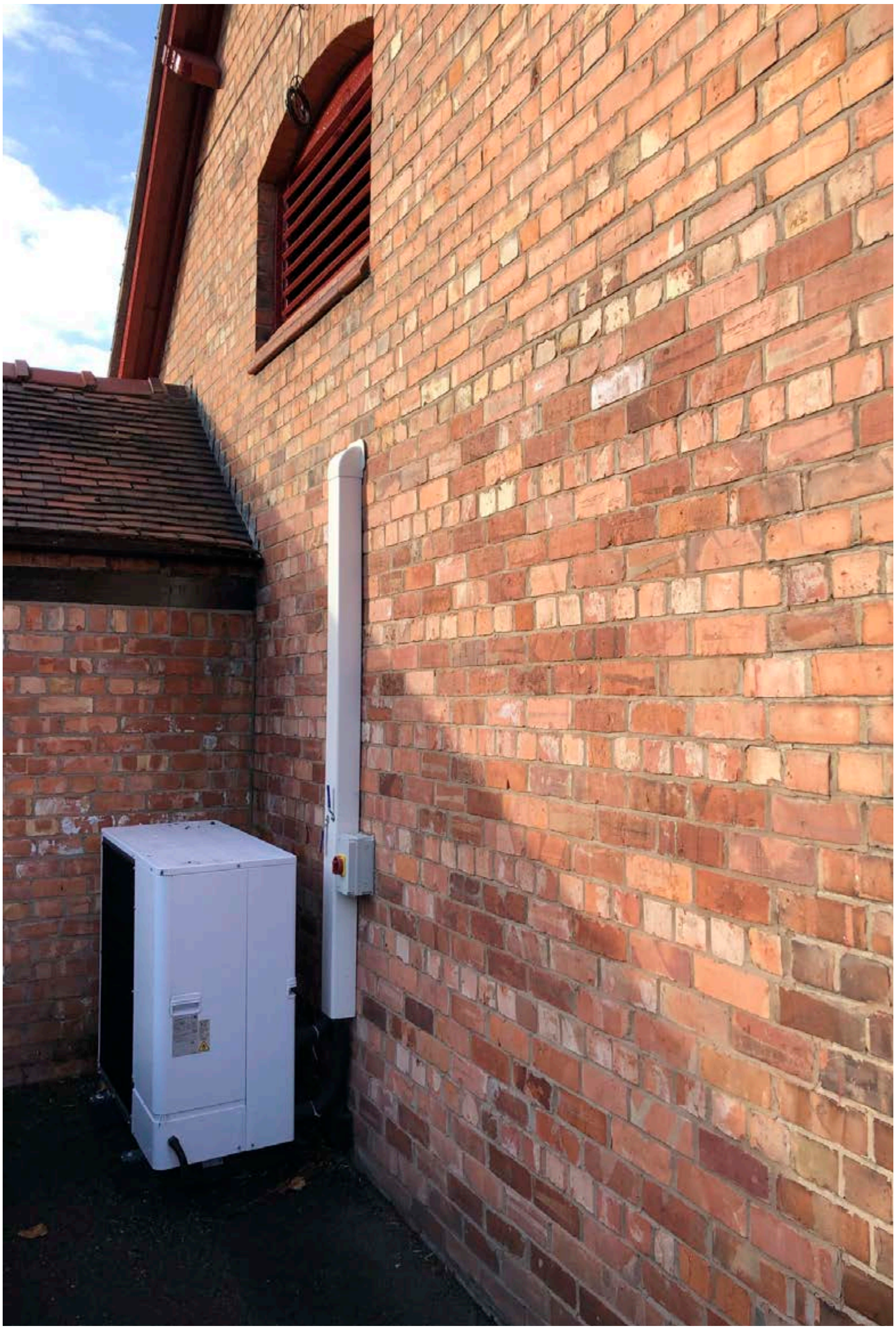
Previously heated by direct electric fan heaters, the property was converted to a monobloc 8.5kW Mitsubishi ASHP central heating system in March 2021. Domestic hot water was provided by a separate small direct electric heater. No changes were made to the building fabric at the time.

System details

Property type	Commercial – gym and therapy room
Heat pump technology	8.5kW monobloc
Heating system	Wet radiator system
Hot water system	Direct electric undercounter hot water
Use pattern	Commercial – Mon to Fri 09:00 to 17:00

Technology choice	☆☆	A DX system could provide quicker warm-up times to the therapy room and provide cooling to the gym area in summer.
Thermal comfort	☆☆	The tenant was using additional electric heaters to improve warm-up times in the therapy room. They were unable to adjust the time clock settings to activate the heat pump earlier in the day.
System design/ installation quality	☆☆	Heat pump was very large for size of property. The heat pump capacity was 189W/m², however the expected range for a renovated property of this size should be 95–110W/m². Maintaining minimum heat pump flow rate would be problematic with thermostatic radiator valves and two thermal zones with different requirements.

Figure 13:
Site 3: The ASHP installed at the side of the property.



- Monobloc systems are better suited to buildings with a domestic hot water load.
- The two internal spaces require different internal temperatures.
- The wet heating system is too complex for a simple building.
- Quick warm-up to the therapy room could be achieved with a DX system.
- A split or multi-split DX system could provide cooling to the gym space in summer.

System observations

- An 8.5kW monobloc ASHP was installed.
- The ASHP used R-32 refrigerant.
- The ASHP was installed on the gable wall of the property, in the car park of a neighbouring building.
- The external ASHP unit was quite visible and stood out against the building. There was a plastic pipe housing running up the wall.
- The location met all of the manufacturer's installation requirements for access and airflow.
- The ASHP was installed on anti-vibration mounts.
- The pipework insulation was loose and was not sealed all the way around the pipe. It was also quite thin (~15mm).
- The ASHP was clean and in good cosmetic condition.
- Condensate drainage had been addressed. The ASHP was installed near a drain, and the flow was directed towards the drain. There was little risk of condensate freezing over walkways.
- The ASHP was not operating and the building was not in use on the day of the visit therefore the property was only inspected externally. Sound and wind speed measurements could not be made, and the sizing and placement of the radiators could not be evaluated.

