DEMAND REDUCTION

- Chillers and HVAC
- Fabric Insulation
- Heat Distribution and Boilers
- LED Lighting
- Variable Speed Drives
- Voltage Optimisation
- Water Efficiency
- Behavioural Management
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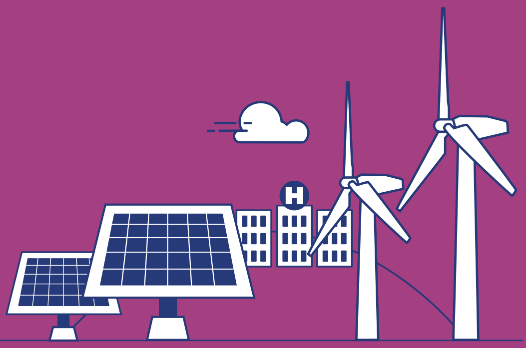
- Contract & Performance Assurance



Chillers and HVAC

KEY FEATURES

- HVAC systems, including chillers, typically account for 15-35% of total hospital electricity energy use
- Many older systems may now be running below optimum efficiency
- Evidence shows scope for over 30% energy reduction
- A wide range of solutions can be applied to improve efficiency and make energy savings
- Benchmarking existing energy usage is an essential starting point.

1. Introduction

HVAC systems, including chiller energy, typically account for between 15 and 35% of total hospital electricity energy use and around 80 to 90% of gas utilisation.

Gas use in HVAC systems is heavily influenced by heat generation plant, such as boilers and (where applicable) CHP, covered elsewhere in this guide.

Heat energy at point of use, however, is influenced by the HVAC system type and its control (e.g. radiators with local hot water control valves, or mechanical supply and extract ventilation to achieve required air-change rates).

General areas of the hospital and areas of specialised clinical use will require different levels and configurations of HVAC, depending on the demand for heating, cooling, dehumidifying/humidifying and provision of fresh air ventilation needed. Heat may be used alongside cooling to deliver a closely controlled environment (such as an operating theatre or laboratory) either as part of a full air-conditioning system, or separately - for example by localised radiators or local fan-coil units.

Cooling provisions are usually integral to air-conditioning systems, which may work with heating and humidification plant to provide close control; whereas separate split air-conditioning units may be installed to provide localised comfort cooling for patients and staff.

HVAC systems have usually evolved alongside estate development, often resulting in dispersed application (numerous localised plant-rooms or packaged external units), or a range of different systems serving different areas. These systems may have been progressively augmented or adapted to meet changing requirements over the years, with (unintended) compromises in operation and maintenance.

As a result, many elements of hospital HVAC systems may not be operating as originally intended. They may have received limited re-investment beyond minimum maintenance upkeep and thus may not be as efficient in energy utilisation as they could be.

2. Key HVAC issues

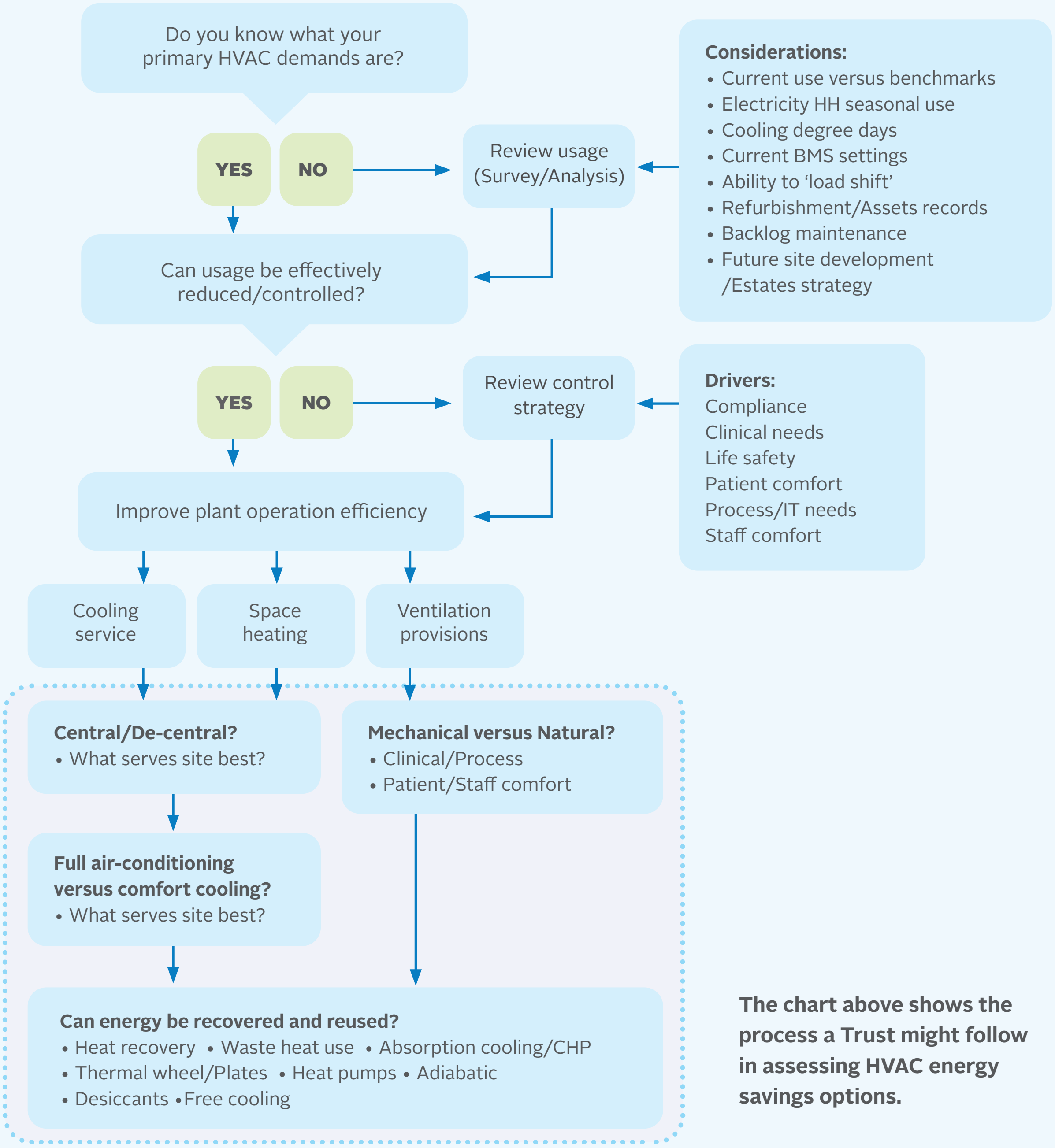
Typically, the primary issues that drive hospital HVAC solutions are:

