



Heat Decarbonisation Pathway for NHS Wales

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Quality information

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Glossary

GHG	Greenhouse Gas
CHP	Combined Heat and power
BMS	Building Management System
EMS	Energy Management System
COP	Coefficient of Performance
REGO	Renewable Energy Guarantees of Origin

Executive summary

Wales has declared a Climate Emergency and is targeting zero carbon by 2050. In addition, there are stretching targets of a 63% reduction against 1990 levels of greenhouse gas emissions and an ambition for a net zero public sector, both by 2030. As well as meeting its duty to achieve a resilient, healthier, and globally responsible Wales, being responsible for over one million tonnes of carbon dioxide equivalent, NHS Wales has a significant contribution to make towards achieving these goals whilst recognising the considerable health and wellbeing benefits that could be realised.

Approximately 20% of the NHS Wales 2018/19 Carbon Footprint in 2018/19 was from energy for buildings, of which roughly half of the reported emissions (approximately 93,000 tonnes of carbon dioxide) were from fossil-fuelled space heating and domestic hot water provision for the buildings of the seven health boards and two trusts. This report presents the need for and challenges of heat decarbonisation in buildings and defines the scope for NHS Wales.

Several options are available to deliver a heat decarbonisation pathway, some utilising more mature technologies than others. When we talk about 'decarbonising' buildings, we often focus on eliminating fossil fuels (usually natural gas or oil) and replacing them with lower-emission renewable energy technologies. Whilst for electricity, large-scale wind and solar PV farms and nuclear power are rapidly decarbonising the electricity grid, the same inroads are not being made in decarbonising the gas network. This leaves organisations with decisions about how to decarbonise the production of heat and domestic hot water in their buildings.

There are several renewable heat-generating options available including electricity (direct, as the grid decarbonises), heat pumps (air, ground or water source), solar thermal, sustainable biomass, biofuels and energy carriers such as hydrogen. Each has its challenges, and none of the low-carbon alternative heat technologies mentioned are currently as economical, from either a capital or operational point of view, as conventional technologies.

Emerging as a universal solution is using heat pumps driven by renewable electricity. Heat pumps operate most efficiently at temperatures lower than the systems currently utilised in most NHS buildings. If the technical issues can be overcome, then the efficiencies delivered by heat pumps should reduce overall energy consumption. However, the fact that electricity is still much more expensive than gas means that careful consideration needs to be given to the business case.

The technical challenge is to improve the thermal performance of the building fabric and adapt the services to deliver heating and domestic hot water services at lower temperatures (noting the need to avoid bacteria growth, etc.) to improve efficiency. However, regardless of the technologies being employed, these measures are fundamental to good energy management. Our ability to understand, control and respond to the thermal performance of building fabric is essential to delivering a healthy, pleasant and affordable internal environment.

Reducing the need to consume energy also addresses another fundamental constraint. Where there is a need to meet the electricity demand of a building by on-site generation, available renewable electricity technologies often cannot generate enough in the space available or, where they can, it is generated at a time when there is little or no demand for the electricity in the building, e.g. electricity driven heating is not needed in summer when generation from solar PV is likely to peak): less demand for energy equals less need to generate energy.

With the above in mind, the immediate way forward for decarbonising heat is to maximise how conventional technologies are adapted and used to reduce carbon emissions. This report emphasises the importance of following the steps of the energy hierarchy and contains four key messages:

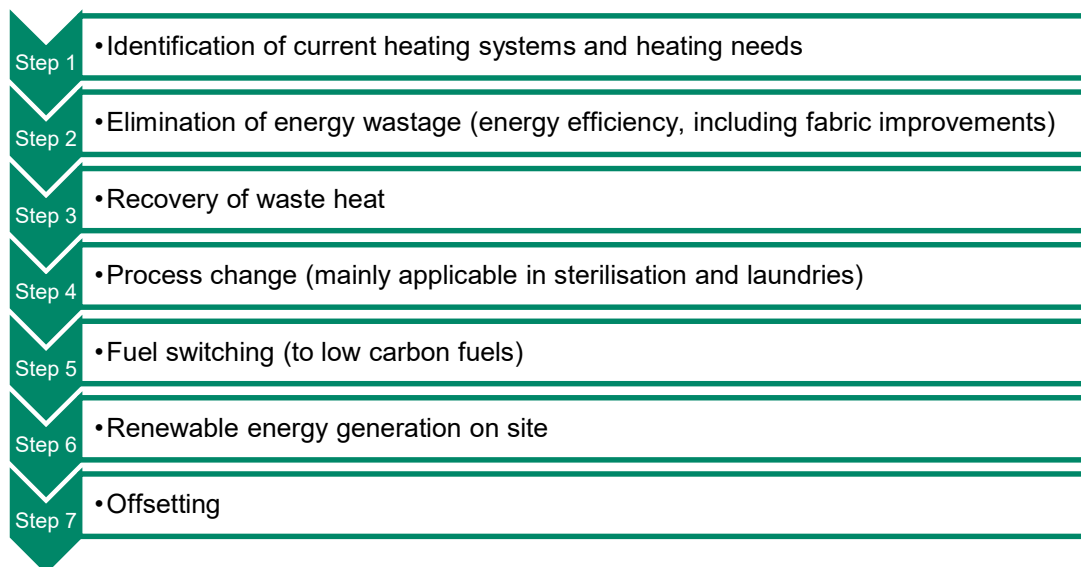
The potential for savings. Analysis of the current data suggests significant opportunities for improving the energy performance of buildings, with the use of combined heat and power engines being noted in particular. A significant contribution to meeting NHS Wales decarbonisation targets can be achieved through reducing the demand for energy as well as improving energy efficiency, without the use of renewables.

Improving the accuracy and availability of energy data. The availability of accurate energy related data is paramount to decarbonising heat. Whilst progress is being made with data collection, there is room for significant improvement in quality and quantity.

The energy management function is central to delivery. Informed through accurate data analysis, projects should be identified to reduce energy wastage through fabric improvement and services optimisation. These projects require a robust business case, delivery through a multi-disciplinary team and the effective monitoring of results: the energy management function is best placed to lead and coordinate.

Having a solid foundation for the selection of renewables. Implementing energy demand reduction and efficiency is critical before any fuel transition. Robust and comprehensive data makes the choice of renewables easier, more robust and cost effective. It also better ensures that the design is resilient.

A clear framework is suggested for heat decarbonisation delivery, comprising seven steps (with the last two being outside the scope of this report). The steps address, amongst others, the issues of fabric, efficiency, and low carbon heat sources, presenting relevant opportunities and points for consideration.



According to NHS England (if we attribute findings to NHS Wales), the potential for cost and carbon savings could be as follows:

Table: Estimated investment costs and savings for the building energy decarbonisation of NHS Wales, based on figures extrapolated from NHS England.

	Step 1	Step 2	Step 3	Step 4	Total
Investment (£)	~ £100m	~ £50m	~ £100m	~ £146m	~ £400m
Operational Savings (£ pa)	~ £26m	~ £2.2m	~ - (minus) £1m	~ £10m	~£40m
Carbon Savings (tCO ₂ e pa)	133,600	16,800	38,900	21,000	210,300
% Total NHS Wales emissions	13.34	1.68	3.88	2.10	21.01
Simple payback (years)	3.8	21.8	n/a	14.7	10.6

This report contains key recommendations to inform and support local decarbonisation plans. The recommendations include:

- Integrate asset management, the condition survey and planned maintenance with heat decarbonisation.
- Identify if key data is being collected. Where gaps are identified, implement strategies to rectify them. This might include the use of sub-metering, Building Energy Management System / controls upgrades, automatic readers, use of energy management software or other measures.
- Ensure that an energy management function and resource is available to update, monitor and analyse data to enable the identification and development of energy saving projects. In support of energy management, help other relevant disciplines to facilitate this process.
- Undertake a detailed review of the use and performance of Combined Heat & Power engines and identify and implement any changes required.

It is envisaged that this Heat Decarbonisation Strategy will be useful to **inform policy and key decision makers (NHS Wales senior management and the Welsh Government) and promote joined-up thinking within organisations on an efficient and realistic decarbonisation pathway.**

1 Scope of the report

Under the Well-being of Future Generations (Wales) Act 2015, NHS Wales has a duty to support Well-being Goals to achieve a resilient, healthier, and globally responsible Wales. With climate change, pollution, and detriment to health linked, it is the responsibility of NHS Wales to ensure that the climate is considered at an everyday decision-making level and to act on the climate and health emergency to support a healthier Wales now and in the future.

As mentioned in the Health Technical Memorandum 07-02: EnCO2de 2015, the Intergovernmental Panel on Climate Change highlights that climate change mitigation requires significant reduction of greenhouse gas emissions. NHS Wales has produced a Decarbonisation Strategic Delivery plan and the scope of this report is to inform the response of NHS Wales Shared Services Partnership – Special Estates Services (NWSSP-SES).

Energy for heat is identified as the most difficult and challenging part in a building's decarbonisation process. With regard to the energy used for heating NHS Wales buildings, this report aims to support the development of investment proposals linked with initiatives as set out in the NHS Wales Decarbonisation Strategic Delivery Plan. Those initiatives are as follows:

- Initiative 4 - Progress a transformational energy and water efficiency retrofit programme across the estate: every building with a long-term future will have undergone a multi-technology energy-efficient upgrade by 2030.
- Initiative 6 - Complete expert heat studies by the end of 2023 for all acute hospitals to set the plan to transition away from fossil fuel heat sources.
- Initiative 7 - Progress low carbon heat generation for all non-acute sites larger than 1,000m² by 2030.
- Initiative 9 - Take an active approach to efficient control of energy in our buildings. All buildings will have up-to-date, standardised, and effective building management systems (BMS). Dedicated resource to optimise the use of energy by BMS control will be put in place by 2023.

This report supports the Health Boards and Trusts in understanding how they can achieve decarbonisation and how energy management can play an important role in scoping the emissions, establishing a baseline, clarifying targets, identifying potential interventions, and measuring and verifying progress. The report sets out the potential cost and carbon saving of energy management and also offers some information on key issues that were identified during site visits and through discussions with different hospitals.

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2 Background on decarbonisation

2.1 Global and local context

The below extract from the NHS Wales Decarbonisation Strategic Delivery Plan sets out the global and local context regarding climate change.

The 2018 Intergovernmental Panel on Climate Change (IPCC) report showed the need to limit global warming to 1.5 degrees to avoid the worst effects of climate change, requiring unprecedented changes globally.

In April 2019, with cross-party support, the Senedd was the first Parliament in the world to declare a Climate Emergency.

The UK was one of the first countries in the world to declare a climate emergency, setting a 2050 net zero target. The Committee on Climate Change shows current targets from countries globally would lead to warming of 3°C by 2100.

