Keep cool, keep efficient

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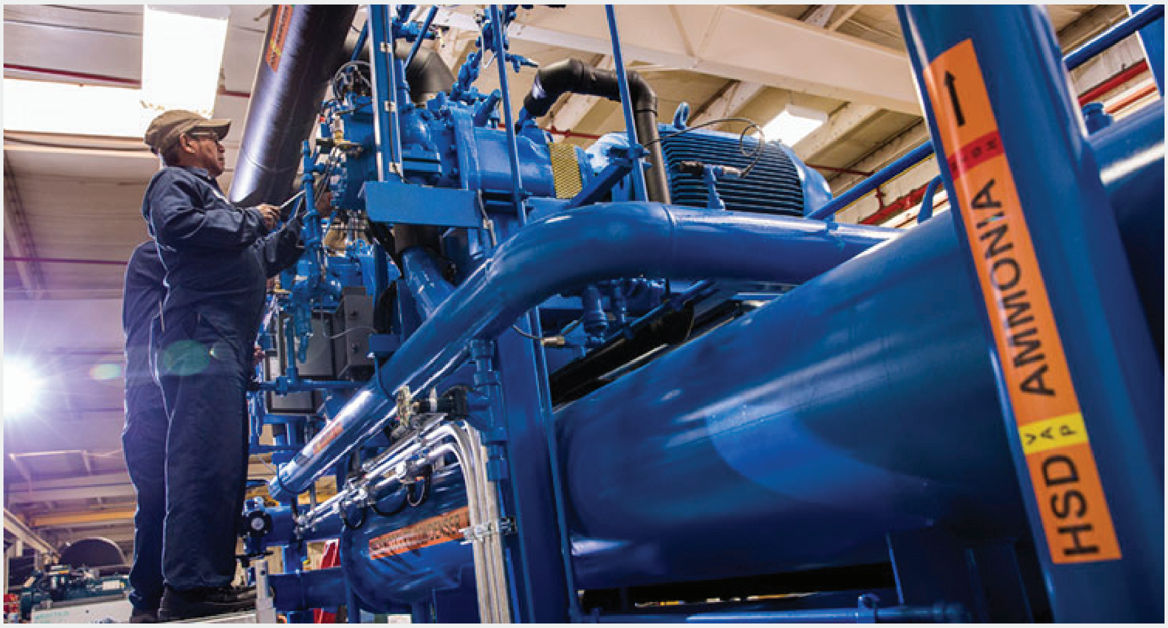
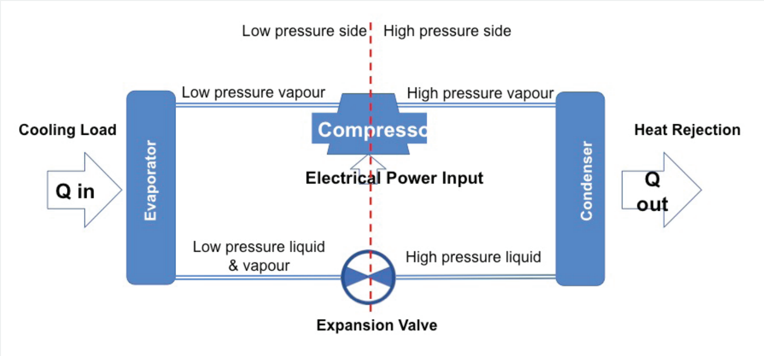


There are four main uses of energy, heating, lighting, motive power and cooling. While energy use for heating and lighting has a long history it is only in relatively recent times that energy has been used for cooling. Early cooling was by way of ice. In winter, ice was cut and stored to provide cooling in the summer months. Scientific work from 1755 paved the way for mechanical cooling but it was not until the 20th century that it became commonplace. For the purposes of this module, we have defined refrigeration as the process of mechanically cooling or reducing the temperature of a space, a product or a process.