- Compliance with NHS and hospital operational policy, usually driven by Health Technical Memoranda (HTMs).
- Specific environmental requirements to satisfy clinical processes and achieve internal space environments that do not compromise life, safety or patient well- being (for example, operating theatre activities or emergency spread of fire/smoke control).
- Environments where patient care and comfort can be maintained consistently throughout the day and during each season of the year (for example avoidance of over-heating in the summer, adequate warmth in the winter).
- Environments where more specialised process needs can be carried out (for example pharmacy, storage and IT server operations).
- General staff and visitor comfort (for example in rest, changing and waiting areas).

More recently, as a result of the SARS-CoV-2 (COVID-19) pandemic, there has been a focus on the ability of HVAC systems to maintain adequate ventilation within wards and clinical spaces to help mitigate the potential for virus transfer and to provide enhanced cooling for staff having to wear PPE continuously within these areas.

Depending on the age of the hospital and arrangements within it, there may be some very simple HVAC solutions, deployed with limited use of air-conditioning. These areas may have less reliance on conditioning 'a sealed building' and rely more on utilisation of natural ventilation (for example opening windows). A 'mixed-mode' philosophy may be in place that makes use of natural ventilation for most of the year, or perhaps only at certain times of the day, to achieve ad-hoc cooling without using high-density HVAC plant, but with localised mechanical cooling provided to sensitive areas only.

3. Initial assessment for HVAC solutions



The chart above shows the process a Trust might follow in assessing HVAC energy savings options.

An initial feasibility assessment is likely to consider some of the following questions. The answers suggest typical approaches needed to answer them:

Q How do I know if my hospital is operating efficient HVAC systems?

A You can't manage what you don't know. Unless you have had a recent review, or carry out ongoing reviews of your HVAC systems, it will be difficult to answer this question in any detail. However, the notes below may form part of a more detailed review to help with an initial assessment.

Q How can I benchmark my hospital's HVAC energy use?

A This may be difficult to do accurately or completely for the whole estate; however, the following actions will provide valuable snapshots of key systems or areas.

- Compare your ERIC returns (gas and electricity use /m^2) to those of other hospitals of similar category/ size. This may help to put into context the more detailed analysis work suggested below.
- Review energy use breakdowns from Display Energy Certificates and accompanying reports, which should provide some pointers on where consumption is highest.
- Track gas usage records over a whole year. Using publicly available heating degree-days, this will determine the relationship of gas use and need for heat. The clearer the relationship, the more likely that heating is being controlled well (i.e. when heating degree-days are low, your gas consumption will be low; it should rise proportionally with heating degree-days).
- Look at consumption of gas from invoices for each season and for the whole year. Relate this to the m2 of areas heated from the gas meter billed to establish the kWh/m^2 demand pattern. How do these compare with benchmarks?
- Track electricity use over the summer against published cooling degree-days to determine if there is a relationship between electricity consumption and need for cooling. This may not be as obvious as for heating, and ideally needs access to half-hour electricity meter data.

Q How do I establish where the biggest opportunities are?

A Identify and target the largest HVAC loads since those improvement projects are likely to harvest the largest savings impacts and most viable paybacks. Smaller systems can be considered once the big picture and main opportunities are understood.