Occupant interview

In an online interview, the tenant reported:

- There were two rooms with quite different heating requirements. The massage space needed to be relatively warm, whereas the main room was used for treadmill training and needed to be cooler for users to be comfortable.
- The ASHP heated the space a lot slower than the previous direct electric heaters. As a result, the tenant frequently used additional direct electric heaters to boost the heating in the mornings as clients complained about being too cold.
- The ASHP would switch off when it detected that the target temperature had been reached (with the help of the heaters). When the heaters were switched off, the ASHP took too long to turn back on again and the temperature dropped.
- They were trying to control the temperature by switching direct electric heaters on and off, rather than having a steady comfortable temperature.
- They liked the fact that the ASHP is good for the environment, but if they have to use additional electric heaters, the system was not ideal.
- They did not know how to use the programmable thermostat. They had read the manual and tried to program the ASHP to come on earlier in the morning so that the building is warm when they arrive, but they had not been able to get it to work. They had asked the landlord for help with this.
- The windows were quite draughty on a windy day. Closing the blinds helped keep the heat in.
- They felt that adding radiators to the walls would not be in keeping with the historic character of the building.
- The noise from the ASHP was quite loud, but not audible within the building.
- The cold air emitted from the ASHP was not been a problem because the unit is located in an adjacent car park.
- They did not know if there had been any changes to the running costs.
- No maintenance of the unit had been carried out.

Discussion

The ASHP seemed to be well installed and should be able to heat the space well. However, the tenant's experience was not ideal, with constant fluctuations in temperature and manual operation of supplementary heaters.

With a typical gas boiler or direct electric heating system, users can often have a good level of thermal comfort without using a programmable controller, due to the quick response time of these systems. With an ASHP, programmed heating can be beneficial in a frequently occupied building because it provides a slow rise in space temperature.

A multi-split DX system would likely be a better solution this property. It would allow for varied heating in the two different spaces and provide a faster heat-up time through air-to-air heating.

Tenants need to be shown how to control their heating systems so that they can get the most out of them.

Site 4 – place of worship, monobloc ASHP

Site 4 is a Grade II listed church in Ings, Cumbria owned by the Church of England. It dates back to 1743.

Previously, the building was heated by direct electric under-pew heaters, which provided a comfortable heat for those sat in the pews. The heating was only switched on 24 hours prior to Sunday gatherings. This meant that the building fabric remained cold, which led to condensation and cold draughts. In 2012, the church underwent major renovations, including installing a 14kW underfloor heating monobloc ASHP system, with 13kW of back-up direct electric radiant wall panels. Fabric improvements were also made, adding floor and loft insulation and secondary glazing. Since these renovations, a small toilet extension had been built, but it was not connected to the underfloor heating circuit and, instead, was heated by a direct electric towel rail radiator.

Figure 14: Site 4

Figure 15:
Site 4: Interior of the church.

System details

Property type	Place of worship/multifunctional space
Heat pump technology	14kW monobloc
Heating system	Wet underfloor heating system
Hot water system	Direct electric
Use pattern	Occupied for one or two weekday evenings and church services on Sundays

Technology choice	★★	Highly successful implementation. The success of the system was closely linked to the building occupancy profile. The building was used throughout the week, allowing the heat pump to deliver a constant low temperature over long periods. Electric radiant panels are an excellent choice of supplementary heating for the coldest days as they offer almost instant heat. Underfloor heating is silent in operation.
Thermal comfort	★★	Congregation members reported a higher level of thermal comfort compared to the previous under-pew heating system. Longer heating run times increased the average internal surface temperature, which improved comfort and eliminated internal condensation.
System design/ installation quality	★★	Simple, robust design; high-quality installation.

System observations

- A 14kW monobloc ASHP was installed.
- The refrigerant was R-410A, which is being phased out.
- The ASHP was installed on the rear of the building and cannot be seen from the approach to the church.

- The pipework ran straight into the building rather than along the exterior wall thereby minimising visual impact.
- The location met all of the manufacturer's installation requirements for access and airflow.
- The ASHP air discharge would cross a path leading to the rear of the church graveyard, but there is 2m between the path and ASHP, and the pathway is not used regularly.
- The ASHP was installed on anti-vibration mounts.
- Condensate drainage had been addressed. The ASHP was installed above a shale soakaway.
- External pipework was well insulated, although there was a small uncovered area where the pipework meets the wall.
- The ASHP appeared to be in good condition with some exterior dirt the only sign of age.
- The mean air speed at the ASHP air outlet was within the manufacturer's recommendations.

Figure 16:
Site 4: The ASHP installed at the rear of the church.

Further observations

- The pipework, pumps and underfloor heating manifold were easily accessed and neatly contained within a storage cupboard in the church porch.

- The underfloor heating circuit covered the main seating area, as shown in Figure 17.

- Pipework was well insulated. However, many of the valves were exposed, which will increase the heat loss.

The back-up radiant panels were distributed throughout the nave to provide heat in the case of extreme cold or ASHP failure.

Occupant interview

The congregation members reported:

- The space was far more comfortable than before. The previous system used under-pew direct electric heating, which was quite comfortable but limited the flexibility of the space.
- Members of the congregation were very happy with the system and surprised at the improvement.
- The underfloor heating system helped the building fabric to retain heat, thus reducing cold draughts and condensation significantly. This has helped to preserve the building.
- The ASHP pump could not be heard from inside the church, and neighbours have not complained.
- Occasionally, condensate did freeze on the tarmac path, but not many people go round that side of the building.
- At the time of the visit heating costs had stayed about the same. However, the building was being used about two or three times more than previously, so it is a big improvement in efficiency.
- The congregation members knew how to control the system as the engineer who designed the system is on-hand as a member to explain how it works.
- To achieve a comfortable temperature, the heating typically needed to be switched on 24 to 30 hours before the building is used. The building users did not see this as a negative – simply something to be factored in when planning services and activities.
- Low running temperatures allowed the ASHP to operate at high efficiencies.
- Long run times allowed the fabric of the building to warm up over time, which improved the mean radiant temperature of the space.
- The controller was 7-day programmable.
- In future, the congregation members would like to be able to control the heating schedule and target temperatures remotely, to avoid travelling to the building to make changes.
- Maintenance had been carried out since the system was installed.

Energy costs

At the time of the visit the tariff comprised daytime, night-time and weekend rates. The night-time and weekend rate were about 10p/kWh, and the daytime rate was about 15p/kWh. The church has found that its energy use and associated costs have stayed about the same as before the renovations, but the use of the building has tripled.