Today mechanical cooling is a significant proportion of total energy use and current estimates are for it to continue to increase. According to the IEA[1] the use of energy for space cooling is growing faster than any other end use in buildings – more than tripling between 1990 and 2016. It also estimated that in 2016 electricity for space cooling amounted to nearly 10 per cent of global electricity use. The IEA also suggests that more than 50 per cent of peak electricity demand in hot climates results from cooling requirements. If we include other refrigeration uses the electricity used globally is 17 per cent[2] accounting for 11.8 per cent of GHG emissions.

Looking at the commercial & industrial use of refrigeration, the Carbon Trust estimates[3] that for cold storage facilities 90 per cent of the total energy use for refrigeration; with 70 per cent in small shops, 50 per cent in supermarkets and 50 per cent in food processing. This overview illustrates why energy efficiency in refrigeration is an aspect that needs to be addressed.

Figure 1: A typical refrigeration cycle



Classify refrigeration

It is appropriate to classify refrigeration by its end uses:

- **unitary air conditioning** – split units, ducted units for commercial/residential;
- **chillers** – air conditioning, process, data centres, etc;
- **commercial refrigeration** – supermarkets, standalone equipment;
- **industrial refrigeration** – centralised systems, standalone systems, cold stores, processing;
- **heat pumps** – see *EiBI* CPD Series 18 Module 05;
- **domestic refrigeration** – fridges & freezers;
- **mobile AC** – cars and large vehicles;
- **transport refrigeration** – refrigerated trucks/trailers.

This module focuses on the first four of these categories, although the principles reviewed apply to the other uses.

There is a range of technologies for mechanical cooling. The majority of systems are based on the vapour compression cycle. In simple terms this cycle involves the circulation of

For details on how to obtain your **Energy Institute CPD Certificate**, see ENTRY FORM and details on page 20 a refrigerant which by evaporating (boiling) absorbs large amounts of heat and then gives this up when condensing. This cycle is illustrated in Figure 1.

The key components of the system are:

• **evaporator** – this is a heat exchanger which absorbs the heat to be removed. One side of the exchanger will be refrigerant with the other either being air (e.g., an air conditioner, cold store) or a liquid (e.g., a water chiller);

• **condenser** - again a heat exchanger - this exchanger rejects the heat removed. Condensers can be air cooled or water cooled. When water cooled the cooling water can be linked to an open or closed cooling tower;

• **compressor** – this compresses the low-pressure vapour from the evaporator and passes it at high pressure to the condenser;

• **expansion valve/device** – this is a restrictor that allows the high-pressure fluid to expand when it enters the evaporator.

Compressor motive power

The main energy input is the motive power for the compressor. This is normally an electric motor, although other motive power units can be used. (For example, for passenger car AC the motive power is from the vehicle's engine). Ancillary equipment also uses energy. On the evaporator side - this could be a fan (for a cold store or AC application) or a pump (chilled water). On the condenser side, motive power will be required to move the air or a fluid that carries the reject heat (fans, cooling towers, etc.). In some systems energy is also required to defrost the evaporator.

As the quantity of heat moved by a refrigeration system exceeds the motive power input, a Coefficient of Performance (CoP) is normally used.