- Check whether large plant are already being 'sub-metered' and sending consumption data to the BMS. Operation trends and load plots may be available.
- Analyse BMS logs for operational times and loads of main chiller plant, AHUs and pumps.
- Consider employing a specialist to fit BMS points data capture analysis software. This will facilitate a more detailed pull-out of existing operational performance and possible opportunities for correction of set points and optimisation.
- In most cases, sub-meter information may be non-existent and if general data is not already being captured, an overview 'walk-round' survey, noting significant pump, compressor and fan motor sizes, will help build a picture.
- Existing asset registers, PPM plans, air-conditioning inspection reports and refrigerant inventory lists may already identify useful information on plant capacity and the areas served.
- Try to capture findings in a manner that helps map where the biggest energy users are.

Q Is usage pattern important?

A Yes. Knowing what areas the main HVAC plant serves and the associated user needs, will help to develop an energy savings strategy that minimises unnecessary plant operation.

- From the initial assessment exercises above, a picture should have emerged of where and when the largest HVAC usage occurs. Review this alongside electricity invoices for opportunities to reduce plant demand during periods of daytime higher-rate tariffs, red tariff periods and Triad periods shown on the bills. This may not require full 'load shifting' or 'load shedding', but might mean relaxing set points during these periods to reduce demand gradually.

- Some clinically critical areas may be out of bounds in terms of adjustments to control HVAC plant and may call for realistic conversations with department managers to establish what is possible and acceptable at a practical level.

Q Is my HVAC plant too old to improve?

A O&M budget constraints may mean replacement of old and/or unreliable plant has been put off.

- Estates teams are usually experts in optimising operation of older machinery to maximise life expectancy. Nevertheless, it is useful periodically to review potential opportunities to replace old/unreliable plant with more efficient or alternative solutions.
- At the same time, consider recent increases in energy prices and the build-up of backlog maintenance, some of which may be considered as an 'avoided cost' to help build a business case for replacement.

Q Will energy savings impact on the need to meet compliance?

A Be clear on what level of solutions are needed to comply with regulation or best practice (HTMs,BS ENs).

- This is important when considering energy saving opportunities that may rely on optimising or reducing plant duty (typically variable speed fan controls, occupancy detection or control setback changes).
- Changes of area use over the years may mean existing plant is either no longer compliant, or no longer needed to operate as originally designed. The high-level review identified above, alongside consultation with end users, should capture this.

Q How do I deal with areas where thermal comfort is not being met?

A Patient wellbeing relies significantly on achievement of thermal comfort. Overheating in many hospitals during more frequent periods of heatwaves may become an issue in the medium to longer term.

- Take a holistic view on any significant areas where there are thermal comfort problems. Any HVAC energy reduction proposal needs to account for the potential influence from existing levels of fabric insulation, impact of unshaded solar gain in the summer and influence from casual gains, including lighting, equipment and people.

Q Do I need to consider the longer-term outlook?

A This may not be possible to assess with total confidence. However, an initial assessment should consider any known impact of the short, medium and long-term estates strategy on current main plant, capacity and primary plant locations.

- Are there plans to remove/change/introduce areas to the estate that may have significant impact to HVAC load (e.g. new clinical scanners, hydrotherapy pools, theatre upgrades, significant IT areas?).
- In short, are any areas scheduled to change that may impact existing systems or create new potential energy improvement opportunities?

4. HVAC procedures and benchmarks

Hospital operational procedures may vary to a degree, but key HTMs associated with HVAC provision include:

- HTM 03-01: *Specialised ventilation for healthcare premises,* which in various parts focuses on design and implementation aspects.
- HTM 07-02 Encode 2015 - *making energy work in healthcare,* which has a very useful and more detailed review of energy management aspects.
- Typical HVAC energy benchmarks for hospitals are published in CIBSE TM46 and in CIBSE Guide F Energy *Efficiency in Buildings.*

A review of the CIBSE benchmarks indicates a difference of c.30% between 'typical' and 'best practice' HVAC electricity energy use in acute and teaching hospitals, suggesting significant scope for HVAC energy reduction.

Caution is needed when isolating individual benchmarks from overall benchmarks, as other performance parameters may influence the HVAC benchmark and visa-versa. For example, reducing lighting energy should reduce heat gains for air-conditioning and comfort cooling, but may also increase winter heating demand.

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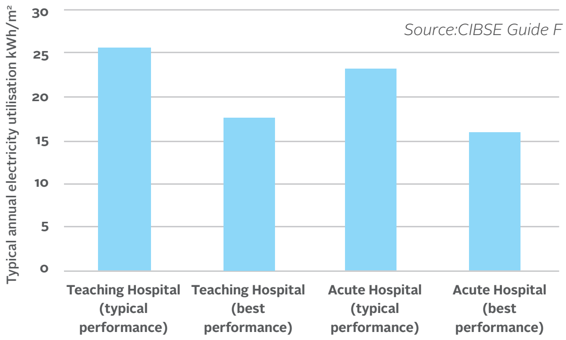
Comparison of ‘typical’ verses ‘good practice’ HVAC electricity energy use



Source:CIBSE Guide F

5. Cooling

Most hospital estates comprise a mixture of different building phases and a variety of cooling solutions may exist, depending on the age of the original estate and primary clinical usage of the area.