Table 1: Highlights of possible climate impacts

Table 3.1 Highlights of possible climate impacts discussed in this chapter						
Temp rise (°C)	Water	Food	Health	Land	Environment	Abrupt and Large-Scale Impacts
1°C	Small glaciers in the Andes disappear completely, threatening water supplies for 50 million people	Modest increases in cereal yields in temperate regions	At least 300,000 people each year die from climate-related diseases (predominantly diarrhoea, malaria, and malnutrition) Reduction in winter mortality in higher latitudes (Northern Europe, USA)	Permafrost thawing damages buildings and roads in parts of Canada and Russia	At least 10% of land species facing extinction (according to one estimate) 80% bleaching of coral reefs, including Great Barrier Reef	Atlantic Thermohaline Circulation starts to weaken
2°C	Potentially 20 - 30% decrease in water availability in some vulnerable regions, e.g. Southern Africa and Mediterranean	Sharp declines in crop yield in tropical regions (5 - 10% in Africa)	40 - 60 million more people exposed to malaria in Africa	Up to 10 million more people affected by coastal flooding each year	15 - 40% of species facing extinction (according to one estimate) High risk of extinction of Arctic species, including polar bear and caribou	Potential for Greenland ice sheet to begin melting irreversibly, accelerating sea level rise and committing world to an eventual 7 m sea level rise
3°C	In Southern Europe, serious droughts occur once every 10 years 1 - 4 billion more people suffer water shortages, while 1 - 5 billion gain water, which may increase	150 - 550 additional millions at risk of hunger (if carbon fertilisation weak) Agricultural yields in higher latitudes likely to peak	1 - 3 million more people die from malnutrition (if carbon fertilisation weak)	1 - 170 million more people affected by coastal flooding each year	20 - 50% of species facing extinction (according to one estimate), including 25 - 60% mammals, 30 - 40% birds and 15 - 70% butterflies in South Africa Collapse of Amazon rainforest (according to some models)	Rising risk of abrupt changes to atmospheric circulations, e.g. the monsoon Rising risk of collapse of West Antarctic Ice Sheet Rising risk of collapse of Atlantic Thermohaline Circulation
4°C	Potentially 30 - 50% decrease in water availability in Southern Africa and Mediterranean	Agricultural yields decline by 15 - 35% in Africa, and entire regions out of production (e.g. parts of Australia)	Up to 80 million more people exposed to malaria in Africa	7 - 300 million more people affected by coastal flooding each year	Loss of around half Arctic tundra Around half of all the world's nature reserves cannot fulfill objectives	
5°C	Possible disappearance of large glaciers in Himalayas, affecting one-quarter of China's population and hundreds of millions in India	Continued increase in ocean acidity seriously disrupting marine ecosystems and possibly fish stocks		Sea level rise threatens small islands, low-lying coastal areas (Florida) and major world cities such as New York, London, and Tokyo		
More than 5°C	The latest science suggests that the Earth's average temperature will rise by even more than 5 or 6°C if emissions continue to grow and positive feedbacks amplify the warming effect of greenhouse gases (e.g. release of carbon dioxide from soils or methane from permafrost). This level of global temperature rise would be equivalent to the amount of warming that occurred between the last age and today - and is likely to lead to major disruption and large-scale movement of population. Such "socially contingent" effects could be catastrophic, but are currently very hard to capture with current models as temperatures would be so far outside human experience.					

Note: This table shows illustrative impacts at different degrees of warming. Some of the uncertainty is captured in the ranges shown, but there will be additional uncertainties about the exact size of impacts (more detail in Box 3.2). Temperatures represent increases relative to pre-industrial levels. At each temperature, the impacts are expressed for a 1°C band around the central temperature, e.g. 1°C represents the range 0.5 - 1.5°C etc. Numbers of people affected at different temperatures assume population and GDP scenarios for the 2080s from the Intergovernmental Panel on Climate Change (IPCC). Figures generally assume adaptation at the level of an individual or firm, but not economy-wide adaptations due to policy intervention (covered in Part V).

Climate change is recognised as the most significant threat to the health of humanity on a global scale. The World Economic Forum states climate change as the greatest risk to the stability of the global economy, in terms of scale and likelihood, which will increase pressure on health systems across the world. The World Health Organization estimates that climate change will lead to around 250,000 extra deaths per year globally from 2030, and that the direct cost impact will be £3-5 billion per year over the next decade.

With climate change and detrimental health impacts inextricably linked, the Climate Emergency must also be recognised as a health emergency.

Increased societal awareness has led to calls for greater action to tackle climate change. Activism has enhanced the media spotlight on the climate agenda. Increased public awareness has led to growing pressure on governments and businesses to act rapidly to mitigate climate change, calling for the UK and devolved governments to formally declare a Climate Emergency. This was also supported in 2019 by an open letter signed by over 1,200 UK doctors calling for direct action against the climate crisis, citing the significant threat that climate change poses to public health.

The Climate Emergency for Wales

Since the Climate Emergency declaration, Welsh Government has accepted the Climate Change Committee's recommendation to increase Wales's 2050 emissions target to a 95% reduction against the baseline year (1990) with a further ambition to achieve net zero. However further advice published in December 2020 has recommended that action needs to be taken sooner, and this must chart a steeper trajectory towards net zero. If accepted, the advice would lead to a net zero target for all sectors in Wales by 2050 and a stretching target of a 63% reduction in greenhouse gas emissions by 2030 (compared with the current target of 45%).

To lead the way on climate action in Wales, Welsh Government has set the ambition for the public sector in Wales to be net zero by 2030.

The Climate Emergency for NHS Wales

NHS Wales recognises it has a significant contribution to make towards the 'Team Wales' target of a net zero public sector. NHS Wales shows leadership and commitment to deliver the Decarbonisation Delivery Plan in order to address the Climate Emergency for Wales as declared by Welsh Government and the Senedd.

The NHS Wales' requirements under the Well-being of Future Generations (Wales) Act 2015 will ensure that the climate is considered at an everyday decision-making level. This world-leading legislation places NHS Wales with a duty to support the seven Well-being Goals put in place by the Act. Decarbonisation has a critical role to play in meeting this duty, in particular to achieve a resilient, healthier, and globally responsible Wales.

With climate change, pollution, and detriment to health linked, it is the responsibility of NHS Wales to act on the climate and health emergency to support a healthier Wales now and in the future.

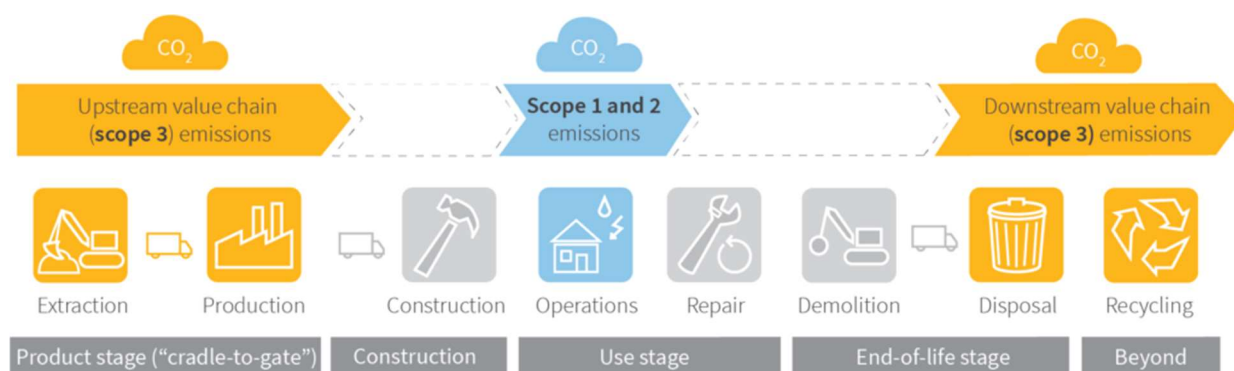
As mentioned in the Health Technical Memorandum 07-02: EnCO2de 2015, the Intergovernmental Panel on Climate Change highlights three major issues: that warming in the climate system is unequivocal, that the effect of humans on the climate is clear, and that climate change mitigation requires significant reduction of greenhouse gas emissions.

This poses a double challenge for healthcare facilities:

- to reduce their carbon emissions and contribute to the national and NHS targets for climate mitigation, identify opportunities for adapting to expected climate change and build resilience to extreme climate events.
- to support resilient communities including planning services for expected changes in health needs and providing high quality healthcare particularly focusing on needs during adverse climatic conditions.

2.2 Carbon emissions

Calculating and reporting carbon emissions is complex and Figure 1 shows the grouping of emissions relating to a building into scopes.



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Figure 1. Building product life cycle stages included in scope 1, 2, and 3 greenhouse gas accounting¹

This report will focus on operational emissions, scope 1 and 2.

Scope 1 includes all direct greenhouse gas (GHG) emissions from the activities of an organisation or under their control. In a healthcare building, these are typically the emissions from burning gas or oil on site, fugitive emissions from refrigeration systems and anaesthetic gases. Anaesthetic gases are not related to energy and therefore are outside the scope of this report.

Scope 2 includes all indirect GHG emissions from the generation of purchased or acquired electricity, steam, heating, or cooling.

The interventions suggested have an element of embodied carbon included, especially when these concern the fabric of buildings. At this stage, these embodied carbon emissions have not been studied in detail.

¹ as described by the Greenhouse Gas Protocol Corporate Value Chain (Scope 3) Reporting Standard. Cradle-to-gate emissions (including extraction, transportation, and production) as well as end-of-life waste disposal and recycling emissions are included in scope 3 emissions. Other life cycle stages, such as construction and demolition, are not clearly attributable to a category.

3 Heat decarbonisation targets for NHS Wales

3.1 NHS Wales emissions

In the NHS Wales Decarbonisation Strategic Delivery Plan the NHS Wales 2018/19 Carbon Footprint has been calculated as approximately 1 million tonnes of CO₂e. These include emissions across all three scopes.

NHS Wales 2018/19 Carbon Footprint

1,001,378 tCO₂e,

which represents around 2.6% of Wales's total greenhouse gas emissions. This has been set as the baseline for emissions reduction targets going forward, presented in the table below taken from the NHS Wales Decarbonisation Strategic Delivery Plan:

Table 2: Emissions reduction targets, according to the NHS Wales Decarbonisation Strategic Delivery Plan

NHS Wales Decarbonisation Target	Emissions (tCO ₂ e)	Percentage reduction from 2018/19	Cumulative savings from initiatives will total (tCO ₂ e)
2025	845,600	-16%	459,000
2030	661,500	-34%	1,982,500

3.1.1 Net emissions

As stated in the NHS Wales Decarbonisation Strategic Delivery Plan, the Greenhouse Gas (GHG) Protocol and UK Environmental Reporting Guidelines encourage dual reporting to allow for reflection of positive carbon activity which cannot be captured within the Carbon Footprint. As part of this assessment, NHS Wales are utilising dual reporting in order to reflect 'Net Emissions'. The 'Net Emissions' take into account any carbon sequestration activities (e.g. tree planting) but also allow for REGO (Renewable Energy Guarantees of Origin) certified electricity to be counted as zero carbon electricity.

The NHS Wales 'Net Emissions as stated in the NHS Wales Decarbonisation Strategic Delivery Plan are:

NHS Wales Net Emissions 2018/19:

939,967 tCO₂e

It is noted that the overall Carbon Footprint remains the primary and reportable footprint against which overall carbon performance will be assessed.