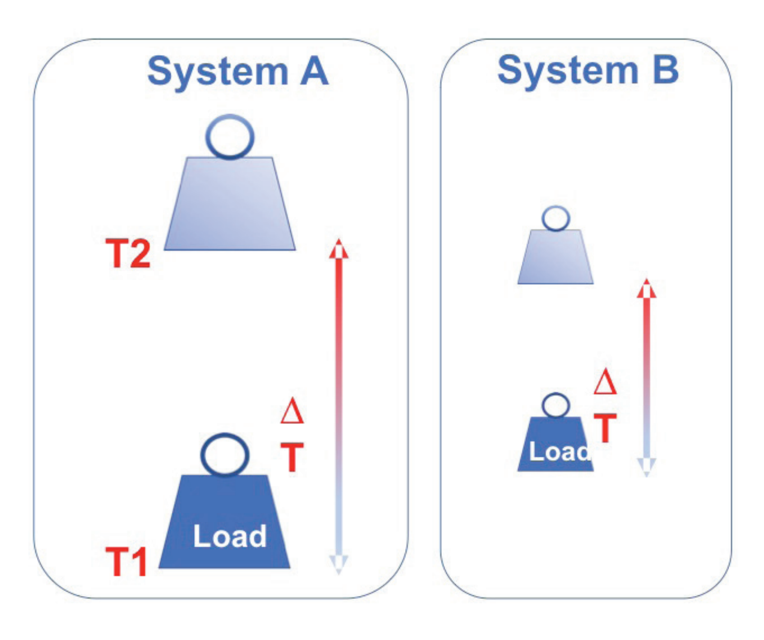
A system has two coefficients. COP (Coefficient of Performance) which is calculated using only the power input to the compressor and COSP (Coefficient of System Performance) which takes account of the power input of the compressor and ancillaries. Both coefficients should be considered when reviewing a system.

$$COSP = \frac{\text{Cooling capacity(kW)}}{\text{Power Input (kW)}}$$

In practice, COPs are typically in the range of 2 to 5 for refrigeration systems – which is about a tenth of the theoretical maximum, which suggests that there is scope for future improvements in the technology.

When looking at the performance of a refrigeration system it is important to understand the impact of what is called the temperature lift. This is the ΔT of the system where the relevant temperatures are the evaporating and condensing temperatures. Put simply, the greater the temperature lift the more energy input is required. To fully understand the energy requirement this needs to be coupled with the size of the cooling load. An analogy often used is that of lifting a weight. The larger the weight and the higher the lift, the more energy required. See Figure 2.

Fig. 2: Like lifting a load, the greater the temperature lift, the more energy input required



There are two pathways for reducing cooling energy use. First is to reduce the cooling load, second is to improve the performance of the system. These pathways are not mutually exclusive and for the optimum outcome both need to be addressed.

The starting point must be to reduce the amount of cooling required. For an air conditioned space it will be about limiting the amount of heat gain, this might be addressed by insulation, solar shading, etc. Equally, designing out cooling by use of building design, natural ventilation is valid.

In the retail environment load reduction could be by using doors/ covers on display cabinets. For cold stores LED lighting will reduce the load. Some aspects of load reduction are available at the design stage, others are operational issues. For example, keeping cold store doors closed as much as possible.

The next aspect is addressing the temperature lift. This is achieved by looking at both the evaporating and condensing conditions. The most obvious is the cooling set point. In air conditioning users should aim for as high a space temperature as acceptable. Likewise for data centres. For cold storage it's best to avoid over cooling that results from setting temperatures lower than needed for product quality/safety.

> "There are two pathways for reducing energy cooling use"

Adjusting the set point for cooling may be obvious, but less attention is often paid to the condensing conditions. High condensing temperatures can arise from fouling of the heat exchanger and/or poor placement of the outdoor unit giving restricted airflow.

Improving performance

So how do you improve performance of each part of a system?

• **compressors** - can be reciprocating, screw, scroll and centrifugal. The size and type of system normally dictates the type of compressor. But as with all equipment some models are more energy efficient than others. When selecting new equipment look for compressors that have good part load efficiency. In practice, systems operate more time at part load than at full load. A low-cost improvement can be the use of 'floating head pressure control'. Most refrigeration systems operate at a higher pressure than necessary. Systems are available that allow head pressure and therefore condensing temperatures to float relative to ambient conditions. This typically requires a technician to implement and can save between 2-4 per cent of compressor power for every 1ºC reduction.

