Fundamental

SERIES 9 MODULE 06

CURRENT THINKING ON...

Heat pumps

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Heat flows down temperature gradients, i.e. from high to low temperatures. Heat loss from buildings in winter takes the form of conduction through the walls, convection and radiation at the outer surfaces to the external environment. All heat flow is in the same direction: outwards.

Heat pumps confound this definition, reversing the flow of heat from a cold medium to a warmer one. This is achieved by using pressurisation and phase change to effect heat transfer. When a liquid evaporates to gaseous phase, it takes heat from its immediate environment. Conversely, heat is lost when a pressurised gas condenses to liquid phase. The latent heat associated with these phase changes is significantly greater than transfer of sensible heat that occurs without evaporation or condensation. The temperatures at which these phase changes occur are important parameters for practical application of this phenomenon in heating and cooling systems.

Substances selected for the suitability of their phase change temperatures, heat transfer and other properties to heating and cooling processes are termed refrigerants. They are the working fluid of refrigeration systems. The common domestic refrigerator is a simple example of a heat pump, whereby heat is removed from the inside of the fridge, which is typically maintained at 5˚C and rejected into the kitchen at around 20˚C. In winter it provides useful heat into the kitchen. A commercial split air conditioning (or comfort cooling) unit is another example of a heat pump. The indoor unit (or evaporator) cools the conditioned space and the outdoor unit (or condenser) rejects the unwanted heat to the external environment. However, the term heat pump is most commonly applied in the UK to systems that take heat from the external environment (i.e. the evaporator is outdoors) and emit it indoors (i.e. the indoor unit is the condenser). Reversible heat pumps are able to provide either heating or cooling into the conditioned space by simply reversing the role of the evaporator and condenser, depending upon indoor conditions and control setpoints.

Heat pump efficiency

A key measure of the efficiency of a heat pump is its heating coefficient of performance (CoP). To comply with Building Regulations the COP of a new electrically driven heat pump used for providing space heating in buildings must exceed 2.2. A 10 per cent margin is allowed for heat pumps providing domestic hot water, which must achieve a COP of 2.0. Greater leeway is allowed for absorption and gas-engine heat pumps, which must achieve CoPs of 0.5 and 1.0 respectively.[1]

The Energy Saving Trust (EST) field trial into electrically powered heat pumps in 83 domestic applications measured total system efficiency (SE). This is the ratio of the total amount of heat produced by the heat pump compared to the amount of electricity needed to run the entire heating system (including domestic hot water, supplementary heating and pumps)[2]. This is arguably a more complete measure of system efficiency than CoP, however, many of the input power items (such as heating distribution pump) are not specific to heat pump installations. The study found that the midrange CoPs of heat pumps exceeded those required by the Building Regulations 2010, however, a number of them did not. The EST concluded that the best performance is achieved by heat pumps installed in highly insulated homes with low temperature heating systems, well set controls and careful system design and maintenance.

Heat pumps remove heat from one location and transfer it to another. The source of heat could be naturally occurring, such as air, water or the ground. Typically the primary heat input into these three sources is from the sun, leading them to be regarded as at least partially renewable. However, the grid electricity or other fuel used to power the heat pump to extract the heat is not renewable, unless it is either supplied by a local renewable energy source, or purchased under a green tariff.

Solar energy heats the surface of the earth and is transferred, through conduction down into the ground. 46 per cent of the solar energy incident upon the atmosphere is absorbed by the earth[3]. At a depth of approximately 12m, the ground remains at a fairly consistent temperature in the 10˚C to 12˚C range throughout the year. This is

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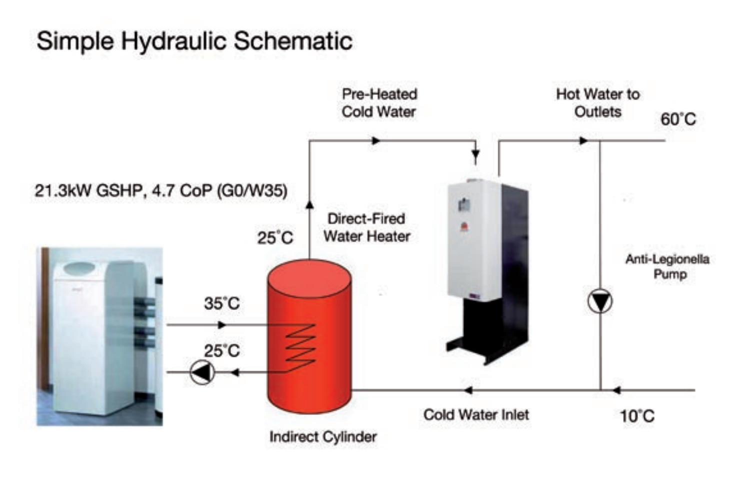
considerably higher than the air temperature in winter and less than the daytime summer temperature. Ground source (or ground coupled) heat pumps use the refrigeration cycle to transfer low-grade heat from the ground to high grade heat for heating systems. This is achieved by installing pipes in the ground and through which a low-temperature water/anti-freeze mix is distributed. The cold water is heated by the ground by means of sensible heat transfer.

