AIR SOURCE HEAT PUMPS – THE IMPACT ON SERVICE, MAINTENANCE AND PERFORMANCE IN THE EVENT OF THE POOR APPLICATION OF THIS LOW CARBON TECHNOLOGY

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1. INTRODUCTION

For thousands of years, humans have burnt wood or fossil fuels in their various forms to provide heat. In that time efficiencies have increased from the low single-digit efficiency of an open fire to the high 90%+ of a modern condensing gas boiler. So successful has our exploitation been that even with the advent of the vapour compression cycle that can provide COP's of 5, 6 or even 7 deployment of heat pumps has been limited in numbers and application. Wood and fossil fuels continue to hold sway for most heating applications from wood-fired burners to direct-fired gas heaters.

Only with the requirement to transition to net zero technologies have heat pumps come to the fore as low carbon alternative. However, heat pumps cannot be seen as a straightforward drop-in replacement. Without robust processes for the design, equipment selection, control, installation and commissioning the application can be severely compromised and the impact on service and maintenance substantial. Any carbon reduction can be compromised, and the expected efficiencies not realised.

This paper discusses each phase of the processes, highlights best practice and analyses the relative performance of Air Source Heat Pumps in installations following best practice and those which did not.

2. COMMERCIAL AND LEGISLATIVE LANDSCAPE

With many organisations having a Net Zero target of 2040 or sooner, the decision of which technology should be used for heating asset replacement is becoming acute. Assets being installed now and in the coming years are likely to be within their operational lifetime at a point when an organisation has committed to be net zero. This potentially risks large carbon offsetting costs and stranded assets should like-for-like gas fire options be selected.

Understanding an organisation's existing gas-fired assets their age, cost to maintain, availability and energy consumption is paramount to facilitating strategic response to an organisation's de-carbonisation journey. This data will also dictate whether the replacement of gas assets can be accommodated under an organisation's existing asset replacement glide path or whether the accelerator needs to be pressed.

Agreeing on the technology to replace natural gas provides the next major decision point. The two main technologies are electric including heat pumps or remaining with a gaseous solution of either biogas or hydrogen. Whilst much has been hyped around hydrogen, the infrastructure to support the widespread availability is still in a nascent stage.

This is particularly true of the carbon capture and storage (CCAS) technologies which are seen as facilitating the transition to hydrogen by using natural gas as a feedstock, stripping out the carbon and sequestering it in undersea or underground caverns effectively forever. The necessary technologies are still in small-scale trials and the commercial model has not yet been developed.

Further challenges include the requirement for changes to the gas supply infrastructure given the large drop in calorific value, the small molecular size, and the fact it burns invisibly and has an explosive range of 4 – 74%. There is also the need to change the legislative and compliance frameworks.

All these factors point to hydrogen being a niche technology for use in particular industries. These likely heavy industries requiring high temperatures are located mainly in the North of the UK. These are where LNG terminals on the North West and North East coasts will be coupled with hydrogen production plants, CCAS locations linked to new hydrogen pipelines to major industrial centres.

Trials utilising natural gas and hydrogen up to 10% in existing gas infrastructure are purely a mechanism to reduce CO_2e emissions in the medium term. The limits of methane/hydrogen mixtures are dictated by the current assets in use in homes and buildings and the ability of gas meters to accurately record the energy consumed in higher blends.

The UK Government's Heat and Buildings Strategy states that they will not make major strategic decisions on the role of hydrogen for heat until 2026. Whilst this timeframe sits comfortably with a 2050 Net Zero target date. Organisations with 2040 or earlier dates may not have the luxury of delay before making a strategic asset choice.

The alternative route is an all-electric solution. This is taking a range of forms based on the application required. This includes the increased application of decentralised point-of-use domestic hot water systems, radiant heaters and for commercial and domestic uses Air Source Heat Pumps (ASHP).