A key action taken between 2016/17 and 2018/19 has been the shift in energy procurement policy to purchase REGO (Renewable Energy Guarantees of Origin) certified renewable electricity², a type of "green" electricity. This is positive progress. However, as the carbon factors for grid electricity (the UK Government Reporting Conversion Factors) already take into account the electricity produced by renewables for which REGOs are generated, reporting REGO certified electricity as zero carbon results in underreporting of carbon emissions. Therefore, REGO

² The Renewable Energy Guarantees of Origin (REGO) scheme provides transparency to consumers about the proportion of electricity that suppliers source from renewable generation.

procured electricity cannot be considered as an offset reduction within the reportable Carbon Footprint. A very simplistic example demonstrating the underreporting of carbon emissions is presented in appendix 8.1.

3.1.2 Building use emissions

From the total of the NHS emissions, this report will focus on the emissions related to buildings. According to the NHS Wales Decarbonisation Strategic Delivery Plan, these make up 21% of the total emissions as shown in the chart below.

NHS Wales Carbon Footprint by Category 2018/19
(1,001,378 tCO₂e)

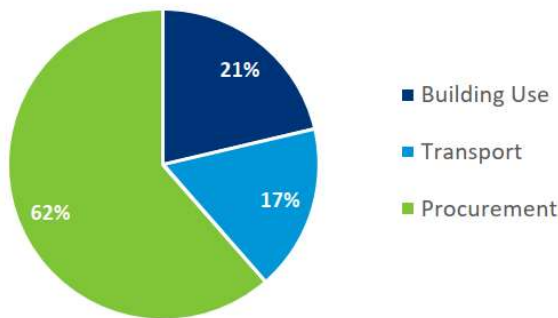


Figure 2. NHS Wales carbon footprint by category 2018/19

Building emissions were calculated to be **210,436 tCO₂e**.

The emissions related to buildings cover energy (84%), upstream energy (14%), i.e. well-to-tank energy associated with fuels, transmission and distribution emissions associated with grid electricity), water and waste.

Building Use Footprint by Type 2018/19 (210,436 tCO₂e)

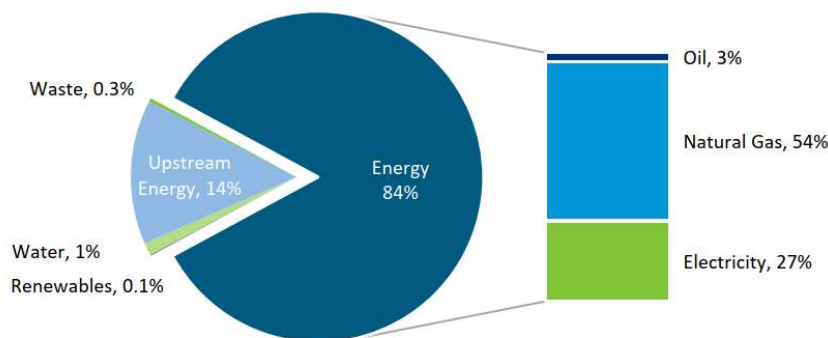


Figure 3. Building use footprint by type 2018/19

Based on the EFPMS data of the last six years (2015-16 to 2020-21), the Energy emissions are calculated per Health Board in the following table. It should be noted that these do not include upstream energy and the EFPMS data does not cover 100% of the NHS buildings. The emissions below are calculated using the grid emission factors published by Defra. These can be found in 8.3 Emissions factors on page 43.

Table 3: Energy related carbon emissions per health board

Health Board	2016	2017	2018	2019	2020	2021
	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)
ANEURIN BEVAN UNIVERSITY HEALTH BOARD	30,977	28,958	28,004	24,566	21,739	20,661
BETSI CADWALADR UNIVERSITY HEALTH BOARD	42,919	41,159	37,424	32,752	34,005	33,827
CARDIFF & VALE UNIVERSITY HEALTH BOARD	32,932	38,006	35,943	33,341	32,306	31,732
CWM TAF MORGANNWG UNIVERSITY HEALTH BOARD	30,655	29,689	27,384	24,892	23,204	23,273
HYWEL DDA UNIVERSITY HEALTH BOARD	21,249	21,388	20,834	18,865	18,635	19,286
POWYS TEACHING HEALTH BOARD	2,750	3,545	4,281	3,661	3,478	3,356
SWANSEA BAY UNIVERSITY HEALTH BOARD	31,530	29,216	27,392	24,661	24,520	23,055
VELINDRE UNIVERSITY NHS TRUST	2,299	1,705	2,012	1,750	1,729	1,429
WELSH AMBULANCE SERVICES NHS TRUST	2,515	2,091	2,208	1,780	1,677	1,630
Grand Total (tCO₂e)	197,826	195,757	185,482	166,267	161,293	158,249

From 1 April 2019, the Abertawe Bro Morgannwg (ABM) University Health Board was renamed to the Swansea Bay University Health Board following a transfer of responsibilities for properties with the neighbouring Cwm Taf University Health Board (renamed to the Cwm Taf Morgannwg University Health Board). Cwm Taf Morgannwg University Health Board took over the control of providing health services in Bridgend, including Princess of Wales hospital.

3.1.3 Energy consumption and CHP

Combined heat and power (CHP) units are a relatively common technology employed by Hospitals. CHP is an efficient process that captures and utilises the heat that is a by-product of the electricity generation process. Therefore, a CHP plant is an installation where there is the simultaneous generation of usable heat and power. This improves the overall energy utilisation of a given fuel compared with the traditional stand-alone boilers. A CHP system typically has an efficiency of over 80% (circa 45% heat and 35% electrical efficiencies). A CHP plant is more efficient than a simple power plant and conventional boiler configuration when the heat output is used effectively, as shown in the figure below:

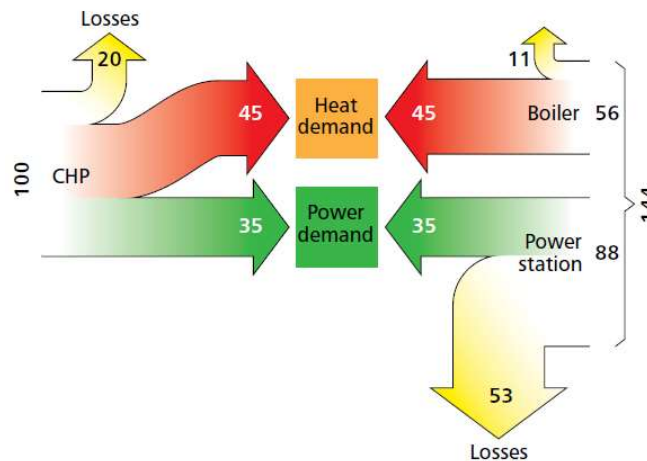


Figure 4. The Efficiency Benefits of CHP over Conventional Power Generation and Boilers. Source: CIBSE AM12³

The CHP technology is well established, and there is a wealth of options for different fuel types and system designs. However, it should be noted that due to electrical grid decarbonisation and changing carbon factors, fossil-

³ Combined Heat and Power for Buildings. CIBSE AM12. 2012.

fuelled CHP systems will no longer achieve carbon savings against a gas boiler counterfactual over the plant lifecycle.

Heat pumps could be an alternative to CHP. Heat pumps take heat from the ambient surroundings (air, ground, water or waste low-grade heat) and deliver this heat at a higher temperature (although most efficient at c50 deg C and not 80-90 as per Gas or CHP unit) through a closed process; either involving a compressor (using electricity) or absorption (using heat; e.g. steam, hot water or flue gas). Air source heat pumps (ASHP) employ the refrigeration cycle and use electricity to move heat from external ambient air to the inside of a building or vice versa. Heat pumps are a highly efficient method of heating since the energy consumed by the pump to move the heat is less than the transferred heat. For an Air Source Heat Pump, the transferred heat is typically 2.5 times the electricity consumption, this value is called the Coefficient of Performance (COP, also otherwise known as Seasonal Coefficient of Performance and Seasonal Efficiency), and it is an expression of the efficiency of a heat pump. The table below compares a conventional gas boiler, a CHP system and an Air Source Heat Pump assuming 100kWh energy input to each system.

Table 4: Efficiency of different heat sources

System	Gas Boiler	CHP	Air Source Heat Pump
Energy Input	100kWh	100kWh	100kWh
Energy Input Type	Natural Gas	Natural Gas	Electricity
Heating Efficiency	90%	44%	250%
Electrical Efficiency	NA	42%	NA
Heat Output	90kWh	44kWh	250kWh
Electrical Output	NA	42kWh	NA

In terms of energy consumption, it can be seen from the table above that where gas boilers are displaced by electrically driven ASHPs, gas consumption (input) drops to zero but *electricity consumption (input) increases*. For gas boilers to achieve 250kWh of heat output 278kWh of gas input is required. However, only 100kWh of electricity input is required to obtain heat output of 250kWh from an ASHP. Moving from a gas boiler to an ASHP therefore reduces the total amount of energy consumed by 178kWh for every 250kWh of heat output (c.64% saving).

Where gas CHP units are displaced by ASHPs, the same applies as above except for a CHP unit to achieve 250kWh of heat output (& 239kWh electrical output), 568kWh of fuel input is required. The much higher gas consumption is due to the unit producing gas and electricity simultaneously. However, only 100kWh of electricity input is required to obtain a heat output of 250kWh from an ASHP. Moving from a gas CHP engine to an ASHP therefore reduces the total amount of gas consumed by 468kWh for every 250kWh of heat output (c. 82% saving).

Of course, in the above analysis, disparities between efficiencies of centralised power generation, relative carbon factors and unit prices are not considered, all of which drove the initial uptake of CHP. However, with carbon factors for electricity and gas becoming more aligned, as well as discussions taking place at Government level about further penalising the use of fossil fuels, any new gas-fed CHP should be very carefully considered.

3.1.4 Emissions related to fossil fuels and CHPs

Natural gas and oil are used almost exclusively in boilers and CHP units (Combined Heat and Power). Natural gas is also used as cooking gas. It is largely accepted that the percentage of gas used as cooking gas in hospitals is very small. This, in combination with the lack of metering data on the cooking gas, leads on the assumption that all of the emissions presented in

Table 5 below take place in either a boiler or a CHP.

Table 5: Emissions related to fossil fuels

Health Board	2016	2017	2018	2019	2020	2021
	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)
ANEURIN BEVAN UNIVERSITY HEALTH BOARD	15,079	14,487	15,991	15,401	14,184	13,974
BETSI CADWALADR UNIVERSITY HEALTH BOARD	21,197	20,823	20,316	21,965	22,326	23,418
CARDIFF & VALE UNIVERSITY HEALTH BOARD	19,490	24,758	24,904	24,111	23,928	24,408
CWM TAF MORGANNWG UNIVERSITY HEALTH BOARD	15,977	16,462	15,633	16,026	14,930	16,169
HYWEL DDA UNIVERSITY HEALTH BOARD	14,182	14,689	14,769	13,463	13,489	14,768
POWYS TEACHING HEALTH BOARD	1,132	2,037	2,916	2,500	2,465	2,478
SWANSEA BAY UNIVERSITY HEALTH BOARD	13,133	13,658	13,026	13,251	14,143	14,196
VELINDRE UNIVERSITY NHS TRUST	605	683	732	698	749	631
WELSH AMBULANCE SERVICES NHS TRUST	736	537	739	677	675	662
Grand Total (tCO₂e)	101,532	108,135	109,027	108,092	106,889	110,704

During 2021, the emissions from burning gas and oil on site were approximately 72% of the total energy emissions, reaching up to 78% for Health Boards with significant sizes of CHP (Combined Heat and Power) units.