• **condensers** – for air-cooling, select a unit with wide fin spacing to minimise blockage and keep it clean. Savings of 5 per cent can come from cleaning while increasing the condenser size by 30 per cent might realise 10 per cent savings. Typically, an increased size condenser, at design stage, will pay for itself in about two years. Another aspect for air-cooled condensers is the fan(s). A typical upgrade is to fit EC fan units. Water-cooled condensers are typically used on larger chilled water and process systems. As with air-cooled systems uprating the unit may be beneficial. Water-cooled systems can be susceptible to fouling if the correct water treatment is not used. Unlike the fouling of an air-cooled unit it can be harder to detect. Evaporative cooling (cooling towers) can be energy efficient, but the system does require adequate controls on Legionella.

• **evaporators** – as with condensers upsizing can be beneficial. While condensers can become blocked with debris, for evaporators the issue can be icing up. Where de-frosting is part of the system operation ensuring 'defrost on demand' as opposed to defrost on a fixed cycle time can lead to savings.

• **expansion valves/devices** – 'smart' devices can be used on larger systems where they are economically viable. Typically for a large system an electronic expansion valve might have a payback of 1-2 years.

• **heat recovery** – given a refrigeration system needs to reject heat, finding a use for that heat will improve overall performance. The issue with all heat recovery is the time and quality match between the waste heat and the potential use. Refrigeration systems can provide around 10 per cent high grade heat (at 50-60ºC via a de-superheater) and low-grade heat at 20-30ºC. Recovered heat can be used to pre-heat hot water – this could be cost effective in a food processing environment where there is a regular demand for hot water.

• **refrigerant charge** – a refrigeration system can operate with a reduced charge and this may not be noticeable, until the system needs to operate at full capacity. However, operating with a reduced change is inefficient. Systems typically become under charged as a result of refrigerant leakage. Many refrigerants are powerful GHGs adding to the impact of system inefficiency and reduced capacity.

• **system monitoring** – while a domestic fridge is pretty much fit and forget, the same is not true of larger systems. System monitoring and control can be used to optimise performance and identify operational issues in advance of failure.
• **insulation** – this is often overlooked, but poor quality or poor condition insulation can have a significant impact on system performance. Low-temperature insulation needs to be airtight as well as having good thermal performance. External insulation needs to be weather protected, otherwise it will breakdown over time. Where there is chilled water pipework poor performing insulation will add to the system load.

Most efficient products

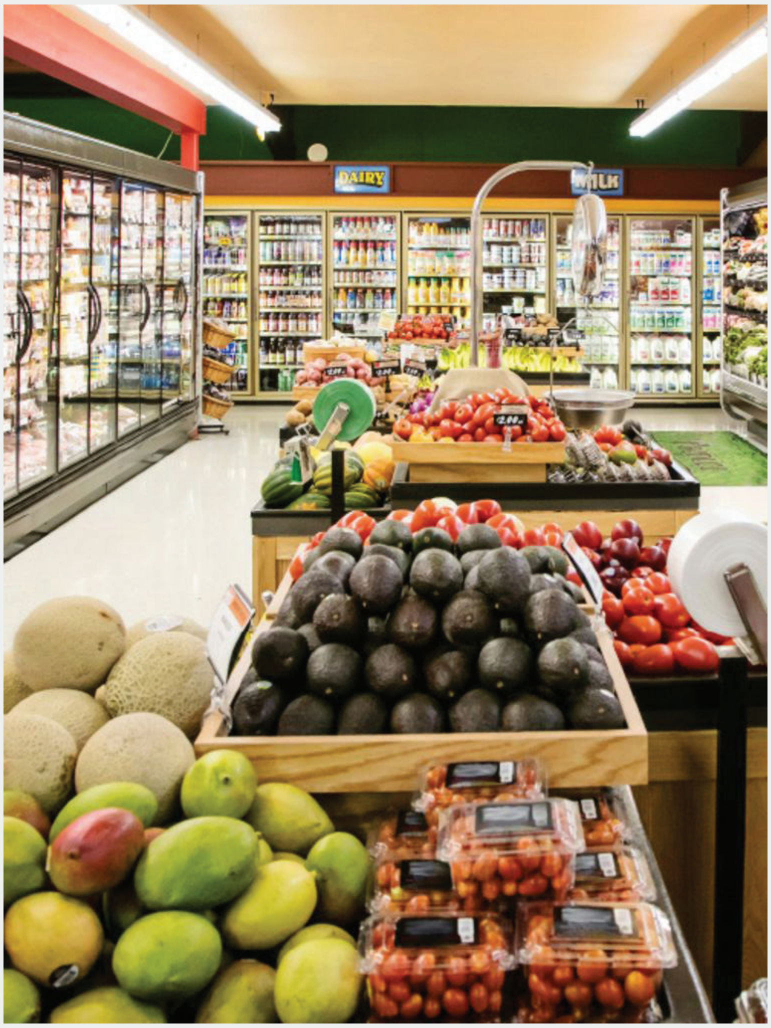
The Government's Energy Technology List[4] has a range of refrigeration equipment listed that is within the top 25 per cent of most efficient products in the marketplace. This includes absorption systems, condensers, chillers, cellar cooling equipment, refrigerated storage and display cabinets, accessories for refrigerated display cabinets, compressors, leakage detection and system controls. When designing a system, it makes sense to review these products as part of the equipment selection process.