It is common for hospital sites to have a centralised boiler plant room with a distributed heating main, serving satellite HVAC plant rooms within various zones and buildings around the hospital site; it less common for cooling to be delivered in the same way.

A single centralised chilled water plant and chilled water distribution main is not always provided and it is common for cooling to be provided by more localised solutions. These may still encompass significant chilled water plant with localised chilled water distribution, but there is usually also a range of smaller cooling plant and systems that have been deployed to serve individual areas and retrofitted over time to suit specific use.

Therefore, cooling energy savings opportunities usually have different focuses relating to either centralised or dispersed plant, some of which are summarised below.

Opportunity	Centralised cooling	Dispersed cooling
Cooling load reduction	Plant size governed by resilience needs (usually N +1), connected site load diversity or load factor (ratio of average load to peak load), and longer-term site needs/ development plans. Review distribution chilled water set points. Is the chilled water flow temperature capable of being compensated or adjusted to suit demand? Is the system still distributing chilled water to buildings that no longer make significant use of it (i.e. have refits been applied to stand-alone systems instead)?	Plant size reduction governed more by flexibility of end users in the area directly served, plant space controllability, bespoke times of use, and set back opportunities. Look at potential for localised solar gain control. External brise soleil shading has greater impact than internal blinds, but more significant retrofit issues (visual impact to existing buildings; local authority planning may be needed). Look at more optimised location of electrical equipment (particularly IT servers); move away from zones more sensitive to solar overheating. Review the need for full close control in areas that do not have critical environmental control parameters. Small adjustments to space temperature and humidity (RH) set points can make significant impacts on consumption over time, and are usually no-cost to implement. Review plant operation times with end-users - are systems operating when there is no user requirement?
Cooling plant efficiency	Potential for good part-load efficiency if cooling circuits are adequately controlled. Use of thermal storage tank buffers is possible to reduce chiller compressor plant cycling. Heat rejection plant efficiency opportunities may be more practical to achieve, e.g. use of adiabatic air-cooled condensers. Consider compressor upgrades to enable VSD control,e.g. potential for ‘Turbocor’ oil-free compressor utilisation with integrated VSD to provide better part-load efficiency.	More dependent on zone controls, e.g. separate local plant or capacity control set up, to deal efficiently with external zones that are subject to more variant demand, versus internal zones in deep-plan buildings. Localised solar, equipment/casual gain control/management in the end use space may have a bigger energy savings impact. Avoid reheat operation on systems i.e. solutions that apply heating after dehumidification. If unavoidable on close control systems, consider utilising waste heat recovery.

Opportunity	Centralised cooling	Dispersed cooling
Cooling energy losses	Ensure chilled water distribution pipework thermal insulation is complete, including valve and fitting thermal covers. Avoid routing chilled water distribution through areas of significant heat gain e.g. boiler rooms, or near high temperature heat distribution pipework. Consider variable pumping control for primary chilled water distribution (VSD drives and 2-port valves at point of CHW usage).	Good local pipework thermal insulation is important. Avoid separated heating and cooling control systems, e.g. comfort cooling units operating with heating radiators active at the same time (simultaneous heating and cooling). Avoid comfort cooling units operating when the windows are open (uncontrolled ventilation).
Cooling energy storage	Consider larger chilled water buffer vessels if appropriate, to smooth out demand and reduce need to run chillers at peak capacity. The ability to do this will depend on diurnal load pattern. Consider phase change ice storage. Again, this is dependent on diurnal load pattern and any savings impact relies on significantly lower night rate electricity tariff and DUoS tariff band timings.	Consider night purging of buildings using cooler night air to pre-cool the building during the summer and delay the need to activate mechanical cooling the following day. Depends on the 'thermal weight' of the building and exposed 'thermal mass.' Difficult to retro-fit with existing deep-plan buildings that are occupied 24/7.
Cooling and cooling heat rejection energy recovery	Consider free cooling i.e. holding off refrigeration compressors and / or controlling heat rejection plant to take maximum advantage of lower ambient temperatures. Consider utilising waste heat from CHP to drive a thermal absorption chiller.	Local plant can also incorporate 'free cooling' and compressor VSD control, although replacement plant with built-in technology is more likely to be viable than retrofitting to individual systems. Consider enthalpy control on fresh air plant, to minimise the need to dehumidify fresh air in AHU cooling coils. Consider refrigerant-to-air heat pump technology and variable refrigerant flow units to maximise use of heat during condensing cycles. Consider thermal wheels on air-conditioning plant to transfer useful energy from extract air to supply air streams.
Cooling systems energy management and monitoring	Install electricity sub-meters on all major chiller plant and monitor half-hour usage to establish load patterns and opportunities to optimise operation and potentially load shed /manage. Meters on large chilled water distribution systems may also help in monitoring demand and optimising ongoing control between seasons.	Sub-metering local chillers and AHUs may be advantageous. Where possible, enable monitoring of remote systems via BMS and ensure out-of-range alarm values (i.e. temperature) are followed up. Effective energy management and savings will be achieved if feedback from monitoring is acted on.