During our investigation, it was noticed that some CHP units operate with very low thermal efficiencies, as shown in Table 6 below, rendering them a very carbon intensive way of electricity and heat generation, much more carbon intensive than the conventional solution of using gas-fired boilers to generate heat and importing electricity from the grid.

Table 6 below shows the efficiencies according to the data submitted for 2021 and the carbon savings if a conventional solution was used instead.

Table 6: CHP efficiencies and related carbon emissions based on the 2020/21 data

Site Name	Installed Electrical Capacity	Heat-to-Power ratio	Thermal Efficiency	Electrical Efficiency	CHP related emissions	Comparative emissions with gas boiler and grid electricity	Carbon savings
	(kW)		(%)	(%)	(tCO ₂ e)	(tCO ₂ e)	(%)
<i>YSBYTY GWYNEDD⁴</i>	660	0.00	0.1%	72.5%	889	818	8%
UNIVERSITY HOSPITAL OF WALES	4370	0.27	10.7%	40.1%	9,770	6,173	37%
PRINCE PHILIP HOSPITAL	600	0.59	21.4%	36.5%	1,511	1,072	29%
WITHYBUSH GENERAL HOSPITAL	600	0.62	25.0%	40.1%	1,024	815	20%
PRINCE CHARLES HOSPITAL	650	0.87	33.1%	38.2%	2,420	2,093	13%
NEVILL HALL HOSPITAL	800	1.24	41.7%	33.7%	1,353	1,225	9%
YSBYTY GLAN CLWYD	670	1.57	44.8%	28.6%	1,885	1,654	12%
BRONGLAIS GENERAL HOSPITAL	210	1.61	50.6%	31.4%	982	961	2%
ROYAL GLAMORGAN HOSPITAL	420	1.61	50.6%	31.4%	1,431	1,402	2%
ST CADOC'S HOSPITAL	80	2.19	52.0%	23.8%	182	163	10%
Grand Total	9060				21,446	16,377	23.6%

The conventional solution, shown in the shaded columns, is only used here for comparison, not as a recommendation for carbon reduction, however, there is the potential of up to 23.6% of carbon reduction in the specific buildings, representing a 3.2% reduction of the building energy carbon throughout NHS Wales.

⁴ Incorrect / incomplete data available

Nevertheless, for the remaining lifetime of the current CHPs and until a low carbon heat plan is implemented, a strong recommendation for both carbon and cost savings would be to investigate the reasons for such low thermal efficiencies (<40%) and find solutions for better use of the heat generated by the CHPs.

For example, increasing the heat efficiency to 40% by better recuperation of heat, would bring annual carbon savings of approx. 4,400 tCO₂e and potential financial savings on gas import reduction of £950,000 (with an assumed gas price of £0.04/kWh) across NHS Wales. Of course, given the ever increasing cost of gas, the value of these savings are only likely to increase into the future.

Table 7: Potential carbon and financial savings if thermal efficiency of CHPs increases to 40%

Site Name	Import gas reduction	Emissions Reduction	Financial savings
	(kWh)	(tCO ₂ e)	(£)
<i>YSBYTY GWYNEDD</i>	2,217,520	408	£88,701
UNIVERSITY HOSPITAL OF WALES	17,876,126	3,287	£715,045
PRINCE PHILIP HOSPITAL	1,756,507	323	£70,260
WITHYBUSH GENERAL HOSPITAL	960,401	177	£38,416
PRINCE CHARLES HOSPITAL	1,039,288	191	£41,572
Total	23,849,842	4,385	£953,994

The above table only includes CHPs with current thermal efficiency lower than 40%.

3.1.5 Emissions related to heat and attribution of CHP emissions

Calculating the emissions related to heat requires some assumptions to be made on:

- how the CHP emissions will be attributed between the heat generated and the electricity generated; and
- whether or not there is enough data to include emissions for heat generated through electricity, for example immersion heaters and VRF (variable refrigerant flow) units, which usually provide space heating and cooling through ceiling-mounted cassette units.

For the attribution of the CHP emissions many different methodologies are available: the “efficiency method” has been used in this report, as it is recommended in the GHG Protocol initiative and the EU Commission Delegated Regulation 2019/331. The exact calculations used can be found in the Appendices, section 8.1.

Regarding the heat already being generated using electricity, it is difficult to have reliable estimates of how much that is without adequate submetering data and number of units. This is therefore not taken into account in the total heat related emissions presented in

Table 8 below. This is not detrimental to getting a fair image of the current heat-related emissions, as currently the amount of electricity generated heat is believed to be a very small proportion of the total heat. Also, as it is already electrified heat, with VRF systems being essentially heat pumps, this section of heat generation is already ahead in the decarbonisation route, as long as the systems have got appropriate controls, integrated in the BMS.

The heat related emissions of the estate, based on EFPMS data are presented in the table below:

Table 8: Heat - fossil fuel emissions (tCO₂e)

Health Board	2016	2017	2018	2019	2020	2021
	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)	(tCO ₂ e)
ANEURIN BEVAN UNIVERSITY HEALTH BOARD	13,935	13,386	14,868	14,171	13,180	13,131
BETSI CADWALADR UNIVERSITY HEALTH BOARD	20,365	20,036	19,276	20,798	20,801	21,572
CARDIFF & VALE UNIVERSITY HEALTH BOARD	19,490	15,828	15,694	17,257	14,605	16,024
CWM TAF MORGANNWG UNIVERSITY HEALTH BOARD	13,950	14,128	13,686	14,129	12,917	13,876
HYWEL DDA UNIVERSITY HEALTH BOARD	10,767	11,336	11,698	10,971	11,342	12,427
POWYS TEACHING HEALTH BOARD	1,132	2,037	2,916	2,500	2,465	2,478
SWANSEA BAY UNIVERSITY HEALTH BOARD	13,133	13,658	13,026	13,251	14,143	14,196
VELINDRE UNIVERSITY NHS TRUST	605	683	732	698	749	631
WELSH AMBULANCE SERVICES NHS TRUST	736	537	739	677	675	662
Grand Total (tCO₂e)	94,114	91,628	92,636	94,451	90,876	94,996

3.2 Emissions reduction targets for buildings

The NHS Wales emissions reduction targets for buildings, as also presented in Table 2 of this Heat Decarbonisation Strategy, are set out in Figure 5 below:

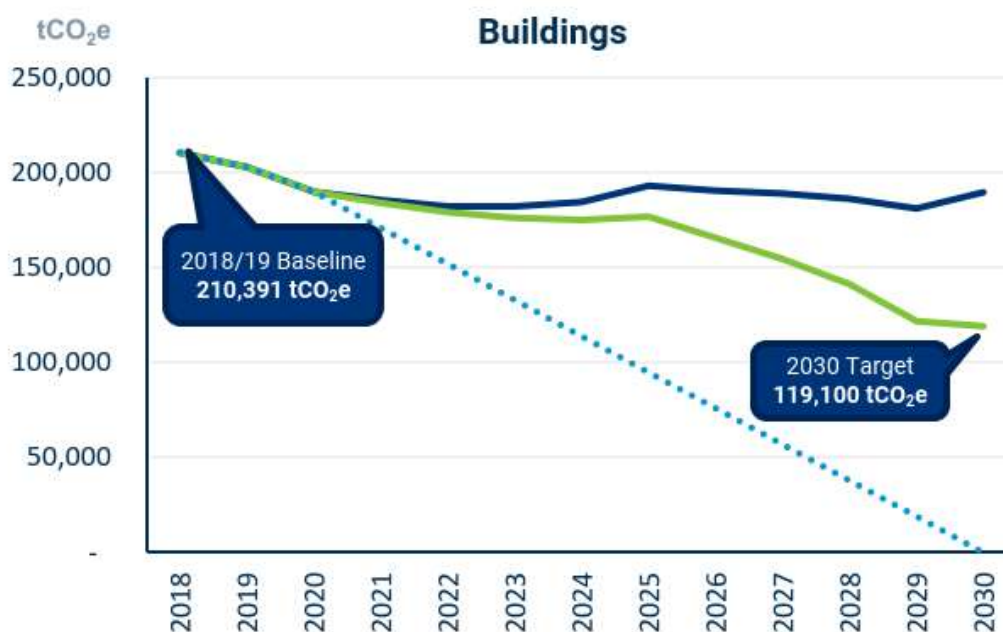


Figure 5. Buildings' category target for 2030 emissions reduction⁵

It is important to note that the percentage of emissions reduction for buildings in 2030 is 43%, greater than the 34% overall target for NHS Wales. This is because the reduction targets are distributed across the different NHS Wales activities possibly according to the relative opportunities to achieve carbon reduction.

These targets concern the total emissions of buildings, so it is interesting to explore what part of the total emissions is related to heat. This is presented in Table 9.

⁵ Source: NHS Wales Decarbonisation Strategic Delivery Plan

Table 9: Heat related emissions as a percentage of total emissions

Health Board	2016	2017	2018	2019	2020	2021
ANEURIN BEVAN UNIVERSITY HEALTH BOARD	45%	46%	53%	58%	61%	64%
BETSI CADWALADR UNIVERSITY HEALTH BOARD	47%	49%	52%	64%	61%	64%
CARDIFF & VALE UNIVERSITY HEALTH BOARD	59%	42%	44%	52%	45%	50%
CWM TAF MORGANNWG UNIVERSITY HEALTH BOARD	46%	48%	50%	57%	56%	60%
HYWEL DDA UNIVERSITY HEALTH BOARD	51%	53%	56%	58%	61%	64%
POWYS TEACHING HEALTH BOARD	41%	57%	68%	68%	71%	74%
SWANSEA BAY UNIVERSITY HEALTH BOARD	42%	47%	48%	54%	58%	62%
VELINDRE UNIVERSITY NHS TRUST	26%	40%	36%	40%	43%	44%
WELSH AMBULANCE SERVICES NHS TRUST	29%	26%	33%	38%	40%	41%
Average across all NHS Wales	48%	47%	50%	57%	56%	60%

The results above show a steady increase of heating's share of total emissions. This is not only because the gas consumption increases, but also because the emissions factor for grid electricity is decreasing, as the UK grid decarbonises. As the electricity grid decarbonises further, gas CHP begins to cost carbon – even when compared with standard gas boilers, Decarbonisation of the electricity grid is therefore now changing the paradigm in terms of the heating technologies that can be employed to reduce emissions. Health Boards with strong reliance on gas-fed CHP electricity generation do not see the full benefit of the electricity grid's decarbonisation, and therefore the percentage of their heat emissions as part of the total will continue to grow.

The red box in Table 9 marks the baseline year 2018/19. The average share of fossil-fuel related emissions was 57% of total emissions that year. This means that, theoretically, the target of 43% reduction by 2030 could be achieved through a fully decarbonised electricity grid alone if there was no increase in gas consumption. A fully decarbonised grid is extremely unlikely in the current environment and so is no increase in gas consumption, as new hospitals have also been built and brought into operation. Therefore, heat decarbonisation becomes very important in achieving the carbon reduction targets.