Fluorinated greenhouse gases (F gases) used as refrigerants are known to cause significant environmental damage. In particular, some have very high Global Warming Potential (GWP). These can be as much as 3,000 times greater than CO_2 – which can also be used as a refrigerant. Arguably, with a sealed system leakage should not be a significant problem. However, it was estimated in 2008 that the average leakage rate was 20 per cent leading to an 11 per cent reduction in efficiency.

Fluorinated greenhouse gases (F gases) include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6)

For this reason, the F-gas regulations were introduced. These regulations place a responsibility on system operators to prevent leakage from their equipment and for contractors to share that responsibility.

On the 1st of January 2021, the EU regulations for F Gas and ozone depleting substances (ODS) ceased to apply in GB (Northern Ireland needs to still comply with EU regulations). Most requirements contained within the EU regulations have now transferred across to the GB legislation and it expected that GB will continue to restrict ODS and phase down HFCs (Hydrofluorocarbons – the most common F Gas). NetRegs[5] provides extensive guidance on the regulations.



Part of the process is the banning of certain gasses for new equipment and for re-gassing. The EU intention is that by 2030 the use of HFCs will have reduced by 79 per cent from the average between 2009 and 2012. This will be achieved by a progressive tightening of restrictions on use.

With effect from 1 January 2020 there is ban on F-gasses where the gas has a GWP that is greater than 2,500, and its CO_2e is greater than 40 tonnes of CO_2. Equipment used for military purposes & equipment used to cool products below -50ºC is exempted. This ban does not mean that existing equipment has to be replaced – just that it cannot be recharged with virgin F-gas.

The banning of gases does provide an opportunity to consider an upgrade or replacement of the system. Another option is the use of a so-called 'drop in' gas – however, these may have an impact on system performance.

Other refrigerants include:
• **ammonia** - NH3 (R717) is a 'natural fluid' with zero ODP and GWP. However, its toxicity, corrosiveness and explosiveness mean it is a niche refrigerant. Typically, it is used in large, industrial refrigeration systems.
• **carbon dioxide** - CO_2 (R744) is also a natural fluid with zero ODP and GWP=1, but without the negative effects of some other natural fluids. CO_2 is now being widely used in retail refrigeration systems.

Obligations to maintain

The Energy Performance of Buildings (England and Wales) Regulations 2012, as amended in 2020 (the EPB regulations) place obligations on anyone who manages or controls an air conditioning system. The main requirement is for a regular inspection (every five years) of air conditioning systems with an effective rated output of more than 12kW. TM44 is the accepted guidance for the UK for assessing the efficiency of air-conditioning units. The inspection must be carried out by an accredited assessor. The assessor's report will tell you about the current efficiency of your equipment; suggestions for improving the efficiency of your equipment; any faults and suggested actions and suggestions on how to reduce your air conditioning use.