Whilst the transition to an all-electric solution poses challenges to the local and national transition networks these challenges are understood. Mechanisms and technologies are being deployed to more closely manage and control demand through the concepts of Smart Grids. Further, the cost of grid re-enforcement creates both a business model and drives an imperative for businesses to reduce demand and partially absorb the additional demand for electric heating.

For many applications, ASHP offers a mature and scalable technology option to replace fossil-fuel-based heating systems. They offer organisations a relatively risk-free lower carbon solution that does not rely upon future technological development and legislative landscapes. Government signalling is also clear with the burden of carbon taxes being shifted from an increasing decarbonised electricity supply to natural gas further improving the business case.

The added value of the technology is the fact that it can provide cooling. ASHP can therefore satisfy both the need for low-carbon heating but also increasing cooling demand due to the impact of climate change.

Challenges to the widespread adoption of ASHP remain, however. These challenges include the ability of the UK to train the necessary people to have the necessary skills to deliver the number of heat pumps required. The UK Government has a target of 600,000 units per year by 2028 rising to 1.3m per year in the mid-2030s. Whilst the majority of these are domestic units they will be pulling on the same resource.

The Construction Industry Training board models that we'll need to be training 15,000 installers per year and suggests we'll need over 50,000 installers by 2030 to meet the demand of the UK's Net Zero strategy.

This adds pressure to a refrigeration industry already struggling with skill shortages. Further, the lack of experience of ASHP in those tasked with design and equipment selection risks the technology being tarnished as unsuitable whilst poor installation, quality control and commissioning risks the technology being unreliable.

3. CASE STUDY BACKGROUND

This paper looks at the challenges of transitioning a large multisite retail chain from existing gas-fired heating systems to an ASHP solution with the sales floor of large supermarkets. The heating systems consist of a mixture of direct or indirect gas-fired Air Handling Units where heat is supplied via modulating gas-fired burners within a heat exchanger in the AHU (direct) or where hot water is supplied via a boiler to a heating coil within the AHU with a modulating valve to control the output (indirect). The warm air is distributed through ducting to the area requiring heat. Return air duct draws air from the sales floor back to the AHU where modulating dampers introduce a percentage of fresh air. Nominally, in heating mode, this fresh air will be set to a fixed design minimum or controlled via carbon dioxide concentrations.

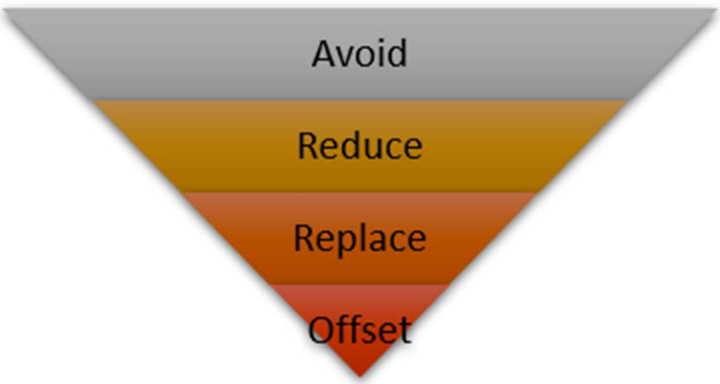
As part of the organisation's ESG Pillar, a date for net zero was set for 2040. This prompted a deep dive into the scope 1 and 2 carbon emissions within the organisation's property operations. The review highlighted that the use of natural gas contributed to 14% of the estate's CO_2e emissions, resulting from the operation of some 4,000 individual gas assets across the estate.

Up to that time, the modular nature of the heating systems could allow for the asset replacement of the boiler, the burners, the heating coils, the fan or the AHU housing or a combination subject to the degree of failure.

A study was undertaken to understand the current run rate of gas asset replacement in relation to the total number of assets. A glide path was established and compared with the requirement of the 2040 Net Zero target.