4 Decarbonisation of heat pathway

4.1 Defining a pathway

Decarbonisation refers to reduction of carbon emissions and this can range from a percentage reduction to complete elimination of emissions. Depending on the short- and long-term goals different strategies can be followed.

Even though there tends to be a lot of focus on low carbon technologies when exploring decarbonisation solutions, experience has shown that a significant part of carbon reduction often comes from energy efficiency, as the cheapest and less polluting kilowatt-hour is the one never used. For further reduction and elimination of carbon emissions, fossil fuels must be replaced with other heat sources with lower emissions. There are several technologies available for that, some more mature than others.

These other heat sources can be:

- electricity (directly),
- heat from outside air, ground or water pumped in the buildings through heat pumps (electricity),
- solar thermal,
- sustainable biomass and
- hydrogen.

Electricity and hydrogen do not emit any gases with greenhouse potential at their point of use, but depending on the way they were generated, they can have high or low indirect emissions. Of the two (electricity and hydrogen), low carbon electricity (electricity generated by low carbon or renewable technologies) is the one that is more mature, causing the emissions factor of the grid electricity to drop. This is why, in many sectors, decarbonisation is becoming synonymous with electrification.

Despite the continual decarbonisation of grid electricity, none of the low carbon alternative heat sources mentioned is cheap or abundant. Therefore, as mentioned, reduction in energy use, also referred to as energy efficiency, is a crucial first step that should precede the fuel switch in the decarbonisation pathway and can be the determining factor of whether decarbonisation is even possible in places with limited electrical capacity if electrification of heat supply is the preferred option.

A simplified approach for a decarbonisation pathway is presented in Figure 6.

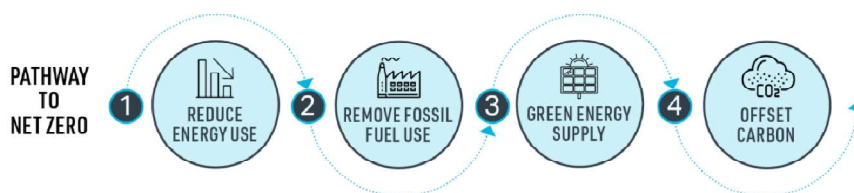


Figure 6. Simplified pathway to decarbonisation⁶

A more detailed methodology for heat decarbonisation is described below and forms the backbone of this report. Its aim is to assist on the implementation of Initiatives 6 and 7 of the NHS Wales Decarbonisation Strategic Delivery Plan. These are:

⁶ Image by AECOM

- Initiative 6: Complete expert heat studies by the end of 2023 for all acute hospitals to set the plan to transition away from fossil fuel heat sources.
- Initiative 7: Progress low carbon heat generation for all non-acute sites larger than 1,000m² by 2030.

4.1.1 Decarbonisation pathway methodology

A recommended methodology for creating and implementing a heat decarbonisation plan comprises of the following seven steps:

Step 1 - Identification of current heating systems and heating needs

This step establishes the basis of the decarbonisation plan. The more information is available at this stage, the more realistic and accurate the decarbonisation plan will be. The information needs to cover the following four elements:

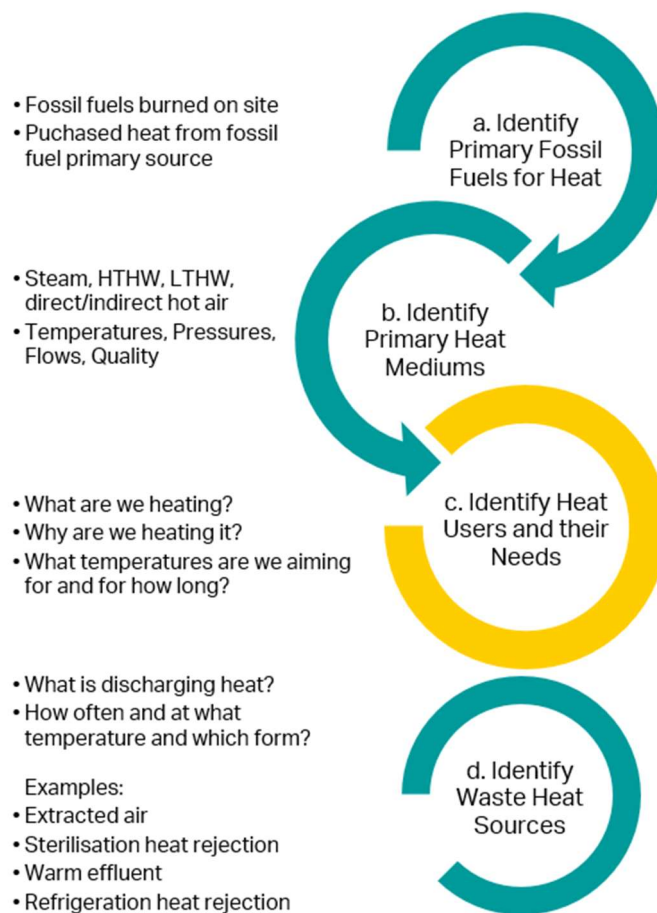


Figure 7. Key elements to identify when starting an energy efficiency and decarbonisation plan

Step 2 - Elimination of wastage

This step is about improving the energy efficiency of the buildings and includes reducing waste heat in heat generation (i.e., more efficient sequencing of the boilers, retrofitting modulating burners), heat medium distribution (i.e., better condensate recovery, pipework insulation, efficient pumping control) but also in reduction of the actual heating needs (i.e., double glazing, roof insulation, better heating scheduling and zoning). In a hospital, where most of the heating needs relate to space heating, reducing heat waste by ensuring a good fabric upgrade is crucial. The

introduction of some efficiency measures can be low cost and easy wins from a cost, energy and carbon perspective. The impact of some such measures can be difficult to isolate and quantify, however:

- The time taken in step 1 to set up robust data collection processes and baselining will facilitate a greater ability to quantify the benefits now and in the future.
- Interventions should be considered over their life cycle as well as their contribution to a transitional plan. For instance, combinations of many small energy demand reductions and efficiency measures may avoid significant costs at a later date i.e. the need for an electrical transformer upgrade avoided because the size of the heat pump needed to fully decarbonise heat (which will also be more expensive energy than is currently used) has been minimised.

Step 3 – Recovery of waste heat

This step focuses on recovering waste heat that cannot be eliminated and using it to partly fulfil the needs. This can include recapturing heat from refrigeration equipment, boiler exhausts (economiser), sterilisation processes, warm effluent, and heat recovery in air handling units.

The measures up to this step are the basis of an energy efficiency plan. The following steps do not necessarily reduce consumption but focus on reducing carbon emissions through fuel switch.

Step 4 - Process change

In this step it is examined whether it is possible to fulfil some of the heating needs with another technology. In a hospital, where most of the heating needs are for space and hot water heating, this would mean looking into the potential of a directly electrical solution, for example point of use boilers, instead of maintaining a centralised hot water system. It could also mean installing air conditioning units that can provide heating and cooling instead of maintaining a wet heating system. Both solutions would only be feasible in small buildings. In sites where there are significant sterilisation processes, or laundries, this step could mean looking into other solutions for sterilisation, for example UV and chemical sterilisation, instead of using high temperatures.

Step 5 - Fuel switching (to low carbon fuels)

Switching the primary heating fuel to a non-fossil, low carbon fuel can reduce further the carbon emissions. The choice of the technology will be defined by constraints posed by the existing heat medium and heating system, if these remain in place during the fuel switch. It might be necessary to consider changing heat medium (or just its temperature) and system (i.e., heat emitters) to accommodate for a fuel switch. These are considerable challenges and will depend on the output of the previous steps.

The following last two steps are slightly outside the scope of this report but are mentioned for completeness.

Step 6 – Renewable energy generation on site

Renewable electricity generation on site will offer low carbon electricity that can reduce further carbon emissions or work as an enabling factor to support a fuel switch in locations where electrical capacity is limited. Due to the physical space needed to generate renewable electricity (m²/kWh), a site is often constrained in being able to generate 100% of its electricity needs. This not an issue if the electricity grid has fully decarbonised or green tariff electricity is used, and this is acceptable for accounting purposes. However, where neither is the case, off-setting could be an option.

Step 7 - Offsetting

Carbon offsetting would involve funding a project that reduces or removes emissions of carbon dioxide or other greenhouse gases to compensate for the emissions of NHS Wales. Due to the lack of visibility and transparency in delivering and accounting for the reduction of emissions from this method, offsetting is currently not a preferred option for NHS Wales.

4.1.2 NHS England Estates ‘Net Zero’ Carbon Delivery Plan

The steps above set out one way of approaching a heat decarbonisation pathway. It is also worth considering the approach published in October 2021, by NHS England in their Estates ‘Net Zero’ Carbon Delivery Plan, which follows a slightly different methodology, summarising the decarbonisation process in four steps, depicted in Figure 8. These are very similar to those shown in Figure 6, with an extra step, Step 2, “prepare buildings for electricity-led heating”. These measures can also be considered as “enabling” interventions.



Figure 8. Four step approach to decarbonise the NHS England estate

An interesting element of the NHS England pathway is that it offers a breakdown of the carbon savings per step and the associated costs.

From the total of 2,668ktCO₂e related to NHS England building energy carbon emissions, 1,757ktCO₂e (66% of the total) can be saved in Step 1, 114ktCO₂e (4%) in Step 2, 519ktCO₂e (19.5%) in Step 3 and the remaining 278ktCO₂e (10.5%) in Step 4.

If a similar breakdown for NHS Wales was followed, it would be prudent to increase the carbon savings of Step 2, to take into account that the NHS Wales portfolio includes slightly older buildings. Therefore, a more realistic breakdown could be:

Table 10: Percentage breakdown of emissions savings in each of the four steps

	Step 1	Step 2	Step 3	Step 4	Total
NHS Wales	63.5%	8%	18.5%	10%	100%
NHS England	66%	4%	19.5%	10.5%	100%

According to the above percentage breakdown of carbon savings to each individual step, the absolute numbers for 210,436ktCO₂e of carbon emissions related to building use in NHS Wales, as presented in section 3.1.2, would be:

Table 11: Breakdown of emissions savings in each of the four steps

NHS Wales	Step 1	Step 2	Step 3	Step 4	Total
Annual Carbon Savings (tCO ₂ e pa)	133,600	16,800	38,900	21,000	210,300

Regarding the investment and operational costs, for Step 1, the investment required was calculated for NHS England as £1.322 billion for a reduction of 1,757ktCO₂e (therefore approximately £750/tCO₂e) with operational cost savings of £0.346 billion annually. There is no published information on the basis of these estimations, so in reality, the numbers might be quite different. It is nevertheless interesting to explore what the costs of decarbonisation of the building energy of NHS Wales would be under these assumptions.

From the NHS England figures, the investment cost per tCO₂e, as well as the operational savings are presented in the table below:

Table 12: Estimated investment costs and operational savings for each of the four steps, per tonne of annual carbon saving, based on figures extrapolated from NHS England.