Borehole or trench

There are two configurations for the ground loop: borehole or trench. The boreholes will typically be of between 45m and 150m depth, enabling a high degree of consistency in ground temperature to be reached across all seasons. Ground coupling pipes are installed in the boreholes and connected via flow and return headers to the heat pump. Horizontal or trenched configurations are typically less costly to install than boreholes, particularly if the trenches are formed and refilled when excavation equipment is needed on site for other tasks, such as digging the foundations for new buildings and extensions. However, at 35 to 55m of pipe[3] or 25m^2 of trenched area[4] required per installed kW of heating capacity, trench configurations require considerably more land than boreholes. For this reason they are suited to domestic and small commercial buildings, whereas boreholes are usually more practical for large installations, particularly in built-up areas.

Ground coupled heat pumps can use as little as 25-30 per cent of the electricity used by conventional direct electric heating systems and 40-50 per cent of that of an air source heat pump on a cold winter's day. In summer, ground source heat pumps can provide cooling more efficiently than conventional, air-cooled chillers or air source heat pumps. Ground source heat pumps cost less to run than heating from LPG or oil and will usually be cheaper than gas, providing they are carefully designed, installed and operated and supply low-temperature heating systems, such as underfloor heating



(UFH). The relative costs of gas and electricity also have a significant impact. Contemporaneous rising electricity prices and falling gas prices could reverse the relationship.

The term 'geothermal' is often incorrectly ascribed to ground source heat pumps. Geothermal energy is heat from a geological, rather than solar source. It is stored in the earth, usually in regions where there is volcanic activity, such as Iceland and New Zealand. The heat is typically extracted by drilling boreholes that can be up to 5km deep, pumping in cool water and extracting hot water, or steam. Geothermal sites usually provide high grade heat and heat pumps are not required.

Whereas ground source heat pumps used a closed loop underground, ground water heat pumps use an open loop. A constant supply of water is extracted from an aquifer via a series of wells and is used as the heat transfer fluid between the ground water and the heat pump. After leaving the building, the water is pumped back into the aquifer via injection wells. Ground water heat pumps are simpler than ground source heat pumps and were commercially established before them. However, they are less universally applicable, as they are dependent upon the availability of an aquifer, or abundant ground water.

These are a low capital cost option and are effective where there is a body of surface water, such as a lake or pond that is of sufficient depth, volume and with a source of heat replenishment, such as a stream, or surface water drainage that is commensurate with the rate of heat removal of the surface water heat pump system.

Lower efficiencies

Air source heat pumps use the heat available in external air as a heat source. The heat pump is usually directly coupled to the outside air (as opposed to via a heat transfer fluid as used for ground and water source heat pumps). The temperature of outside air in winter is considerably lower than that of the ground and hence, air source heat pumps should be expected to have significantly lower efficiencies than ground source. However they are simpler and considerably less expensive to install than ground source heat pumps as they do not require costly ground works.

Common refrigerant categories include:

Fluorinated hydrocarbons	**Natural Refrigerants'**
Chlorofluorocarbon (CFC)	Hydrocarbons (HC)
Hydrochlorofluorocarbon (HCFC)	Ammonia
Hydrofluorocarbon (HFC)	Carbon Dioxide

Consequently, they are more common and better understood by both designers and installers, leading to their design, installation and operation being more likely to be optimised than for the relatively rare ground source heat pump, leading to less of a differential in COPs in practice.

Heat pumps can be used to recover heat from sources of waste heat, such as exhaust air. In principle this is similar to air source heat pumps. However, there are many variations, particularly on the heat use side of the heat pump, whereby heat extracted from exhaust air could be used to heat supply air in winter, or swimming pool water throughout the year. Domestic hot water can also be heated, or preheated.