6. Chillers

Conventional chiller energy utilisation comes primarily from the electric motors operating screw or centrifugal compressors to drive the refrigeration cycle. The efficiency of this process is largely governed by the ability to match compressor loading to prevailing cooling load.

Ideally, efficient chiller control avoids compressor operation until needed, and also prevents too many starts and stops to reduce occurrences of overshooting demand and 'hunting' around a control point, with associated mechanical compressor wear. The advent of cheaper variable speed drives and intelligent controls has made more dynamic compressor control possible. However, the mismatch of chiller capacity to actual cooling loads is still common. Significant energy savings may sometimes be made by installing an additional, small part-load / mid-season chiller, that can operate more efficiently than the original larger units outside peak load situations.

The ability to reject heat efficiently from the condensing cycle also has a significant bearing on overall chiller efficiency. Chillers used within hospitals are mainly of two types:

- **Water-cooled.** Having refrigerant condenser heat cooled by water (indirect or occasionally direct acting cooling tower)

Or;

- **Air-cooled.** Having refrigerant condenser heat cooled by external ambient air (radiator and fan).

There may be hybrids of these types, but essentially, they cover all refrigerant-based cooling solutions.

Water-cooled chillers are generally more efficient, as they use the latent heat from water evaporation to increase the efficiency of heat transfer from the refrigerant condenser to the air. However, because of concerns over Legionella risk, conventional cooling towers are not usually deployed in hospitals. Air-cooled chillers are used widely, although their efficiency drops off when the ambient air temperature is highest and closer to the temperature at which the refrigerant is condensing.

Chiller efficiency saving is usually considered in terms of ability to improve the seasonal energy efficiency ratio (SEER); that is the total cooling energy provided by the chiller, divided by the total energy delivered into the chiller over the course of a year. SEER will account for the ability to cool more efficiently when the external ambient temperatures are lower.

Annual seasonal efficiency ratios of more than 4 can be delivered using modern electric chillers that deploy variable speed compressors and system controls that enable good part-load efficiency, coupled with condenser designs which can make use of lower ambient external temperatures to reduce reliance on compressor operation.

Retrofitting improvements. It is worth considering possible retrofit improvements to existing machines where these units have a viable life expectancy, such as adiabatic cooling, which involves spraying water into the ambient air being drawn over an air-cooled condenser. This pre-cools the condenser and increases the efficiency of heat rejection, reducing the power needed from the refrigeration compressors. All the water sprayed onto the condenser coil is evaporated, so there is no recirculation. This 'total loss' system avoids the Legionella bacterial growth risk posed by conventional cooling towers. It is still advisable to assess risk and ensure there are no elements of standing water in connecting pipework and drains, and belt-and-braces solutions may also incorporate treatment with ultra-violet light.

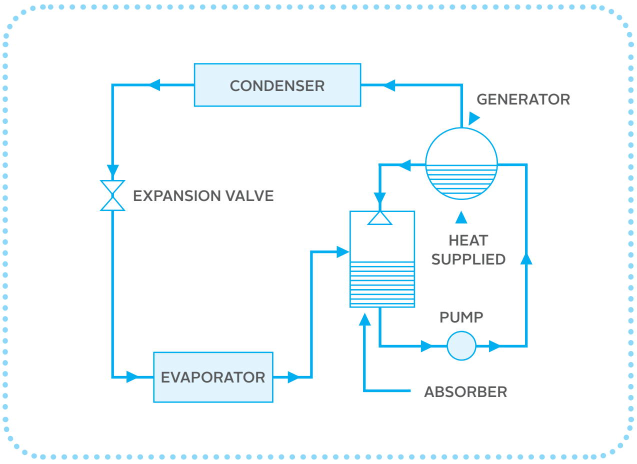
The Carbon Trust Guide "*How to add adiabatic cooling to your refrigeration plant*" suggests typical installation costs of c.£2000 for a 300 kW chiller with an anticipated payback of less than 2 years based on 1500 hours annual operation.

Refrigerant issues. Synthetic fluorinated greenhouse gas refrigerants are almost universally used in conventional electric chillers, packaged air-conditioning / split units and heat pumps. Since 2001, in Europe and the UK, traditional HVAC refrigerants like R22 which is a Hydrochlorofluorocarbon (HCFC) have been banned from use in new equipment and, since 2015, can no longer be used to top-up existing refrigeration plant. Consequently, most hospitals will now have replaced their old HCFC systems either with new plant using a hydrofluorocarbon (HFC) alternative synthetic blend or a drop-in replacement. While HFCs have zero ozone depleting potential, they still have high global warming potential. Although HFC refrigerants have generally replaced HCFCs, they are now the focus of the F-Gas Regulations which came into force in 2006 and were updated in 2014. These regulations require mandatory leak checks and repairs and automatic leak detection for systems above a certain threshold. They also dictate the need to keep records about air conditioning and heat pump equipment using HFC refrigerants, as well as the requirement to use qualified technicians for leak checking and refrigerant handling operations.