	Step 1	Step 2	Step 3	Step 4
Investment (£/tCO ₂ e)	750	2,900	2,600	6,900
Annual Operational Savings (£/tCO ₂ e)	200	130	-28	470

Applying the above factors to the NHS Wales carbon emissions presented in Table 11, an estimation can be derived of the costs and savings for the decarbonisation of the building energy. This is presented in the table below.

Table 13: Estimated investment costs and savings for the building energy decarbonisation of NHS Wales, based on figures extrapolated from NHS England

	Step 1	Step 2	Step 3	Step 4	Total
Investment (£)	~ £ 100,000,000	~ £ 50,000,000	~ £ 100,000,000	~ £ 146,000,000	~ £ 400,000,000
Operational Savings (£ pa)	~ £ 26,000,000	~ £ 2,200,000	~ - (minus) £ 1,000,000	~ £ 10,000,000	~£ 40,000,000
Carbon Savings (tCO ₂ e pa)	133,600	16,800	38,900	21,000	210,436
Simple payback (years)	3.8	21.8	n/a	14.7	10.6

4.2 Delivering decarbonisation – Carbon and Energy Management

For all building portfolios, but particularly for NHS Wales with an ageing estate where new technologies are difficult to deploy in a cost-effective manner Carbon and Energy Management is the cornerstone of decarbonisation, overseeing the whole of the decarbonisation pathway. It is the element that will engage with all stakeholders to gather the required information, present which interventions should be implemented, ascertain if the implementation has been successful and delivering the expected savings, and whether a Health Board is on track to meet their energy and carbon reduction targets. Carbon and Energy Management can also give an insight of which areas or systems of a hospital are most and least efficient and potentially set up key performance indicators (KPIs) and targets for energy efficiency.

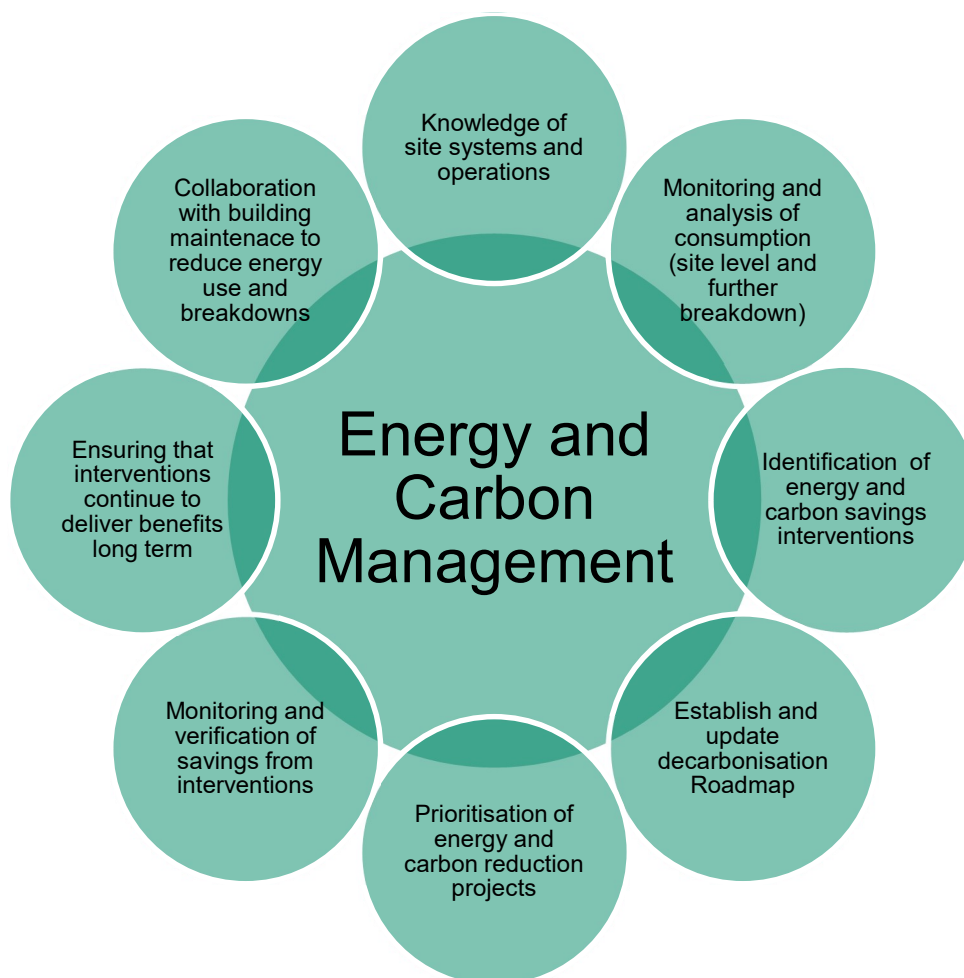


Figure 9. The central role of Energy and Carbon Management

To effectively operate, Carbon and Energy Management need to have access to sufficient and reliable data. This can be achieved by using submetering data provided by the BMS in place, or through improving it. Various data analysis tools can be used to extract as much insight as possible for the buildings and systems.

To improve efficiency, Energy Management should work closely with operation and maintenance to optimise the control and operation of the equipment. Better control regimes can also be achieved through the BMS.

Carbon and Energy Management should be considered as much more than a reporting function, it should be a crucial part of day-to-day operations.

It is recommended that energy audits be carried out every 2 years, under the Carbon and Energy Management regime and according to Initiative 4 of the NHS Wales Decarbonisation Strategic Delivery Plan; this will help give an in-depth view of the current state of the energy systems and help in identification of opportunities.

4.2.1.1 Energy data collection and analysis

It is recommended that energy data collection is timely and of high quality. Energy data includes the main utility meters but also a very wide range of meters and sensors: gas, electricity, temperatures, flows, pressures, valve and damper positions, as well as weather data. All the data mentioned should be captured by the BMS (and/or a separate energy management system) and some of them will be used already for the operation and maintenance of the equipment. Other data that are relevant to energy management are operation times, levels of occupancy of different parts of the hospitals at different times, maintenance records (parts and labour) and all with associated cost data.

Analysis of this data should be carried out periodically in order to monitor (and if needed, report) the energy performance of the hospital. It is recommended that this be done weekly, using hourly energy data. A monthly analysis should include as a minimum a regression analysis with weather (Heating and Cooling Degree Days).

4.2.1.2 Measurement and Verification (M&V)

Energy Management is also the best placed to carry out the measurement and verification of all implemented projects (including simple changes in controls). Having the appropriate data and understanding of the systems, the hospital's energy management team can establish what can be considered as the "baseline" and how the building or system performs after the implementation of a project. Depending on the complexity and scope of the project, the energy management team might need the support of a Measurement and Verification expert.

5 NHS Wales heat decarbonisation pathway

5.1 Step 1 - Identification of heating systems and needs

It is recommended that the identification of heating systems and needs be carried out by a combination of site surveys and information requests of each hospital, prioritising the highest consuming sites. Appendix 8.7.1 comprises an initial prioritised site list for NHS Wales as well as detail about the survey form to be employed. There are five components to the identification of heating systems and needs, as follows:

- Gain an understanding of the primary fuels and heat mediums of different heating systems (8.7.2).
- Identify the characteristics associated with the heating needs of the buildings (8.7.3).
- As one of the key drivers of heating demand, establish the condition of the building fabric (8.7.4). A retrofit plan would include condition surveys, thermography, detailed surveys of the structural building elements, asbestos register survey and airtightness tests. Undertake energy audits encompassing data collection, field work and analysis (8.7.5).
- Estate-wide overview. (Suggestions about the information that should be collected to inform estate strategies can be found in 8.7.6)

5.2 Step 2 - Elimination of energy waste/reducing demand

There are different ways that energy efficiency can be achieved, particularly for NHS Wales that has a diverse portfolio of assets in terms of building age and construction specification (as per Appendix 8.8). Some of these ways include:

- Addressing heat demand reduction through fabric improvements (8.8.1). A good fabric standard is easier and more cost effective to achieve in new buildings. Usually, newer buildings have less scope to achieve emissions savings from fabric upgrades than older ones. Therefore, prior to fabric upgrades, targets should be considered which may align with Building Regulations (8.8.1.1) or EnerPHit (8.8.1.2).
- Variable speed fans/pumps and insulating pipework (8.8.2).
- Fixing steam leaks (8.8.3).
- Condensate recovery (8.8.4).
- Reassessing heating requirements (8.8.5).
- Optimising Heating and Ventilation and Air Conditioning (HVAC). The main principles of HVAC operations, including the importance of heat recovery are presented in section 8.8.6. There are several aspects to optimising HVAC including heat zoning (8.8.6.1), scheduling (8.8.6.2) and avoiding simultaneous heating and cooling (8.8.6.3).
- Decentralising and separating heating and hot water loads (8.8.7), including the decentralising of uses (8.8.7.1).

5.3 Step 3 - Closing the loops / heat recovery

Heat can be recovered from Air Handling Units (AHU) (8.9). This can be achieved through use of a range of heat exchangers, pipes and pumps (8.9.1), as well as from wastewater (8.9.2).

5.4 Step 4 - process change

This step is mainly applicable to sterilisation processes and laundries, rather than space heating. This step requires in-depth expertise on the processes and their requirements so this report refrains from making any technical suggestions (see 8.10)

5.5 Step 5 - Fuel switch / Alternative fuels and heat sources

In the longer term, it is possible that hydrogen or biogas could provide low carbon heating sources in the future, but at present the cost of green hydrogen is prohibitive and biogas resource in the UK is limited. Therefore, it is likely that heat pumps, or connection to low carbon district heating networks, will provide the low carbon heating solution for most buildings. Descriptions of potential low carbon resources and technologies are appended as follows:

- Heat Pumps (8.11.1)
- Solar Thermal Hot Water (8.11.2)
- Hydrogen (8.11.3)
- Liquid biofuels and biomass (8.11.4)

6 Constraints

6.1 Electricity Grid capacity

The capacity of the electricity grid is probably the biggest risk in heat decarbonisation, especially in Wales where the grid capacity is already under strain in certain areas.

As seen in Figure 10, the gas maximum demand can be almost three times higher than the maximum electricity demand. If we were to decarbonise heat through electrification, a big part of the gas demand would be transferred to electricity. Even if we assume that electric heating is more efficient than gas (gas boilers have an efficiency of 85-90%) and, as an extreme scenario, that all this heat is delivered through heat pumps, this means that the peak electricity demand could double during winter.



Figure 10. UK wide electricity and gas demand in the period 2014-2018

Electricity demand is also expected to rise due to electric vehicle charging. At the same time, the rise of renewable power generation, essential for the decarbonisation of electricity, demands even greater flexibility of the grid.

The above-mentioned factors make it urgent that electrical infrastructure be strengthened and transformed from a centralised to a distributed generation system, i.e., a smart grid.

It is essential that NHS Wales collaborates with the DNOs, the National Grid in the south and SP Energy Networks in the north, to ensure that enough capacity will be available as the hospitals decarbonise the heating systems and install vehicle chargers. This will be more effective if done on a portfolio level, instead of a building-by-building approach.

A way to mitigate partly the risk of low electricity capacity is with the integration of renewable generation on site, or the connection to renewable generation nearby. The intermittent nature of this generation will require careful sizing and potentially the use of energy storage, see also section 6.3. below.