The study concluded that the rate that gas assets were being replaced was below that required to meet the organisation's Net Zero target without incurring potentially significant costs to offset residual carbon emissions.

Carbon offsetting should be seen as the last resort in the mitigation hierarchy:



The study also investigated other sources of CO_2e including refrigeration systems. The output was a report that provided the business with a plan that detailed the capital investment to achieve nearly Net Zero with the revenue expenditure risks and opportunities.

The report highlighted a need to act now to phase out natural gas or risk-stranded assets. Air source heat pumps were the logical choice for the following reasons:

- Readily available
- Scalable
- Could be integrated into existing systems
- No external dependencies
- Provides cooling capacity improving conditions in a warming climate

The report highlighted that there would be, due to the nature of the technologies, residual emissions. However, such emissions were not material but highlighted a need to review and agree to a mechanism of quality carbon offsetting. The report formed the basis of a new Energy and Carbon strategy that at its core was the requirement to decarbonise heat through the use of air-source heat pumps.

In agreeing to the choice of technology, the process of applying the technology through the asset replacement and new build programme commenced. This involved multiple stakeholders through a Mechanical and Electrical continuous improvement group. This group included M&E consultants, contractors, the FM team and representatives of the client's construction and property teams.

There were a number of challenges to the introduction of air source heat pumps as well as learnings as the organisation pivoted away from the traditional and well-understood burning of gas.

4. ASHP CONFIGURATION

Centrally ducted ASHP are almost always installed to provide the entire heating load of a site. Installers typically ensure that the heating load can be met by the ASHP capacity and auxiliary backup heating at the outdoor design temperature for the site's location. However, for decarbonisation and cost purposes there are unlikely to be options for auxiliary backup heating.

An important consideration in the design of an ASHP installation is the availability of electrical power. Understanding the increased electrical demand against the current contracted supply capacity as well as the existing power infrastructure at the early stages is imperative.

Applications for additional capacity with the DNO can be a lengthy process. Should supply reinforcement be required this can add significant cost to the project.

Within food retail, the maximum demand is dictated by summer temperatures. During the winter, demand is much reduced. Further, investment in energy efficiency measures such as LED lighting has created significant capacity headroom for the transition to electric heating. This may not be the case in all applications.

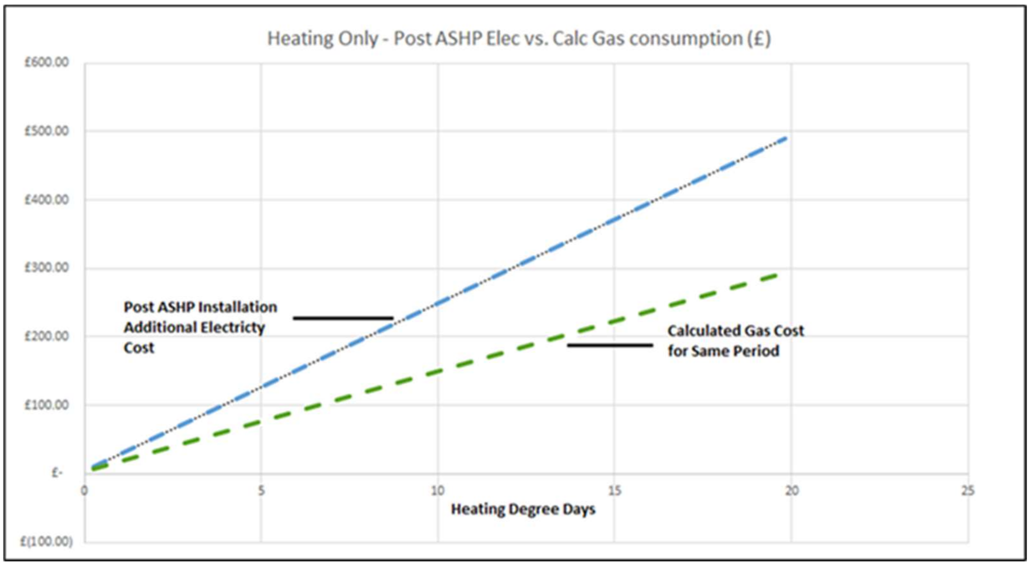
The maximum airflow capacity of existing ductwork may limit the maximum size and heating capacity of the central ASHP that can be installed.