New replacement chillers should be checked for compliance with F-Gas and the use of natural refrigerants may also be considered as an alternative to HFCs where practical. Natural refrigerants such as Hydrocarbons (propane and butane), ammonia and CO2 are possible alternatives to HFCs, but each has its own practical implementation issues. Hospitals with a large base chiller load that are also considering applying Combined Heat and Power (CHP) technology may consider an absorption chiller as an alternative, which typically works on a process that encompasses natural refrigerants such as a water in a lithium bromide solution.

7. Absorption chiller economics

Absorption chillers use heat to drive a chemical refrigeration effect (as opposed to electricity used in conventional chillers to run mechanical gas compressors). If waste heat can be harnessed to drive a chemical absorption refrigeration process, and this supplants a conventional electric chiller operation, it may be possible to show significant energy savings.



Simplified schematic of an absorption refrigeration process

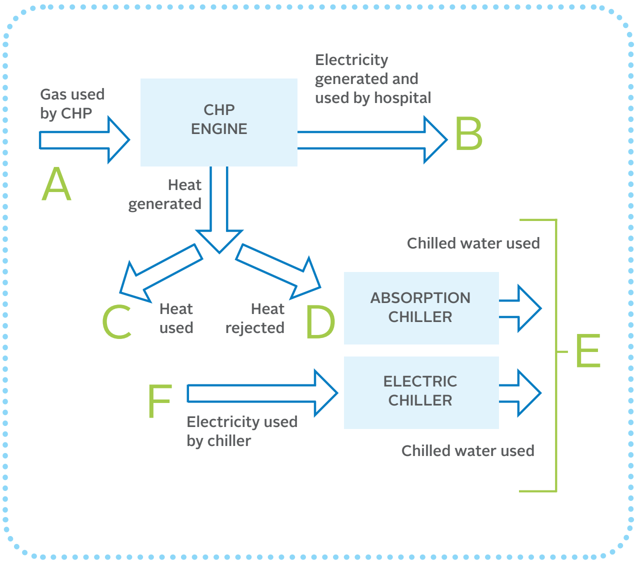
The thermodynamic efficiency of the absorption refrigeration process is poor compared to a conventional electric compressor chiller and is driven by the grade of heat applied in the 'generator'. Single-stage absorption chillers that use waste heat at around 80 deg C will have a typical efficiency ratio of around 0.6 to 0.7. This can double when double-stage absorption chillers are used, but to achieve this they require high-grade heat inputs above 140 deg C (typically from waste steam, or recovered heat from CHP exhaust gas).

In common with electric water-cooled chillers, absorption chillers need water to carry away heat from the condenser using cooling towers, dry or adiabatic coolers, but the cooling water temperature must be kept above 20 deg C to avoid lithium bromide solution crystallisation. The viability for absorption cooling rests on:

- Access to high-grade waste heat - i.e. heat that is truly a by-product of another beneficial process such as CHP (in certain circumstances).
- Access to as large a base cooling load as possible - absorption chillers are generally not widely available at small scale and tend to operate best when subject to a relatively consistent demand.

An ideal scenario would be one where there is an existing centralised chilled water system and a CHP that can provide waste heat to drive an absorption chiller (connected to the chilled water distribution) during the cooling season. This improves CHP operational efficiency by reducing the amount of heat that may have otherwise been 'dumped' because of reduced summer heat demand, by extending the annual CHP hours, or by enabling a larger CHP to be considered, to generate greater savings.

A typical absorption chiller energy savings model is based on the inputs and outputs shown below. This model can be used to compare the absorption chiller CHP with existing hospital chiller efficiency, as well the potential for new high-efficiency electric chiller replacement.



The values of 'A' (gas used by CHP), 'B' (electricity generated by CHP in place of grid supply), 'C' (heat used for space heating or hot water) and 'D' (heat not required and rejected from the CHP) will depend on the type and size of CHP and prevailing base demands.

'D' may be high-grade or low-grade waste heat or a combination of both; the choice would depend on type of CHP utilised and will dictate the SEER of the absorption chiller achieved.

The model compares the total cost of energy to operate a CHP with absorption cooling to the equivalent cost for operating electric chillers. The amount of cooling delivered (E) is the same in each case. The electrical energy input (F) is based on the electric chiller SEER.

The table below shows the inputs and outputs for a modest 1.2 MWe reciprocating natural gas CHP, with and without absorption cooling, together with a comparison of the equivalent cooling output being generated by the hospital's existing electric chiller:

Element	CHP without absorption chiller	CHP with absorption chiller
Total annual gas used by CHP (A)	25,814,844 kWh	25,814,844 kWh
Total annual gas cost for CHP (£=A x gas tariff)	£771,864	£771,864
Total electricity generated by CHP used by hospital (B)	9,181,253 kWh	9,181,253 kWh
Total value of electricity generated by CHP used by hospital (£=B x elec tariffs)	£922,815	£922,815
Total heat recovered from CHP used by hospital (C)	7,672,074	7,672,074
Seasonal efficiency of existing hospital gas boilers (n1)	75%	75%
Equivalent annual existing hospital boiler gas saved (=C/n1)	10,229,432	10,229,432
Total value of existing hospital boiler gas saved (£= C x gas tariff)	£327,444	£327,444
Total heat rejected from CHP used for absorption chiller (D)	0 kWh	660,085 kWh
Seasonal efficiency of absorption chiller (n2)	0.00	1.00
Total cooling generated by absorption chiller (E=D x n2)	0 kWh	660,085 kWh
Cooling delivered by electric chiller (=E for comparison)	660,085 kWh	0 kWh
Seasonal efficiency of electric chiller (n3)	3.0	0.0
Equivalent electric chiller annual electricity (F=E/n3)	220,028 kWh	0 kWh
Total cost of chiller energy input (£=F x elec tariffs)	£23,004	£0
Total CHP + cooling solution energy operating cost (£B + £C - £A - £F)	£455,392	£478,396
Total saving compared to CHP without absorption cooling	**£0**	**£23,004**
Total carbon emissions from CHP excld. absorption chiller (=G)	-541 tCO2e	-541 tCO2e
Cooling carbon saved (=H)	-557 tCO2e	557 tCO2e
Total net carbon saved CHP + Cooling (=G+H)	-1098 tCO2e	16 tCO2e

On the face of it, there is a modest energy savings benefit in providing absorption cooling. However, this saving is very sensitive to the following variables:

- The amount of true CHP waste heat available. More absorption cooling could be provided, but may come at the cost of using CHP heat that would otherwise have been used to offset hospital space heating and DHW gas boiler use, rather than just the CHP waste heat that would have been 'thrown away'. The boiler efficiency that the CHP heat is offsetting may therefore also impact the amount of absorption chiller capacity that is most viable to use.
- The size of CHP in relation to site electricity load; for example, if the CHP is sized to follow base electricity load, a significant reduction in electric chiller operation may require reduced CHP output to avoid export to grid. This may significantly impact the overall savings achieved.
- The SEER of the electric chiller that the absorption chiller CHP is being compared against. The higher the electric chiller SEER achievable, the lower the CHP absorption chiller savings advantage.
- The CHP spark gap (difference between electricity price displaced by CHP and cost of gas to fuel the CHP).

Probably the most influential factor, however, is implementation cost, which is very site-specific. Absorption chillers are only marginally more expensive than an equivalent packaged electric chiller, but viability depends on optimisation to suit a CHP waste heat source and integration into an existing site chilled water system. This in turn will depend upon how centralised the site cooling load is, and the availability of additional plant space. These issues can significantly affect implementation costs and what can be achievable on site. It is difficult to demonstrate the viability of CHP with absorption chiller retrofits, and they are uncommon.

The ability of a CHP heat powered absorption chiller to save carbon compared to operating an electric chiller without CHP may be increasingly reduced. This is because grid electricity carbon content is reducing year on year and the alternative, that would consider a modern all electric vapour compression electric chiller, can now deliver much higher levels of COP. However, the idea of linking a CHP to an absorption chiller is to increase the utilisation of heat take from CHP to make it more efficient.

A CHP that is able to deliver more heat utilisation in the summer by sending it to an absorption chiller is likely to increase its summer carbon savings between 5% and 20% compared to the same CHP operating and throwing the heat away. The overall annual carbon saving will depend on how well the CHP recovers all of its heat, not just heat used in the absorption process and what you are comparing the absorption chiller-CHP operation with, in terms of alternative electric vapour compression chiller operation.

If the CHP is generally operating at a poor level of efficiency, then, while the carbon saving impact from operation with an absorption chiller is improved, the impact of operating the CHP may well still have a negative carbon saving impact compared to not having a CHP.

8. Heat recovery

HVAC systems involve exchange of energy, and once used within a heating or cooling process there may still be useful residue that can be re-used to benefit another (usually adjacent) systems rather than just throwing it away. Generally, the lower the grade of residual waste energy, the less viable it is to recover.

The Carbon Trust Guide: "*Heat recovery - A guide to key systems and applications*" provides useful details of HVAC heat recovery applications. Typical examples of potential within hospital environments are summarised in the following table.