6.2 Requirements for resilience

The HTMs define the requirements for resilience. The effect these requirements can have in assessing the decarbonisation option is mainly in cases where de-centralisation is considered, as it might significantly increase the capital cost and space requirements for equipment.

It is worth noting that, whilst perhaps only impacting a minor proportion of heat requirements, fabric improvements improve resilience by potentially reducing the need for plant equipment (and therefore back-up equipment).

6.3 Intermittent availability of renewable energy

The intermittent availability of renewable energy is a constraint in decarbonisation. Solar energy, for example, is only available during the day and more abundant in summer, whereas, in a hospital, most of the heating is required during the winter nights if it is a 24h operation, or early in the winter mornings, when it is still dark.

This discrepancy in availability and demand requires energy storage. Batteries are one of the widely known and established technologies, but they have their own limitations in efficiency, costs, safety risks and environmental impact of sourcing of their component materials. As their technology progresses very rapidly addressing these limitations, other technologies emerge as well, like heat storage.

Heat storage is a very promising component of heat decarbonisation, but the exact mechanism through which heat storage will be implemented in a heating system is yet to be defined. Low temperature mediums have low losses and can be delivered by a heat pump with a good efficiency, but they require a very large space in order to store

significant amounts of energy. Mediums in high temperature (like steam) are much denser in heat, so they are a very space-efficient storage medium, but would probably require a direct electric generation, that would only be cost-effective if the renewable electricity is cheap.

Other types of heat storage include thermochemical heat storage (TCHS), or thermochemical energy storage (TCES) systems. These use thermochemical materials to store and release heat in a reversible endothermic and exothermic reaction process. Their development is very crucial for heat decarbonisation as they will be able to offer long term storage with minimal losses.

Many storage options are still being refined or requiring costs to be driven down before they become widespread in use. For this reason we recommend that storage technologies are kept under regular reviews e.g. at 3 year intervals.

7 Conclusion and Recommendations

Alongside the continuing need for an affordable and secure supply of energy, the need to respond to climate change (and the investment that will be required to achieve this) further increases the importance of an informed Heat Decarbonisation Strategy. Given that the decarbonisation of energy is a multi-faceted topic that involves numerous different disciplines, the strategy enables a unified approach to longer term delivery. This report concludes that an Energy Management approach is the best placed discipline to oversee progress and co-ordinate all the stakeholders in a common pathway.

Without Energy Management there is a lack of accuracy and therefore understanding of:

- Actual energy demands.
- Nature and level of energy and cost waste.
- Where investment is best targeted.
- Optimal engineering designs.
- The effectiveness of interventions.

Energy Management provides the accurate information required to understand heating needs, identify available waste heat and develop low carbon solutions. NHS England suggest potential savings of approximately 20%, with a significant proportion achievable through accurate data analysis and controls with relatively small capital investment.

With the currently available technologies, if no other measures are taken, decarbonisation itself (switching to non-emitting or less emitting energy sources) can be synonymous with significant increases, both in capital investment and operational costs.

Improved energy efficiency represents an achievable opportunity to reduce operational costs and generate savings for reinvestment as well as delivering the national decarbonisation agenda. This then provides a more effective platform for taking advantage of the development of technologies, including heat and electricity storage which will change decarbonisation options in the short to medium term.

Interventions should be based, not on assumptions and industry averages, but on robust, site-specific data. Such data can be available and fully utilised by all relevant functions within NHS Wales if appropriate building and energy management systems are put in place.

Robust data informs a successful business case and enables the verification of the success of implemented energy projects. In the decarbonisation pathway, it is therefore crucial that Energy Management is placed at the heart of the daily operations of the facilities.

The report contains recommendations to inform and support local decarbonisation plans, as follows:

- In order to assess the heating demand driven by the fabric condition of the building, condition surveys of the fabric and structural elements (already likely to be undertaken by NHS Wales at regular periods), should align

Key elements for successful decarbonisation:

- Energy Management is central to decarbonisation.
- Gathering of accurate information of the heating needs, including fabric condition surveys.
- Robust BMS in place including controls and metering.
- Fabric and energy efficiency priority approach.
- Careful sizing of heating system.

Common opportunities in a hospital environment:

- Fabric upgrade (double glazing, insulation).
- Variable flow circuits & pipework insulation.
- Area specific heating and ventilation controls – zoning and system set back.
- Condensate recovery and reduction of steam leaks.
- Heat recovery.

Most suitable low carbon heat sources:

- Heat pumps (exact setup is site specific).
- Solar thermal
- Low carbon district heat networks

with decarbonisation plans to ensure that such surveys assist with consequent steps for energy management to enable prioritising the most cost-efficient retrofit fabric upgrades.

- Within estates strategies and asset registers, ensure key building information is collected, available and updated to provide an informed overview on the whole estate and facilitate the smooth progress of decarbonisation. Key building information includes:
 - Size (floor areas).
 - Age (year of construction and latest significant refurbishment).
 - Fabric.
 - Condition (of building fabric as well as building services).
 - Heating / hot water system mediums (steam/LTHW/point of use electric DHW).
 - Type of heat delivery (type of emitters / AHU (more efficient fans and improved Specific Fan Power)/dual duct systems).
 - Specification of heat delivery (theatres, imaging or other “high requirements” environments).
 - Presence of steam sterilisation.
 - Heating needs.
 - Controls that are in place, presence and capabilities of the BMS.
 - Presence of high energy consuming equipment (in order to investigate potential for recovery of emitted heat in Step 3).
 - Location and surrounding area (potential for PV and wind generation in Step 6, connection to a heat network)
- Sub-metering should be in place to enable accurate energy consumption data (preferably half hourly) as well as flow and return temperatures. This data should feed into a BMS and/or energy management system.
- Ensure VRFs are sub-metered, have appropriate controls and are integrated into the BMS For current CHPs, until a low carbon heat plan is implemented::
 - Undertake a detailed pilot study of three Health Board buildings that employ gas-fed CHP to understand how emissions for space heating are changing and what can be done to mitigate.
 - Investigate the reasons for thermal efficiencies <40% and develop solutions for better use of the heat generated.
 - Validate and refine the initial carbon emissions targets with respect to the changing picture related to the use of gas-fed CHP for space heating and electricity generation.

One way in which the recommendations of this report can be initiated is by conducting a feasibility to assess how best a building can be retrofitted. The feasibility process should enable identification of data / process gaps and is highly recommended. The exercise will facilitate a well-informed decision for the next steps of delivering high performance healthcare buildings.

Despite the many difficulties in the decarbonisation pathway, decarbonisation is possible and that, whilst 2030 is a challenging timeframe, much can be done now to work towards delivery.



8 Appendices

8.1 Reporting of REGO certified electricity

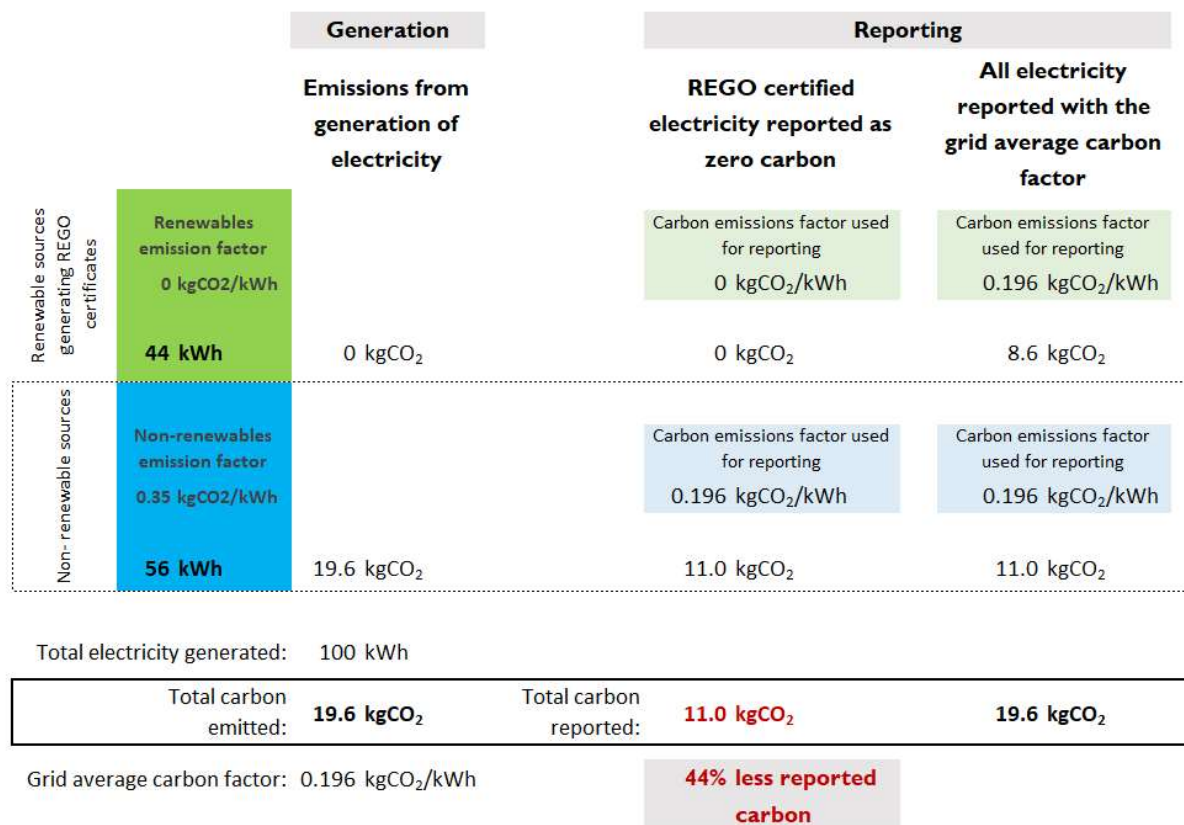


Figure 11. Simplistic example of differences between reporting methodologies

The figure above aims to demonstrate why reporting REGO certified electricity as zero carbon can lead to underreporting of carbon emissions.

Please note that it is a very simplistic approach and the carbon factors used, as well as the split between renewables and non-renewables are just assumptions.

8.2 Attribution of CHP emissions

For the attribution of the CHP emissions many different methodologies are available: the “efficiency method” has been used in this report, as it is recommended in the GHG Protocol initiative and the EU Commission Delegated Regulation 2019/331.

According to this methodology, the emissions factor for the heat generation is calculated as:

$$F_{CHP,heat} = \frac{\eta_{heat}/\eta_{ref,heat}}{\eta_{heat}/\eta_{ref,heat} + \eta_{ele}/\eta_{ref,ele}}$$

Where:

η_{heat} : thermal efficiency of the CHP

$\eta_{ref,heat}$: typical thermal efficiency of a gas boiler, $\eta_{ref,heat} = 0.87$

η_{elec} : electrical efficiency

$\eta_{ref,ele}$: typical efficiency for separate production of electricity using gas as fuel, $\eta_{ref,ele} = 0.525$

The electrical emissions factor is:

$$F_{CHP,ele} = \frac{\eta_{ele}/\eta_{ref,ele}}{\eta_{heat}/\eta_{ref,heat} + \eta_{ele}/\eta_{ref,ele}}$$

8.3 Emissions factors

The below emissions factors have been used for the calculations of carbon emissions. These are sources from the Department for Business, Energy & Industrial Strategy.