Discussion

The success of this project is a result of carefully adapting the existing building to provide a flexible and comfortable space for its users. The fabric upgrades have reduced drafts and minimised heat loss from the floor, roof and windows, while the underfloor heating delivered heat in a flexible way. The massive reduction in condensation will benefit the conservation of the building fabric. The underfloor system had been perfectly matched with an ASHP to provide a low-cost heating source that requires very little maintenance. A unique factor in the success of this system is that it was designed by a member of the church with an engineering background. They continue to ensure the correct operation of the system.

This project should be seen as a success from every angle. Not only does the historic building benefit from a low carbon heat source, but the improvements mean that the space is more flexible and can now serve more of the community.

Figure 17:
Site 4: Underfloor heating was laid during refurbishment works.

Site 5 – commercial, DX ASHPs

These listed brick four storey-terraced houses in central London date from the early to mid-19th century. Site 5 is an optician's premises and includes a ground-floor level shop, and a treatment room, staff area and a toilet at basement level.

As part of a building refurbishment project, the landlord installed two 5.4kW Toshiba inverter ASHPs (DX single split systems). They provided heating and cooling through wall-mounted condenser units, to the shop and treatment room only. Domestic hot water was supplied via a small electric water heater in the kitchen.

Property type	Commercial – optician's business
Heat pump technology	5.4kW DX split (2 units)
Heating system	Wall-mounted condenser
Hot water system	Direct electric
Use pattern	Open 7 days a week

Technology choice	★★	The building consisted of two rooms with different characteristics, which could require heating and cooling simultaneously. Separate DX split systems for each room offered a cost-effective method of delivering this functionality. The installed heating capacity was 432W/m^2. The choice of equipment was likely to have been driven by its cooling capacity, to counteract the large shop windows.
Thermal comfort	n/a	The occupant was not using the heat pump at the time of the visit.
System design/ installation quality	☆☆	Poor placement of external units positioned at ground level in a courtyard with 3m-high walls on all sides. Possible issues with cold air recirculation when in heating mode. Neighbouring cooling unit may help to lessen the impact of this design choice. No issues with installation quality in general.

System details

System observations

- Two 5.4kW DX ASHPs installed.
- The ASHPs used R-32 refrigerant.
- The ASHPs were located in a 7.35m^2 outdoor courtyard, which complied with the maintenance space required by the manufacturer.
- The ASHPs were not running at the start of the visit.
- The external courtyard is surrounded by 3m-high walls on all sides.

Figure 18:
Site 5

- In winter, cold air expelled from the ASHPs would sink to the floor of the courtyard, where it would be drawn back into the units. As the temperature of the air in the courtyard drops, the ASHPs will become less efficient. Fortunately, a neighbouring property has also installed an ASHP in the courtyard. At the time of the visit, this ASHP was providing cooling and was, therefore, expelling hot air. As long as the neighbouring ASHP is operating in this manner, the issue with cold air recirculation may be mitigated.

- The ASHPs would benefit from being installed as high up the wall as possible. However, they would have to be accessible for maintenance.

- Condensate drainage was allowed to run freely from the external units across the courtyard to a yard gully drain. In winter, this could present a slip hazard.

- Pipework was well insulated against outdoor conditions.

- The external evaporator was piped with refrigerant to the internal condensers. The pipes ran vertically up the outside of the building before entering close to the internal condenser.

- The pipework and wires on the outside of the building were not concealed. However, the rear of the building is not overlooked.

- The indoor units were painted to match the internal wall colour. They were, therefore, very discreet.

Occupant interview

The tenant's staff reported:

- They were not aware that they had an ASHP heating and cooling system or how to use it.
- The staff had never noticed the internal condenser units and had, therefore, never questioned what they might be used for.
- Electric heaters were being used to heat the shop. When the shop was too warm, the tenant would open the door to provide cooling. This is a very expensive way to heat the space.
- The installation date of the two ASHPs is unknown. It is assumed that the ASHPs were used by the previous tenant, given the weathering to the outside units.
- The instruction manual was found next to the kitchen water heater. During the site visit, the building services engineer turned the ASHPs on and explained how to use the system. The staff turned off the electric heaters and began using the ASHPs for heating.

Discussion

The lack of guidance on how to use the ASHP had resulted in direct electric heaters being used as the primary source of heating. Running costs were three to four times higher than they would be using a well-functioning ASHP.

The large W/m^2 heating capacity is common for split systems of this type. It is rare that systems can be purchased small enough to closely match the load of small rooms. Capacity is driven by the cooling capacity of the units.

The use of two split DX systems is a sensible choice for this type of building. The two rooms have different heating/cooling profiles. The shop is likely to require cooling on sunny days throughout the year, due to the solar gain via the large shop windows. At the same time, the basement treatment room will require heating. A variable refrigerant DX ASHP would provide simultaneous heating and cooling, but this type of system is likely to be a more expensive solution at this small scale.

Figure 19:
Site 5: The ASHPs in the courtyard.

Site 6 – commercial, DX ASHPs

Site 6 is a shop and office property in central London. This block of Grade II listed stuccoed terraced houses was built in the 19th century.

It had been recently refurbished, and ASHPs were installed for heating and cooling. On the ground floor is a shop with two ancillary rooms in the basement (Site 6a). Above the shop, there is an office on three floors with a kitchen, toilets and a shower room (Site 6b). The shop and office were both vacant and without tenants at the time of the site visit.

The refurbishment has made extensive use of split DX ASHPs. The shop sales area is heated and cooled via two ceiling-mounted indoor units. The offices are heated and cooled by floor-standing evaporators. Using split DX ASHPs meant that eight external units had to be accommodated. Four of these units are on the roof, with good access for maintenance and replacement. The remaining four are in an area that is difficult to access and is close to neighbouring windows.

System details

Property type	Commercial – shop and office
Heat pump technology	DX split (8 units)
Heating system	Office: floor-standing units Shop: ceiling-mounted units
Hot water system	Direct electric
Use pattern	Unknown – currently unoccupied

Technology choice	★	The eight external DX split units resulted in access and noise issues. A variable refrigerant volume system could have limited the number of external units while maintaining the ability to simultaneously heat and cool the property.
Thermal comfort	n/a	Building unoccupied.
System design/ installation quality	☆☆	Issues related to the large number of external units. For the non-roof units, there were issues relating to poor access for maintenance, cold air recirculation and close proximity to neighbouring single-glazed windows (noise issues).