Heat pumps operate at their greatest efficiency when the temperature difference between the heat source and the heating medium are minimised. Heating systems that use low grade heat, such as underfloor heating and radiant heating panels are therefore a good match for heat pumps. Conversely, cooling systems that use high temperature chilled water, such as chilled beams and radiant cooling panels are preferable to the majority of conventional cooling coils and fan coil units. To avoid oversizing heat pumps and hence optimise their operating efficiency, it is worthwhile coupling them with a thermal store. This allows them to operate at full capacity for longer than with a direct coupled system. It also provides additional capacity at times of peak heating demand. A similar approach can be taken to cooling.

The provision of domestic hot water is achievable with both air and ground source heat pumps. However, it is not ideally suited to heat pump applications, as it increases the required temperature differential required between the condenser and evaporator compared to that required for low temperature heating systems. To optimise heat pump efficiencies, alternative arrangements should be considered for domestic water heating.

When providing cooling, the effectiveness of the condenser at rejecting heat has a significant impact upon overall system efficiency. Adiabatic, or spray cooling considerably increases the effectiveness of condenser heat rejection and should be considered for heat pumps in cooling applications.

Electricity is the most common fuel for heat pumps. The compressor is the primary source of energy consumption in a heat pump system and this is usually electrically powered. However, absorption heat pumps can be powered by natural gas, or waste heat from CHP units, or other high-grade heat sources, including solar thermal collectors. Gas-fired heat pumps are a well-established technology, but in less common use than electrically powered heat pumps. CoPs for absorption heat pumps tend to be considerably less than those for electrically powered heat pumps. Their COPs tend to improve as the temperature of heat input increases, such that gas-fired heat pumps will tend to have greater COP than waste-heat powered units, as reflected in the Building Regulations requirements referred to above.

Selecting Refrigerants for Heat Pump Applications

Refrigerants are the working fluid of heat pump systems. They are selected for their compliance with environmental targets and regulations (arising from the Montreal Protocol for ODP and the Kyoto Protocol for GWP) and their physical properties affecting energy efficiency, safety and other aspects, specific to each application. Refrigerant selection is affected by the application in which it will be used.

Refrigerants have positive qualities that boost their effectiveness and efficiency for heat transfer and negative 'side effects' such as toxicity, flammability and environmental impacts that must be managed. Air was used as a refrigerant in the early history of refrigerant applications; ammonia is a long standing refrigerant, however, due to its toxicity its use is mainly restricted to industrial applications; fluorinated hydrocarbons are the most practical and widely used refrigerants; the migration from CFCs and HCFCs to HFCs has led to the replacement of R-22 (an HCFC) by R-410A (an HFC) as the preferred refrigerant for domestic and commercial cooling and heat pump applications in the UK, along with R-134A in automotive cooling and domestic fridges; carbon dioxide is of increasing use due to its high efficiency, low GWP & ODP, low toxicity and inflammability, its high boiling temperature and high pressure at high temperatures are well controlled in cascade systems, including supermarket refrigeration[5], but have been limiting factors in its use; hydrocarbons (such as butane and propane) have high efficiency, low GWP and low toxicity and are becoming increasingly applied in situations where their highly flammable nature can be controlled, for example in small hermetically sealed systems and in large, cascade supermarket refrigeration systems.

The temperature at which a refrigerant vaporises should be below the target temperature in a refrigeration appliance, leading to different refrigerants being suitable for domestic fridges (+5˚C), and ultra-low temperature laboratory freezers (-86˚C).

Key advantages of heat pumps are their versatility, controllability, low maintenance, low energy costs and their suitability for integration with other renewable energy technologies. They are well proven technologies that are relatively inexpensive to maintain.

They must be treated differently to conventional heating systems and particular attention should be given to specific characteristics when specifying them, such as:

- the highest water output temperatures from heat pumps providing space heating are typically required in coldest external temperature, leading to the lowest COP in coldest weather
- they are not ideal for domestic hot water provision
- their use of refrigerants can lead to a risk of significant global warming potential if refrigerant leaks are not avoided and managed. This is a risk that does not apply to boilers and other non-refrigerant based systems. (The risk can be mitigated by selection of 'natural' refrigerants with low GWP).

While heat pumps are capable of achieving significant cost and carbon savings compared to conventional heating systems, they are less forgiving and greater attention must be paid to design parameters and operating conditions to avoid significant system under-performance and inefficiencies.