The difference between the vapour compression cycle and the absorption cycle is that the compressor in the vapour compression cycle is replaced by a chemical absorption process and generator, with a pump to provide the circulation and pressure change.

The absorption cycle is referred to as a heat-operated cycle because most of the energy required to operate the cycle is heat energy. As it uses a compressor the vapour compression cycle is described as a work-operated cycle.

Absorption chilling is a relatively small part of the total refrigeration market. At the smaller end of the market there are absorption fridges/freezers powered by LPG for mobile applications. Where larger scale units come into play there is an available waste or low-cost heat stream. Possible applications include: new CHP plant; existing CHP with spare heat; applications where waste heat is available (e.g., exhaust steam); where a low-cost source of heat is available (e.g., landfill gas, geothermal); and where solar energy can be harnessed. Absorption chillers can be part of a so-called tri generation system – which generate electricity, provide heat and provide cooling.

There are various types of absorption chillers, but they all work on a similar principle. An absorption fluid is evaporated, removing heat from the chilled water. A heat source such as steam, exhaust gas or hot water is then used to regenerate the absorption solution. Typical absorption solutions are lithium bromide and water and ammonia and water.

Looking at refrigeration equipment itself, there are two potential future pathways. One is advanced vapour compression systems with low or ultra-low GWP refrigerants the other non-traditional technologies.

However, better management and operation of existing systems has a potential that can be exploited today. The Kigali Cooling Efficiency Program[6] suggests that optimisation, monitoring & maintenance alone can reduce total cooling GHG emissions by 13 per cent with 20 per cent electricity savings. This is a significant saving, but it could be offset by increasing demand unless that issue is addressed. ■

REFERENCES

- The Future of Cooling, International Energy Agency, 2018
- A Cool World, University of Birmingham, 2018
- CTV076 Refrigeration, Carbon Trust, 2019
- https://etl.beis.gov.uk/
- https://www.netregs.org.uk/environmental-topics/air-pollution/fluorinated-gases-f-gases/
- https://www.k-cep.org/

ENTRY FORM

Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. 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, return it to the address below. Photocopies are acceptable.

Questions

1) Refrigeration accounts for what percentage of total global electricity use.
☐ 10 per cent
☐ 14 per cent
☐ 17 per cent
☐ 19 per cent

2) What percentage of a supermarket's energy use is accounted for by refrigeration?
☐ 70 per cent
☐ 60 per cent
☐ 50 per cent
☐ 40 per cent

3) What is the most common type of refrigeration cycle?
☐ Absorption
☐ Vapour condensation
☐ Vapour compression
☐ Vapour evaporation

4) Which part of the refrigeration system uses the most input energy?
☐ Evaporator
☐ Compressor
☐ Condenser
☐ Defrosting

5) COSP is short for
☐ Coefficient of System Pressure
☐ Coefficient of System Performance
☐ Coefficient of Specific Performance
☐ Coefficient of Specific Pressure

6) What is a typical range for COP?
☐ 1-3
☐ 1-4
☐ 2-5
☐ 3-10

7) Which of these is not a type of refrigeration compressor?
☐ Scroll
☐ Screw
☐ Script
☐ Reciprocating

8) What savings could be expected from a 1oC reduction from floating head pressure control?
☐ 2-4 per cent
☐ 3-5 per cent
☐ 4-6 per cent
☐ 5-7 per cent

9) Increasing a condenser size by 30 per cent might realise savings of?
☐ 5 per cent
☐ 10 per cent
☐ 15 per cent
☐ 20 per cent

10) What percentage of recovered heat could be 'high-grade'?
☐ 5 per cent
☐ 10 per cent
☐ 15 per cent
☐ 20 per cent

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