System observations

Observations made in relation to the general installation:

- Eight DX ASHPs had been installed.
- The ASHPs used R-32 refrigerant.
- The external pipework was well insulated.

Figure 20:
Site 6.

Observations made in relation to the rooftop units:

- The rooftop location means that the units were hidden from neighbours.

- The nearest noise-sensitive location is more than 5m away. The rear courtyard is noticeably noisy from an ASHP belonging to a neighbouring property. There is a general background hum from external ASHP units, but the soundscape was dominated by a single kitchen extractor fan.

- The units had been installed in accordance with the manufacturer's requirements for access and airflow.

- There was no defined condensate drainage route, and water flowed directly across the flat roof to the nearest roof outlet. This could present a slip hazard when frozen for those accessing the roof.

The multiple split system allows the electricity consumed by each unit to be measured. Some variable refrigerant systems have sub-metering capability that would allow the energy used by each internal unit to be calculated separately. This information could be used for billing individual tenants.

Observations made in relation to the courtyard units:

- These units were wall-mounted on brackets at the rear of the property.

- There was 1.8m between the face of the ASHPs and neighbouring single-glazed windows. It is likely that any noise from these four units would be masked by other noises in the vicinity. However, this is not a reason to place units where they may cause a noise problem.

- The neighbouring windows were obscured with an opaque window film. The ASHPs are, therefore, hidden from view.

- It was not obvious how maintenance on these units would be carried out. The ground-floor window into the courtyard area was too small to climb through. Access would need to be from above, via an area of flat roof. Ladders could be lowered down to allow a scaffold to be erected.

- Condensate drainage dropped into the courtyard and ran along the ground. This might freeze in winter but should not be a problem because the area is not accessed regularly.

Figure 21:
Site 6: ASHPs installed on the flat rooftop.

Figure 22:
Site 6: Wall-mounted ASHPs installed in the courtyard.

Further observations

- The internal units were sympathetically installed, with concealed pipework and custom-made boxing around floor-standing units.
- The unit capacities could cope with the peak cooling demand of around 100W/m^2.
- There was no integrated back-up system.
- The system design seemed robust. Open-plan spaces had at least two heat emitters powered by separate external units.
- It was assumed that the domestic hot water was provided by a hot water cylinder with a direct electric immersion coil. It was not possible to locate this because storage cupboards were locked at the time of the visit.
- There was no evidence of any gas appliances in the building.
- Hot water for showering was provided by an electric shower.

Discussion

The internal units appeared to be well installed, and the pipework was discreet.

Using multiple split systems rather than a single variable refrigerant system meant that the external units were installed in compromised locations in terms of safe access and acoustics. The choice of a multiple split DX system added to this poor acoustic environment.

The courtyard units will be expensive to maintain because a scaffold is needed to provide safe access. This may discourage regular maintenance. Alternatively, maintenance personnel may have to use ladders, which presents unnecessary risks.

Figure 23:
Site 6: A floor-standing condenser (left) and a ceiling-mounted condenser (right).

In areas with low background noise levels, it would not be appropriate to position external units in such close proximity to neighbouring windows. Given the high levels of background noise in this particular location, it was unlikely that the noise from the courtyard ASHP units would cause complaints.

A variable refrigerant DX system to serve the shop and offices would provide a similar user experience and would need only one external unit. There is ample rooftop space to mount a single external unit.

A variable refrigerant system could meet simultaneous heating and cooling demands, which would help to increase system efficiency and lower running costs.

Site 7 – commerical, DX ASHP

Site 7 is a multi-tenancy office building in a row of Grade II listed large houses in central London. The row was built in the late 19th century.

The property was renovated in 2021, when internal wall insulation, secondary glazing and a variable refrigerant DX ASHP were installed. Each floor is a separate tenancy consisting of two rooms with opposite aspects. The case study looked at one of these tenancies, a third-floor office.

The two rooms were heated and cooled by floor-standing fan coil units. These were powered by a communal 23.2kW Daikin VRV ASHP located on the roof. The ASHP provided space heating and cooling. Domestic hot water was heated by undercounter direct electric water heaters.

The VRV system design allows for each floor to be set to either heating or cooling mode. On a single floor, both rooms must be in the same mode.

The two open-plan offices on each floor have opposite aspects - south-east and north-west. It is likely, therefore, that the two spaces will have conflicting heating and cooling requirements at certain times.

A system configuration that allows simultaneous heating and cooling on a single floor could improve heating and cooling efficiencies. However, this would require additional equipment to be installed on each floor, and there may not be enough space for this.

System details

Property type	Commercial – office
Heat pump technology	23.2kW DX (variable refrigerant)
Heating system	Floor-standing fan coil units
Hot water system	Direct electric
Use pattern	Monday to Friday

Technology choice	★★	Only one external unit, discreetly located on the roof. Each tenancy (single floor) consists of two rooms with opposite aspects. These rooms could require simultaneous heating and cooling. System design limits each tenancy to heating or cooling mode. Occupants did not express that this limitation was an issue.
Thermal comfort	n/a	No direct comparison to previous heating system was possible. Occupants were satisfied with thermal comfort.
System design/ installation quality	★★	High quality installation.

System observations

- A 23.2kW Daikin VRV ASHP had been installed.
- The refrigerant was R-410A, which is now being phased out.
- The ASHP was installed on an anti-vibration mount, and the work seemed to be of a high standard.
- Condensate drainage had not been addressed and condensate will flow across the roof to the nearest rainwater outlet.
- The ASHP had sufficient airflow.
- The pipework was insulated for outdoor conditions.
- The external ASHP was located discreetly on the roof, away from any noise-sensitive locations so any noise from the unit could not be heard from inside the building.

Occupant interview

The tenants reported:

- There were no issues with the heating/cooling system.
- They used the fan coil unit for heating and cooling, and they set the required temperature using the remote control.
- The temperature was set at 19°C at the time of the visit.
- There had been no issues with the controller. They had received some guidance on how to use the remote control, but thought it was self-explanatory.
- The floor-standing fan coil units need maintenance once a year, or when an error light shows. If the red maintenance light comes on, they tell the landlord that the filters need to be replaced.
- They had no issue with the noise emitted from the ASHP. It was located on the roof of the four-storey building, and the office was on the third floor.
- They did not have any energy bills or information about the ASHP's running costs.