5. DESIGN

ASHP are significantly more complex than their gas-fired equivalents. Whilst within the packaged AHU it looks very much like an indirect fired system with a heating coil and fan, the way the heat is supplied is very different. Gas will provide a constant output whilst an ASHP must shut down periodically to defrost the condenser. During these periods a design decision needs to be made.

During defrost cycles heat is taken from the internal environment unless additional resistive electrical defrost heaters are specified. This will reduce the overall CoP and increase running costs. Alternatively, dual circuit systems can be specified to reduce the impact on comfort conditions during defrost.

It is important at the design stage to model the energy/carbon benefit of the transition to ASHP. This is both when the units are in use for heating as well as cooling mode vs the technologies currently utilised. The planned reallocation of climate-related taxation from electricity to gas favours ASHP but it is important to recognise whilst overall energy consumption and associated carbon emissions will reduce, the energy costs may not. The current price differential between electricity and gas requires an overall COP of 4.5 for breakeven. However, opportunities to either derate or remove gas from a site can result in cost savings to support the business case.

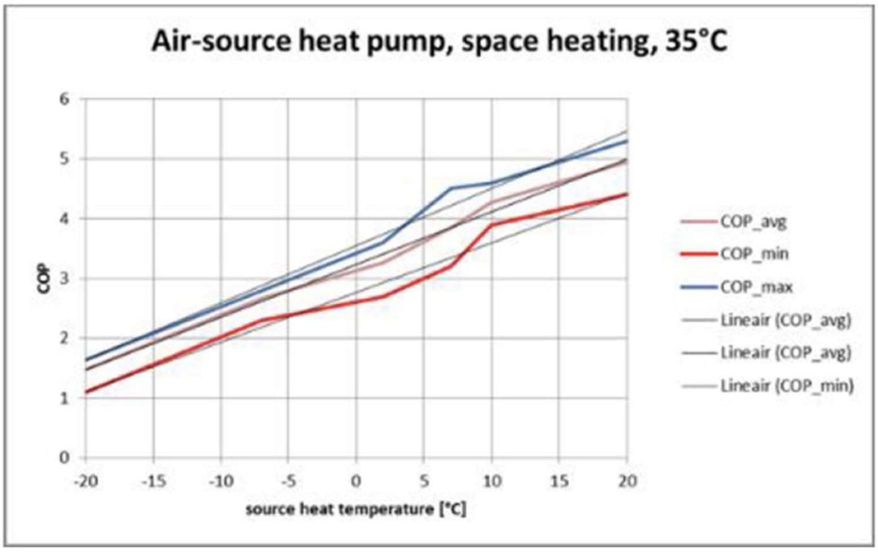


6. SELECTION, SIZING APPROACH AND TARGET CAPACITY

The sizing of a traditional gas fire heating system is a relatively simple and well-understood process. The major benefit of a gas fire system is that it will deliver its rated output under all ambient conditions - subject to vagaries of the heat distribution system.

Air source heat pumps need careful sizing. There needs to be an alignment of ambient temperature between the heat-load calculations with packaged ASHP-rated output. Calculating the heat requirement at for example -2°C ambient temperature to provide sufficient output to deliver internal design conditions versus the specification sheet for output sized at 7°C could leave a system undersized by 40% and may also result in the incorrect product being selected for the actual operating conditions.

The COP of heat pumps fall off dramatically with external conditions whilst manufacturers will want to promote their product at ideal conditions. Understanding the performance curves of the equipment to be selected is imperative.