Prominent Environmental Impacts of Refrigerants

Refrigerants can contribute to both ozone depletion and the greenhouse effect, both of which are important considerations when selecting a refrigerant for a heat pump application. Refrigerants contribution towards these environmental impacts are measured by ozone depletion potential (ODP) and global warming potential (GWP) indices.

CFCs and HCFCs are inert, non-toxic refrigerants falling into a larger family of substances known as halogens. However, both have significant ODP and were phased out by the Montreal Protocol and EC and UK regulations arising from it.

HFCs were specifically developed to provide alternatives to CFCs and HCFCs and are the most common choice of refrigerant for new systems. As with CFCs and HCFCs, they are non-toxic and inflammable. They have no chlorine content and no ozone depletion potential. However, many have high GWP, thousands of times greater than that of carbon dioxide (CO2). Nonetheless, only 15% of greenhouse gas emissions from UK refrigeration arises directly from refrigerants, the vast majority arising indirectly from emission of CO_2 arising from energy use and electricity generation in particular[6].

HC refrigerants have low ODP and low GWP. However, they are flammable and should only be used in systems designed to manage this risk.

A selection of some common refrigerant applications

HFCs

- R-134A – automotive air conditioning; domestic fridges; replacement for R-12
- R-404A – commercial refrigerated and frozen food storage and display; replacement for R-12, R-22
- R-407C – broad range of HVAC applications; replacement for R-22
- R-410A – broad range of HVAC applications designed specifically for R-410A, including variable refrigerant flow and reversible heat pump applications.
- R-508B – ultra low temperature applications, such as laboratory freezers (-86C); replacing R-13

'Natural Refrigerants'

- R-744 Carbon dioxide – supermarket refrigeration using cascade systems
- R-290 Propane – mobile refrigeration systems, supermarket refrigeration using cascade systems
- R-717 Ammonia – industrial cooling processes, domestic scale gas-fired heat pumps

References

1) Non-Domestic Building Services Compliance Guide, HM Government, 2010 http://www.planningportal.gov.uk/uploads/br/non-domestic_building_compliance_guide_2010.pdf

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4) Heat pumps – air, ground and water source, Heating, Ventilation and Cooling Association (HVCA) http://www.hvca.org.uk/sustainability/technology-choices/heat-pumps/, 2011 .

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SERIES 9 MODULE 06: QUESTIONS

Heat pumps

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

1. What is the minimum COP that must be achieved by an electrically-powered heat pump under ADL2A, 2010?

☐ 2.2 ☐ 2.0 ☐ 1.0 ☐ 0.5

2. What is the name of the guide that specifies minimum COPs for heat pumps in commercial buildings under the Building Regulations 2010?

☐ Heating Compliance Guide
☐ Domestic Building Services Compliance Guide
☐ Heat Pump Compliance Guide
☐ Non-Domestic Building Services Compliance Guide

3. Which of the following was first used as a refrigerant?

☐ Carbon dioxide ☐ Ammonia ☐ Water ☐ Air

4. Which of the following is not a 'natural refrigerant'?

☐ R-744 ☐ R-410A ☐ R-290 ☐ R-717

5. What percentage of greenhouse gas emissions from the use of refrigerant systems arise indirectly from consumption of electricity, rather than refrigerant supply, use and disposal?

☐ 15 per cent ☐ 25 per cent ☐ 85 per cent ☐ 75 per cent

6. Which of the follow heat emitters is best for distributing heat produced by a ground source heat pump?

☐ Gas-fired radiant tubes
☐ Underfloor heat pipes
☐ Electric underfloor heating
☐ Conventional radiators

7. Which of the following are not typically exploited by heat pumps?

☐ Geothermal energy
☐ Ground source heat
☐ Air source heat
☐ Surface water source heat

8. What is the index for quantifying a substance's potential for contributing to climate change?

☐ Climate Change Indicator (CCI)
☐ Climate Index (CI)
☐ Greenhouse Gas Emission (GGE)
☐ Global Warming Potential (GWP)

9. What is the index for quantifying a substance's potential for contributing to the loss of stratospheric ozone?

☐ Ozone Duplication Potential (ODP)
☐ Ozone Hazard Substance (OHS)
☐ Ozone Warming Potential (OWP)
☐ Ozone Depletion Potential (ODP)

10. Which of the following cannot be categorised as a heat pump?

☐ Refrigerator
☐ Absorption chiller
☐ Heating pump
☐ Ground source heat pump