Discussion

The system appeared to work well and had been well designed. The renovation was completed a year before the site visit, and the tenants had not experienced any issues with the heating or cooling. They had a good understanding of how to use the system.

The system could be improved by allowing simultaneous heating and cooling of each office on a single floor. However, users are aware of this limitation and it had not been an issue so far.

The single external unit was in a discreet and sensitive location on the roof.

The fact that this variable refrigerant system requires only one external unit is a major advantage over multiple split systems, as seen at Site 6.

Figure 24:
Site 7.

Figure 25:
Site 7: ASHP installed on the roof.

Site 8 – place of worship, monobloc ASHP

Site 8 is a Grade II listed church in Oddington, Gloucestershire owned by the Church of England. The church was built in 1852.

The church underwent a significant renovation in 2012, but no thermal improvements were made to the walls, roof or windows. Insulation was added to the floor as part of the new underfloor heating system, which was powered by a 14kW monobloc ASHP. The renovation was, in part, intended to increase the use of the church throughout the week, by attracting other community groups. Pews were removed and replaced with flexible seating. Previously, the building was heated by an oil-fired boiler, cast iron radiators and trench heaters.

Figure 26:
Site 8.

Figure 27:
Site 8: Church interior.

System details

Property type	Place of worship
Heat pump technology	14kW monobloc
Heating system	Wet underfloor heating system
Hot water system	Direct electric
Use pattern	Used on average once a week

Technology choice	☆☆	The chosen heat delivery method of underfloor heating did not work with the once-a-week occupancy. Underfloor heating, whether powered by a gas boiler or an electric heat pump, is inherently slow to respond. Heat should be delivered to underfloor heating in a continuous manner, rather than in pulses. Underfloor heating lends itself to providing continuous stable conditions. Heat pumps complement underfloor heating as they operate most efficiently at low flow temperatures with long run times. This makes underfloor heating and heat pumps an efficient combination for spaces requiring stable temperatures. However, heating all week cannot be justified by the church from a running cost perspective. A system with a faster response time would be better suited to an intermittently used building.
Thermal comfort	☆☆	The heating setback through the week is 7°C. The target temperature is then set to 18°C on the Friday evening prior to the Sunday service, returning to 7°C on the Sunday evening. However, the temperature that was achieved in the service is only 14/15°C and was not perceived as being comfortable. In previous years the setback temperature was set to 14°C, and it was reported that 18°C could be achieved on Sundays.
System design/ installation quality	☆☆	To improve warm-up times, a 9kW direct electric inline boiler was added in series with the heat pump. The warm-up is limited by the slow response of the underfloor heating, not the heat source. Adding additional heating system capacity in this way has not improved warm-up times and had reduced the combined seasonal coefficient of performance (SCOP) of the system to as low as 1.6. A COP of 3.5 should be easily achievable by a modern heat pump. Every system alteration made to reduce running costs had adversely affected the system's efficiency. The church plans to install a DX system and abandon the underfloor heating to enable faster warm-up times.

System observations

Observations made in relation to the ASHP installation

- A 14kW monobloc ASHP had been installed.
- The refrigerant was R-410A, which is now being phased out.

- The ASHP was installed on the left-hand side of the church in a small recess in the ground. It was likely it had been positioned so that the top edge of the ASHP was below the level of the perimeter wall.

- The placement of the ASHP pump in the recess leads to leaves and snow collecting around it and did little to hide the unit. It would be better if the ASHP had been at ground level to avoid leaf and snow build-up.

- Initially, the ASHP was surrounded by a hazel fence, but most of it had been destroyed by high winds. It had not been replaced.

- No flooding issues were reported. However, installing the equipment below ground level leaves it susceptible to localised flooding.

- The pipework between the external unit and the church basement ran underground. Where pipework was exposed, it was insulated.

- The location met all the manufacturer's installation requirements for access and airflow.

- There were no noise-sensitive locations within 5m of the ASHP.

- Condensate drainage dissipated via a gravel soakaway that surrounded the ASHP's concrete mounting base.

- The ASHP appeared to be in good condition, with normal levels of weathering.

Observations made in relation to the heating system

- The underfloor heating manifold and controls were easily accessed and neatly contained within a storage cupboard in the church office.

- The underfloor heating manifold incorporated a mixing/blending circuit. Historically, mixing/blending circuits were provided to allow the high output temperatures of a fossil fuel heat source to be mixed down to suitable underfloor heating temperatures before entering the floor pipes.

- ASHP systems do not always need mixing/blending valves. There is a danger that such valves may cause unnecessary mixing, which will artificially degrade the flow temperature to the underfloor heating. As a result, the ASHP's flow temperature may need to be increased, which, in turn, will reduce ASHP efficiency. However, this is unlikely to be the source of problems experienced at this church.

- No buffer vessel was installed. Ample system buffering should be provided by the thermally massive underfloor heating system.

- Care should be taken to ensure minimum system flow rates are maintained. In an underfloor heating system, this can be achieved by leaving the actuator heads off the loops that serve the same area as the main thermostat.

- Pipework was well insulated, but many of the valves were exposed. This would increase heat loss.

- The 14kW ASHP could provide 60W/m^2 of space heating to the main church area. This is smaller than recommended for a building that has not undergone any fabric improvements.

- Small ASHP pump capacities do not automatically result in poor performance. Oversized ASHPs can have an equally detrimental effect on system efficiencies.

Observations made in relation to the system's suitability and operation

- The congregation was initially happy with the thermal comfort the system provided until they received the first electricity bill.

- Comfort is only achievable when the system operates on a continuous basis. This is expected for this type of system and is consistent with churches using underfloor heating powered by gas boilers.

- The ASHP was not run continuously.

- It is understood that the ASHP pump is capable of providing comfort if it was run continuously.

- In very cold weather, the ASHP consumed a lot of electricity but the heating temperature was not achieved.

Figure 28:
Site 8: The sunken ASHP and the hurdle fence screen.