One other major consideration when making final equipment selection once the duty, modulation requirements, and staging have been settled is the noise ratings. In urban areas, this could be a factor, particularly where there are noise restrictions in place under the original planning consent.

7. INSTALLATION

Best practice for the installation of ASHP shares many requirements with installing a central refrigeration or chiller plant. Access and safe working for maintenance purposes is the primary consideration. Ensuring the plant is placed to avoid hot wells is obvious but could result in constraints in some applications where space is limited.

8. CONTROL & COMMISSIONING

As the majority of ASHP installations will be the asset replacement of an existing boiler or direct-fired burner, they will be interfaced with an existing Building Management System (BMS). These can vary in sophistication. The simplest systems provide a set point with various parameters such as night setback, and ambient holdoffs. These systems usually allow for the equipment itself to modulate on its control strategy the output to match the control parameters. More sophisticated systems will have optimisation strategies controlling the plant directly.

The retrofit of an air source heat pump to replace a gas asset will also require a review of the Description of Operation that defines how the BMS will control the units. Traditionally gas assets will continually modulate their output to deliver comfort conditions when ambient conditions are above the design condition. At temperatures below design conditions, gas units will ramp up and run at maximum output. Operating at maximum output for continued periods has little impact on the reliability of a gas burner.

For an ASHP application, this may not be the appropriate strategy. As temperatures drop and heating demand increases the ability of the ASHP to provide the necessary output diminishes.

ASHP operating at the maximum rated output for extended periods have a high incidence of breakdowns usually associated with compressor failure. The period between defrost periods is also significantly shortened.

Consideration should be made to operating heat pumps at a constant rating at a point below maximum output. Whilst the actual heat output will vary with external conditions, the thermal mass of the site operates to smooth out any fluctuation in internal conditions. Avoiding operating the units at maximum output reduces compressor failure and extends the periods between defrost cycles.

In converting to ASHPs the lower flow and return temperature means slower pre-heat periods and consideration in this regard needs to be made to ensure comfort conditions are met.

9. HANDOVER

The handover of new assets to the maintenance contractor is critical in ensuring a range of benefits from quality snagging to the installation to access to O&M material, Des of Ops. Examples exist of air inlet cowlings installed incorrectly by 180° providing excellent ingress of rainwater into the unit.

The old gas assets must be removed from the gas register. There is the added benefit of no longer having to carry out statutory gas certification. However, the assets and associated capacity and charge will need to be added to an organisation's F-Gas register to ensure compliance.

10. IMPACTS OF NON-OPTIMAL DELIVERY

The impacts of the transition to ASHP whereby a robust process at all stages has not been followed are significant. The difference between correctly sized well controlled installations is considerable not just in the perception of comfort conditioning by the occupiers but in the maintenance operation.

In undersized and poorly controlled installations the units were spending up to 50% of the time in defrost mode. With warm air being taken from the treated space to defrost the coils, this was resulting in supply temperatures dropping to as low as 13°C. The cold drafts as well as the impact on space temperatures resulted in 312% more complaints relating to comfort conditions.

With the units working at maximum output for extended periods, there were 82% more callouts for engineers because of equipment failure. The majority of failures in sites with undersized heat pumps were compressor failures. Repair times were extended by 50% due to lead times of sourcing replacement compressors requiring 14% more time per job at the site.

These impacts are not inconsiderate and significant remedial works needed to be undertaken to bring the installation up to the desired standards. It also impacted the trust in the chosen solution.

11. CONCLUSIONS

The root cause of the issues was down to poorly understood design principles resulting in inappropriate equipment selection and control. This could have been avoided with better expertise at the design stages with individuals knowledgeable in refrigeration. The landscape of HVAC is moving towards an ever-increasing reliance on refrigeration technology transitioning to HVAC&R as a single requirement. As an industry body, the IOR must lead the way to ensure those with the right skills are involved in every step of the transition process so that Net Zero can become a reality.