Opportunity	Typical location	Typical viability
Low-grade heat recovery from chiller condensers	Main air conditioning chillers	• Only viable if simultaneous heating demand while cooling. • Not widely practised in hospitals.
Thermal wheel	Principal air handling units (AHUs)	• Difficult to retrofit, due to significant space requirement and impact on existing plant. • Cross-contamination of air streams may be a risk in clinical areas. • Heat transfer typically between 65% and 75% efficient.
Plate heat exchanger	Principal AHUs	• Difficult to retrofit, due to significant space requirement and impact on existing plant. • Heat transfer typically between 55% and 65% efficient.
Run-around-coil	Most supply and extract AHUs	• Usually possible to retrofit • Heat transfer typically only between 45% and 50% efficient.
Heat pumps (also see heat pumps section)	Unitary packaged basis room by room, or more centralised systems.	• Air-to-air heat pumps most common. See below for other heat pump types.
Heat pipes and heat pump coils (also see heat pumps section)	Principle AHUs	• Heat pump coils remove heat or cooling energy from one location to another i.e. between two separate air streams. They need to be in close proximity. Typical heat transfer between 50% and 65% efficient. • Heat pipes only used where the supply and extract air streams are contained in the same AHU. Typical heat transfer between 50% to 55% on horizontal pipes and up to 75% on vertical pipes. Limited ability to control.
Flue gas economisers	Most boilers > 100 kW	• Usually viable if space available. • Consider replacement with condensing boilers if existing boiler < 150 kW. • Typical net thermal efficiency improvement up to 5% using. • A non-condensing gas-to-water economiser or by up to 15% if condensing.
Pre-heat combustion air	Large boilers	• Pre-heating combustion air to the burner by using a flue economiser or drawing warm air from the top of the energy centre or boiler shell. • Typical boiler efficiency saving 1% to 2% by raising the combustion air temperature by 20°C.
Blowdown on steam boilers	Steam boilers	• Recover flash steam and residual heat from the blowdown process through a flash vessel. • Typical blowdown energy loss savings up to 50%, achieving energy saving of 0.5% to 3.5% of boiler heat input. • Typical payback in 2 years.

Because of the recent global SARS-CoV-2 (COVID-19) pandemic, HVAC systems that use heat recovery that involves mixing return air from occupied spaces with fresh air have been identified as high risk and the CIBSE has published general guidance on their website associated with ventilation system operation [https://www.cibse.org/coronavirus-covid-19/coronavirus-covid-19-and-hvac-systems]. Guidance consensus suggests that *"the potential benefit to public health at this time outweighs the reduction in energy efficiency caused by not recirculating air"*. The guidance also suggests that *"any ventilation or air conditioning system that normally runs with a recirculation mode should now be set up to run on full outside air where this is possible"*.

9. Ventilation

New hospital building designs might incorporate ultra-low energy natural or mixed-mode ventilation solutions to areas not requiring close control, through careful design of building fabric, form and orientation.

Savings opportunities in existing facilities are likely to come from upgrading components and optimising the control of existing mechanical ventilation systems that may be quite old and inefficient. Typical opportunities are listed below. The potential savings, practical viability and resulting paybacks for these measures will vary considerably, depending upon the scope and scale of application, but the following measures are ordered in a typical hierarchy for consideration (starting with the generally low-cost measures first):

- Make sure filters in AHUs are changed regularly as part of PPM and that any excessively dirty filters are always changed even if this is before normal scheduled replacement.
- Retrofit low pressure drop filters in AHUs.
- Minimise duct air leakage - ensure duct access panels are properly fitted and any commissioning holes used for pitot tubes properly plugged.
- Ensure supply ducts and return air ducts (where air is recirculated) are thermally insulated or insulation repaired and upgraded where damaged.
- Replace existing v-belts and pulleys with cogged/synchronous belts.
- Provide effectively controlled free cooling wherever possible, particularly those controlling outside air supplied for heating and cooling in AHUs. Ensure dampers are not stuck, or incorrectly controlled. Consider review of operation so that only the minimum amount of outside air is cooled or heated.
- Retrofit low energy motors - electronically commutated or direct current may be possible.
- Retrofit VSD to existing motors.
- Retrofit low energy plug fans.

This is not an exhaustive list, and these measures would be considered alongside some of the controls and energy recovery measures mentioned elsewhere.

Some of the impacts to HVAC system design and operation following the recent SARS-CoV-2 (COVID-19) pandemic has been previously identified, and the guidance published by CIBSE highlighted. Designers of ventilation systems will need to refer to this alongside REHVA (Federation of European Heating, Ventilation and Air Conditioning Associations) COVID-19 guidance [**https://www.rehva.eu/activities/covid-19-guidance?no_cache=1**] as well as the most contemporary and emerging advice from NHS England & NHS Improvement.

10. HVAC controls

Controls for HVAC are linked to improvements in BMS which is detailed in the BMS section of this guide. In general, efficient HVAC controls rely on the following factors:

- Appropriate Zoning - ensuring areas have as local a control as possible. Ensure that AHU, duct and room control sensors are located in representative positions for the services being controlled.
- Optimising start and stop - ensuring systems can be switched off or set-back to back-ground operation when areas are not in use and that they can be activated in good time to achieve comfort conditions following setback or periods of deactivation.
- Avoiding simultaneous heating and cooling - avoiding the possibility of two separate systems heating and cooling the same space at the same time.
- Controlling ventilation - uncontrolled ventilation from draughts through poor fabric, or in appropriate

opening of windows and doors will affect efficiency of both heating and cooling controls within a space.

References

- *HTM 03-01: Specialised ventilation for healthcare premises*
- *HTM 07-02 Encode 2015 - making energy work in healthcare*
- *CIBSE Guide F - Energy Efficiency in Buildings*
- *Carbon Trust Guide "How to add adiabatic cooling to your refrigeration plant"*
- *Carbon Trust Guide "Heat recovery - A guide to key systems and applications"*