- When an ASHP starts up, there should be a rise in system temperature/ pressure in its internal refrigeration circuit. If the temperature/pressure is not achieved within a given period, the ASHP is programmed to assume that the lack of heat in the system is due to frosting on the evaporator. At this church, the reason for the lack of heat in the system was simply that a small heating device was trying to heat a cold stone church. The ASHP was mistakenly attempting to defrost the evaporator. When a defrost cycle is triggered, heat is taken out of the heating circuit. Once the ASHP has completed the defrost cycle, it tries again to deliver heat to the cold building, and the cycle continues. This cycle is known as a ‘defrost frenzy’; it consumes high amounts of electricity and delivers little heat. It is likely that the defrost frenzy was a symptom of allowing the church to get cold during the week. If the heating was activated in autumn when the external temperature is mild and the stone walls and floor still retains some of the summer warmth the heat pump would be able to deliver heat without entering a defrost frenzy.

- The situation at the church is probably caused by allowing the building to get cold during the week. If the heating were activated in autumn, when the external temperature is mild and the stone walls and floor still retain some of the summer warmth, the ASHP would be able to deliver heat without entering a defrost frenzy.

- The congregation approached the original installer to remedy the situation. The installer suggested adding a 9kW direct electric heater between the ASHP output and the underfloor heating input. A thermostat had been set to activate this top-up heater when the outside air temperature was below 5°C. This seems to have stopped the ASHP entering a defrost frenzy.

- The ASHP and direct electric heater combined provide 99W/m^2 of space heating.

- Adding a direct electric heater had significantly reduced the system coefficient of performance (COP). The COP is the ratio between the electricity consumed and the heat transferred to the condenser. For example, a modern ASHP should easily achieve a COP of 3.5. Combining the ASHP with a direct electric heater has lowered the COP to around 1.6.

- The congregation had tried to reduce running costs by lowering the heating set points over time. Through the week, the setback temperature is 7°C. The target temperature was then set to 18°C on the Friday evening prior to the Sunday service, and returned to 7°C on the Sunday evening. However, the temperature that is achieved during the service was only 14/15°C, which was not perceived as comfortable. In previous years, the setback temperature was 14°C, and 18°C could be achieved on Sundays.

- Alternative alterations, such as providing a valve to mix the ASHP output water back into the ASHP return, would have protected the

ASHP from the very low return temperatures from the underfloor heating circuit and allowed the ASHP to work within its operational temperatures. However, this would not have improved the system warm-up time because this is dominated by the performance of the underfloor heating.

- The system capacity could have been increased using a buffer vessel, allowing the small ASHP to store heat over an extended period (preferably using the off-peak electricity period), ready to be deployed into the heating system on the Friday evening.

Occupant interview

The congregation members reported:

- They were very unhappy with the performance of the heating system, poor thermal comfort and high energy bills.
- The system took too long to heat it up. If the system was switched on 48 hours before the Sunday service, the building still does not achieve a comfortable temperature.
- The new heating system was more comfortable than the previous oil boiler.
- They had no issue with the noise or the airflow from the ASHP.
- There was a problem with leaves and snow collecting in the recess.
- In the future, they would like to replace the entire heating system to achieve a faster response time when the ASHP is on. The new system will likely include four DX ASHPs on the rear of the church. Floor-standing fan coil units will replace the underfloor heating. Such a system needs to be carefully designed to avoid warm air stratifying at high level and leaving the congregation uncomfortable.

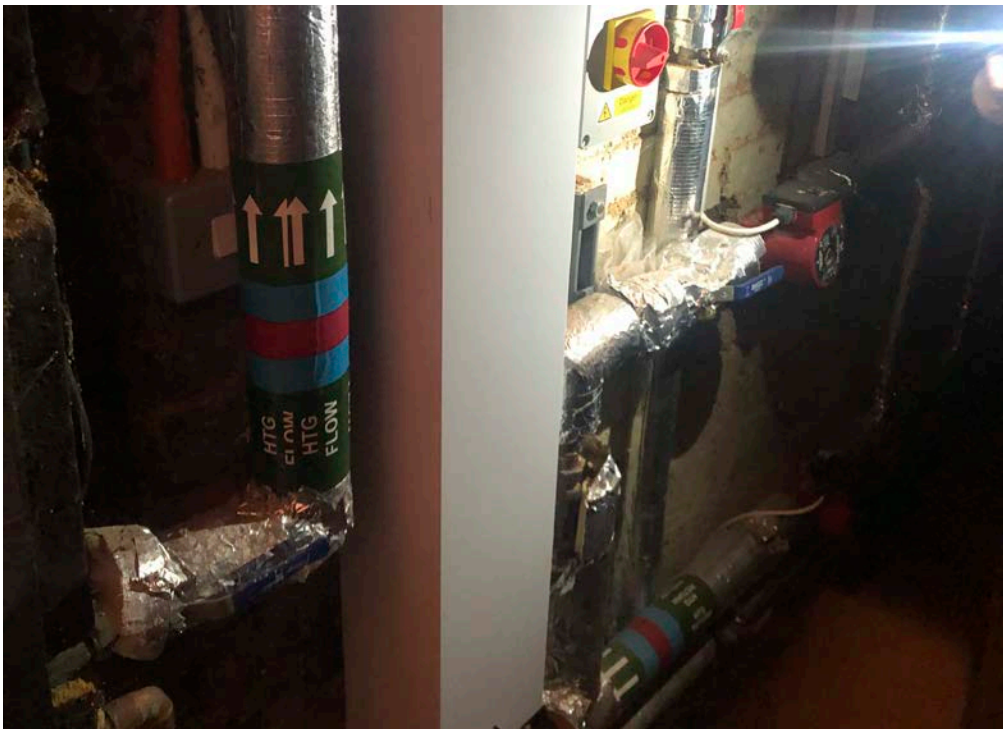


Figure 29:
Site 8: The inline back-up/top-up electric heater.

Energy bills

- The church had a renewable energy tariff, with peak and off-peak options.
- The way that the building was used means that 75% of its electrical energy was consumed at peak times.
- Compared with Site 4, this church is spending an additional 37% on electricity. This was surprising given that the Site 4 church was used more through the week and had a more northernly and exposed location.
- There was not enough data to make firm conclusions about energy consumption.
- The cost of one unit of heat from the ASHP in the off-peak period is approximately 23% cheaper than the ASHP and the direct electric unit during peak time. Utilising the off-peak tariff may help to control bills.

Improvement options

The congregation could:

- Reduce the use of the 9kW top-up heater and maximise input from the ASHP.
- Keep some heat in the floor slab all week, so there is a better chance that the ASHP will manage on its own without entering a defrost frenzy.
- When the floor slab is warmest, turn off the power supply to the direct electric heater so it does not contribute to the heating system. The efficiency of the ASHP on its own might be around 300%; in conjunction with the direct electric heater, this may drop to 160%.
- Adjust the heating programme to take advantage of off-peak electricity rates, as per the schedule in Table 5.
- Set the flow temperature to approximately 35°C, or make sure the weather-compensated regime is enabled with a peak flow temperature of 40°C at -3°C external to ensure that the ASHP is operating at its most efficient. An ASHP loses about 2.5% efficiency for every one degree increase in the flow temperature, so lowering the flow temperature is always worth considering. When the original installer was trying to sort out the complaints, they may have increased the flow temperature from the ASHP to a level that impacted its operating efficiency.

Table 5:
Site 8: Suggested temperature settings to maximise off-peak consumption.

Day	Period	Target set point
Monday to Thursday	00:00 to 07:00 (off-peak)	16°C
Monday to Thursday	07:01 to 23:59 (peak)	14°C
Friday	00:00 to 07:00 (off-peak)	18°C
Friday	07:01 to 23:59 (peak)	16°C
Saturday	00:00 to 07:00 (off-peak)	18°C
Saturday	07:01 to 23:59 (peak)	16°C
Sunday	00:00 to 07:00 (off-peak)	18°C
Sunday	07:01 to 23:59 (peak)	16°C

Table 6:
Comparison of the heating system design for the two churches: Site 8 and Site 4.

	Site 8	Site 4
Heat pump capacity	$60W/m^2$	$94W/m^2$
Combined heat pump and top-up capacity	$99W/m^2$	$182W/m^2$
Heating top-up system	Slow response direct electric boiler piped into underfloor heating system	Fast response direct electric radiant heating panels around the perimeter of the main seating area
Thermal improvements	Floor insulation only	Floor and attic insulation, secondary glazing
Occupancy profile	Once a week	Two to three times a week

Discussion

The two churches in these case studies had installed similar heating systems yet had completely different user experiences. The Site 4 church installation is a great success unlike this site. Table 6 sets out the differences in refurbishment and heating system design.

In the Site 8 property thermal comfort is achievable, but not at a cost the church can justify. The decisions the church congregation are making to limit running costs are leaving them with poor thermal comfort.

Although the church now offers a flexible space, it is still not being used any more than it was previously. This is probably because the community hall is close to the church and offers an equally flexible space with additional amenities, such as more toilets and kitchen facilities.

The church continues to be occupied on average only once a week. Its congregation, therefore, feel that it is wasteful and expensive to maintain a background level of heat during the week. This means that the church remains under used because it does not offer comfortable temperatures compared to the community hall.

Of all the differences highlighted in Table 6, occupancy profile has probably had the most profound effect on the success of the ASHP project. Any church wishing to follow a similar route to decarbonisation should carefully consider their use profile. If maintaining a level of heat in the building while it is unoccupied is not affordable, then a fast response heating system should be considered.

Site 9 – residential, DX ASHPs

Site 9 is a two-storey, two-bedroom residential property in Cornwall. It was built in 1800.

In 2017, the first of two Daikin DX ASHPs was installed to heat the kitchen, which is the primary living area. A second DX system was added the following year to provide heat upstairs. The house was previously heated by electric storage heaters. The domestic hot water system was provided by an immersion heater within a hot water cylinder and could be used to take advantage of off-peak electricity tariffs. Secondary glazing had been added to improve the thermal performance of the existing single-glazed windows. Modern levels of loft insulation had not been installed.

System details

Property type	Residential
Heat pump technology	2.5kW DX split (2 units)
Heating system	Wall-mounted condenser
Hot water system	Direct electric immersion heater to storage cylinder
Use pattern	Retired occupant

Technology choice	★☆	Matches the occupant's needs. Multiple systems installed at different times have resulted in several external units. A small multi-split may have been a more cost-effective solution. A small amount of noise generated by internal wall units was seen as an acceptable trade-off for an efficient and cost-effective heating system. The ASHP can provide heating and cooling, but the tenant has only used it for heating because the property does not overheat in summer.
Thermal comfort	★★	High degree of satisfaction with comfort, especially with the quick warm-up times provided by the DX system.
System design/ installation quality	★★	High-quality installation. Internal piping was routed neatly in plastic trunking. From a historical viewpoint, the system is not particularly sympathetic, but minimal disruption was caused during installation and no floors or floor finishes were disrupted.

System observations

- Two 2.5kW Daikin DX ASHPs had been installed.
- The refrigerant was R-410A, which is now being phased out.
- No low GWP alternative is currently available for small DX systems.
- The external units were installed on wall-mounted brackets facing the driveway.

- Their position was elevated, protecting them from any potential flooding or snowfall.

- The location met all the manufacturer's installation requirements for access and airflow.

- Pipework was well insulated.

- Condensate drainage from the external units was allowed to fall onto the driveway below. The water made its way to a nearby land drain. In freezing temperatures, this could present a slip hazard. The user had never perceived this to be an issue because there is ample space to walk, avoiding this section of the driveway.

- The ASHP pump seemed to be well designed and installed.

Figure 30:
Site 9: The two ASHPs installed at the rear of the building.

Figure 31:
Site 9: A wall-mounted interior condenser unit.

Occupant interview

The occupant reported:

- They had no issue with the ASHPs. The two inside units heat up the rooms quickly and are cheap to run.
- Since the ASHPs had been installed, the spaces are far more comfortable and the unit in the kitchen can heat the entire home.
- The ASHPs are audible outside, but the occupant cannot hear them from inside.
- Road traffic noise masked much of the noise from the ASHPs.
- They had no issue with the cold air coming from the ASHPs.
- The temperature was set to 19°C. They observed there was not much difference in running costs if the temperature was set between 19–22°C.
- They used the controller to switch the units on/off and to control the set point temperature. No timer function was used because spaces heated up very quickly when the ASHP was switched on.
- Five years warranty was provided with the ASHPs.
- The level of refrigerant in the ASHPs was checked as part of maintenance routines every two years.
- They cleaned the inside unit filters once a month.
- No issues had occurred since installation in 2017.

Energy bills

The owner thought it is a very economical form of heating and the running costs supported their decision to install a second system of the same type.

Discussion

The success of the first DX system with its improved thermal comfort and cheap running costs led to a second ASHP being installed a year later in 2018. The occupant sometimes uses the existing storage heaters to take advantage of off-peak electricity prices.

Small split systems are widely used in mainland Europe for residential heating and cooling. They are less common in the UK because the internal units make noise inside the home when delivering heating/cooling. Most UK homes do not require cooling, and silent heating systems such as radiators or underfloor heating systems are preferred. This case study shows that small DX systems are a good solution for some applications and should not be overlooked.

Site 10 – residential, monobloc ASHP

Site 10 is in Cornwall. The property is one of a group of historic barns that were converted into homes in the 1990s.

Originally, the three-bedroom home had an oil boiler provided the heating and hot water. The decision in 2018 to replace the system with an ASHP was driven by the owners' desire to lower the property's carbon footprint.

The 8.5kW Mitsubishi-Ecodan monobloc ASHP was installed on the existing oil tank plinth. A compatible hot water cylinder was installed as part of the system upgrade. This is common because these cylinders contain a larger heating coil, which allows the pump to heat the water in a comparable time to a higher temperature oil or gas system. The existing radiator and pipework system did not need to be replaced, so there was minimal disruption. The property had double-glazed windows and loft and wall insulation installed as part of this retrofit. Insulation levels could not be verified, but they were assumed to be in line with building regulations at the time.

System details

Property type		Residential
Heat pump technology		8.5kW Mitsubishi-Ecodan monobloc
Heating system		Wet radiator system
Hot water system		Domestic hot water storage cylinder
Use pattern		Residential, retired occupant
Technology choice	★★	Monobloc heat pumps are ideal for residential properties where the external unit can be located close to the domestic hot water cylinder. Existing radiators and pipework are compatible with new system flow rates.
Thermal comfort	★★	High degree of satisfaction. Equal comfort with the previous oil boiler system. User operates the system at a constant set point of 18°C 24 hours a day.
System design/ installation quality	★★	High-quality installation. Existing heating system radiators and pipework were compatible with the heat pump system.

System observations

Observations made in relation to the ASHP installation

- A 8.5kW monobloc ASHP had been installed.
- The refrigerant was R-410A, which is now being phased out.
- The ASHP was installed in the driveway of the property on a concrete plinth where the oil tank had been positioned.
- The location met all the manufacturer's installation requirements for access and airflow.

Figure 32:
Site 10: The ASHP installed at the side of the converted barn.

- No system buffer vessel was installed.
- The ASHP was quiet, and the closest noise-sensitive point is 8m away.
- Pipework was well insulated, both externally and internally.
- Condensate drainage was allowed to disperse through the gravel driveway. No issues of freezing were reported.
- The ASHP was located around 2m from the interior hot water cylinder.

Observations made in relation to the plant room and radiators

- The radiators appeared to be well sized, reflecting the larger sizes required for a 5–10° ΔT system.
- Most of the radiators were connected to the heating circuit with 15mm copper pipework, with the main distribution using 22mm pipework.
- The existing radiators had been retained and connected to the new system, which had resulted in a cheaper and less disruptive ASHP installation.
- Glycol concentration level provided freezing protection down to -3°C.
- The heating was enabled 24 hours a day and was controlled by the manufacturer's room thermostat which was set to 18°C.

Occupant interview

The tenant reported:

- They had no issues with the ASHP.
- Weather compensation automatically adjusted the heating flow temperature to match the building's heat loss, based on external air temperature.
- There was good thermal comfort in the property. There was not much difference between the new system and the previous oil system.
- The noise of the ASHP had not been a problem. Neighbours had not mentioned hearing the external unit.
- There had been no issues with the condensate discharge from the ASHP freezing in the area.
- They were well supported by the installation company and they were well informed on how to use the control and how ASHPs work.
- They had an annual maintenance contract of £150 per year with the installer to check the ASHP and heating system.

Energy bills

Since the ASHP was installed, the energy bills had increased compared to the previous system. The occupant had chosen a renewable electricity tariff in step with their aim to reduce their carbon footprint.

Discussion

This case study demonstrates how switching to a low carbon heating system can be straightforward. Understanding how to operate the system to achieve the best performance has resulted in a comfortable, low carbon home.

5 Conclusions

Monobloc and DX systems each have their strengths and weaknesses. Their differences should be considered when selecting the type of ASHP to match the building and its uses.

Several of the case studies had high-quality installations but were let down by the choice of heat emitter or the detailed hydraulic system design.

Designers should consider how the heat emitters will match the occupancy of the building. A slow response underfloor heating system is well suited to a building that is used several times a week. However, in a building that is occupied only occasionally, it can seem like a waste of money to heat an empty building. The two church case studies demonstrate this point. They have almost identical systems installed, yet the outcomes for the users are very different.

A common problem was that the occupants did not know to adjust ASHP timer settings. To provide comfortable conditions first thing in the morning, several users plugged in electric heaters, rather than extend their ASHP run times. The controllers did not seem to be particularly intuitive to use and occupants need support to effectively operate them.

Small changes in ASHP flow temperatures can significantly affect running costs. The occupant is best placed to tune these temperatures, over time, to best match their property's characteristics and drive down running costs. Flow temperatures are typically set by the installer when they commission the system. They may set the flow temperatures a little high because they do not want to be called back because the occupant is too cold. Typically, occupants were not shown how to optimise their systems. It is unlikely that they would be able to assimilate this knowledge during a short handover. Landlords could support tenants to help minimise their heating bills.

Only one user considered their ASHP heating system to be a cheap alternative to other forms of heating. This is probably because in 2021/22 electricity was approximately four times more expensive than gas. To improve the economic feasibility of ASHPs, the UK government has committed, in principle, to reduce the gap between the cost of electricity and more polluting fossil fuels.

The overwhelming impression from the occupant interviews was that the visual appearance of the ASHPs was not an issue for them. Given all the case studies were historic buildings, it was assumed that a variety of mitigation measures would have been used to lessen the visual impact of external units. However, only one participant had taken measures to hide the unit behind a fence. The fence was not repaired when some of it blew down in high winds, which suggests that visual appearance is not a major issue.

The noise and cold air produced by the external heat pumps was not a problem for the occupants in the case studies. The external units in the residential case studies were positioned away from noise-sensitive locations or where cold air plumes would not be an issue.

6 Acknowledgements

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