Gas Emissions Factor 0.18387 kgCO₂e/kWh

Oil 0.25672 kgCO₂e/kWh

Table 14: Grid electricity emissions

Report year	Grid Electricity Emissions Factor		Transport and Distribution		Total	
2021	0.23314	kgCO ₂ e/kWh	0.02005	kgCO ₂ e/kWh	0.25319	kgCO ₂ e/kWh
2020	0.2556	kgCO ₂ e/kWh	0.0217	kgCO ₂ e/kWh	0.2773	kgCO ₂ e/kWh
2019	0.28307	kgCO ₂ e/kWh	0.02413	kgCO ₂ e/kWh	0.3072	kgCO ₂ e/kWh
2018	0.35156	kgCO ₂ e/kWh	0.03287	kgCO ₂ e/kWh	0.38443	kgCO ₂ e/kWh
2017	0.41205	kgCO ₂ e/kWh	0.03727	kgCO ₂ e/kWh	0.44932	kgCO ₂ e/kWh
2016	0.46219	kgCO ₂ e/kWh	0.03816	kgCO ₂ e/kWh	0.50035	kgCO ₂ e/kWh

8.4 NHS Wales Estate portfolio - Building age

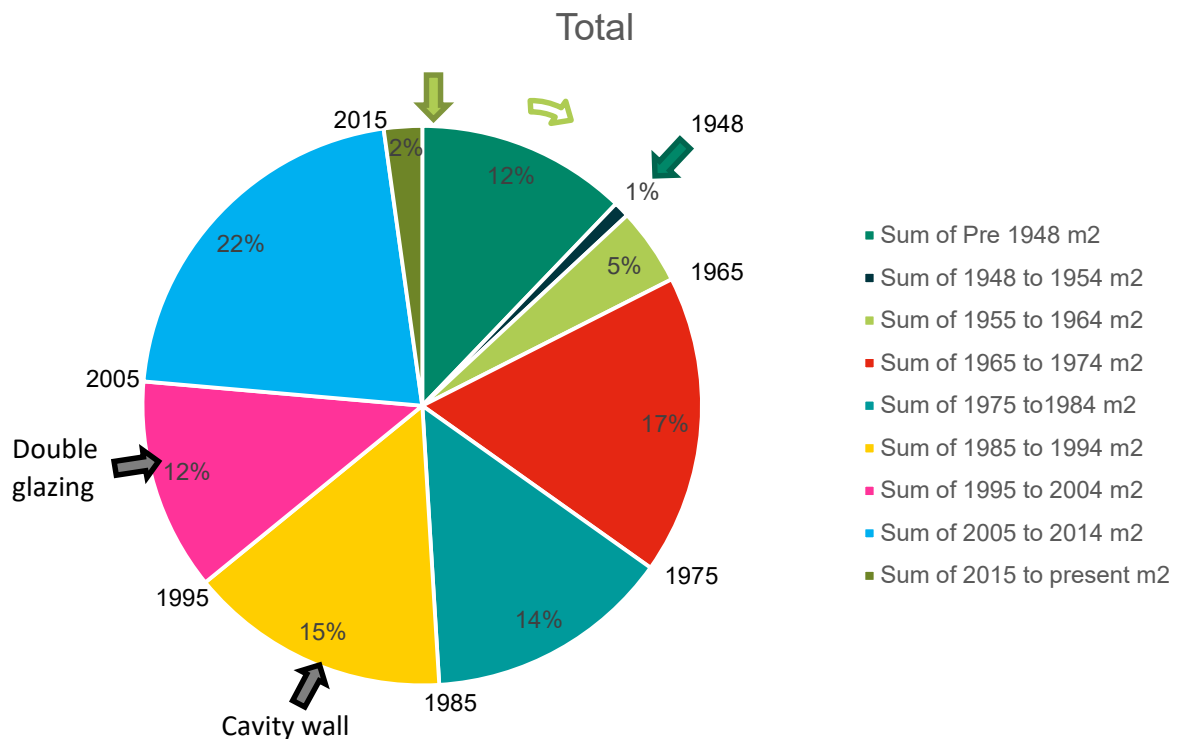


Figure 12. Age of the estate

Figure 12 above shows the age of the whole estate, based on EFPMS data. Even though it is very tempting to draw conclusions from this, unfortunately these would not be accurate, as the information does not include recent refurbishments. For example, most of the pre-1948 parts of the estate will have had some level of refurbishment. This can vary from light, cosmetic interventions, to installing insulation and double glazing and upgrading the building services.

The only assumption that could be made, still with a level of caution, would be that the buildings before the 1990s would not have been built with cavity wall insulation and that the buildings before 2000 would not have been built with double glazing.

Nevertheless, more information is needed regarding refurbishment projects that have been undertaken to retrofit cavity wall insulation and double glazing.

The limiting values of fabric standards for replacement thermal elements (Table 4.1 in ADL2 2022 are improved for the new 2022 Building Regulations Wales Approved Document L: Conservation of Fuel & Power. Where fabric improvement is not planned as part of the refurbishment, we recommend that consideration is given to improving thermal elements in line with the limiting values in Table 4.2 column (b) in ADL2 2022 (reproduced in table 15 of this Heat Decarbonisation Strategy).

Yellow hydrogen is used by some to refer to hydrogen made through electrolysis with solar power, while confusingly, others consider it as electrolysed hydrogen made using power of mixed origin — i.e. the mix of renewable and fossil power actually flowing through the grid.

Pink hydrogen is a term used when the electricity for the electrolysis is produced by nuclear energy.

White hydrogen is a naturally occurring geological hydrogen found in underground deposits and created through fracking. There are no strategies to exploit this hydrogen at present.

8.7 NHS Wales heat decarbonisation pathway

8.7.1 Step 1 - Identification of heating systems and needs

The whole estate currently reported in EFPMS comprises 88 buildings and a further 9 groups of aggregated sites. Due to the large number of hospitals, it would be beneficial to start this exercise with the highest consuming ones.

The following 17 hospitals were identified as the most significant energy users of the estate (excluding aggregated sites). These comprise mainly acute hospitals and represent 73% of the total natural gas consumption. The Grange University Hospital is also included in the group of high energy users. As it opened in 2020, there is still no EFPMS data for the Grange but BMS data can be used until EFPMS data become available.

Table 16: List of most significant energy users, selected for collection of site-specific information

ANEURIN BEVAN LHB

GRANGE UNIVERSITY HOSPITAL
NEVILL HALL HOSPITAL
ROYAL GWENT HOSPITAL
YSBYTY YSTRAD FAWR HOSPITAL

BETSI CADWALADR UNIVERSITY LHB

YSBYTY GLAN CLWYD
YSBYTY GWYNEDD
YSBYTY MAELOR HOSPITAL

CARDIFF & VALE UNIVERSITY LHB

LLANDOUGH HOSPITAL
UNIVERSITY HOSPITAL OF WALES

CWM TAF LHB

PRINCE CHARLES HOSPITAL
PRINCESS OF WALES HOSPITAL
ROYAL GLAMORGAN HOSPITAL

HYWEL DDA LHB

BRONGLAIS GENERAL HOSPITAL
GLANGWILI GENERAL HOSPITAL
PRINCE PHILIP HOSPITAL
WITHYBUSH GENERAL HOSPITAL

SWANSEA BAY UNIVERSITY HEALTH BOARD

MORRISTON HOSPITAL
SINGLETON HOSPITAL

In order to identify the heating systems of the hospitals in scope, it is recommended to use the questionnaire included in Appendix 6 of the Health Technical Memorandum 07-02, which includes a list of questions regarding the building's condition, as well as examples for a set of standard stationery forms that can be used in a site energy audit. These can be very useful in establishing a better overview of the Estate and will contribute to the information needed, set out in the following paragraphs.

It is also recommended to gather information regarding the location and surroundings of the buildings, as this will define their potential role in heat networks, as well as the potential for renewable technology installations that could play a role in balancing the electrical and heat demand.

8.7.2 Identification of primary fuels and heat mediums

In order to understand what the identification of primary fuels and heating mediums include, it is helpful to examine the typical heating system of a hospital.

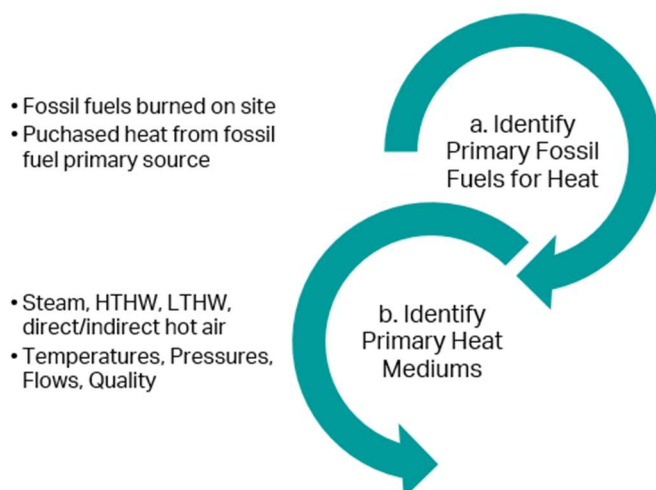


Figure 13. Important points to capture regarding primary fuels and heat mediums

The typical hospital heating system is based on a centralised energy centre (boiler house). The gas or oil-fired boilers there produce steam, medium temperature hot water (MTHW) or low temperature hot water (LTHW). LTHW signifies that the system operates to a maximum temperature of 90°C and maximum pressure is usually 30 psi (2 bar). MTHW ranges from 90°C to 120°C and high temperature hot water (HTHW) uses water in higher than 120°C. Steam is usually generated in the region of 6-7 barg. It is an important part of the identification of the system to define the pressures, temperatures and flows of steam or hot water, and if and how these change throughout the year.

Steam or LTHW are then circulated around the site to local plantrooms. In those plantrooms the steam (through heat exchangers and calorifiers) or LTHW heat two types of secondary systems. One is for space heating and one for domestic hot water (DHW or HWS). Often, heat exchangers for the DHW are also positioned in the main boiler house.



Figure 14. Heat exchanger for domestic hot water keeps the hot water vessel at 62°C (left), Steam to LTHW plate heat exchanger feeds the heating system with LTHW at 75°C (middle and right)

The space heating system is usually split into two circuits, the constant temperature (CT) one and the variable temperature (VT) one.

Older NHS Wales buildings typically utilise flow circuits with 3-port valves whereby the higher constant temperature is fed through air handling unit (AHU) coils and fan coils (FCU). The control of heat delivery in those coils is achieved by adjusting the flow across the coil with a valve. The AHUs can be equipped with variable speed fans, which can modulate the air flow according to the space needs. The air flow and temperature is also useful information to measure and monitor.



Figure 15. Heating coil of AHU

Where the variable temperature circuit feeds radiators, the heat delivery of the system is controlled primarily by the temperature of the water that flows in the radiators. Radiators can have TRVs (Thermostatic Radiator Valves) to control hot water flow to radiators according to the individual heating requirements of the room. The temperature of the water is determined by the outside temperature, through a weather compensation calculation.

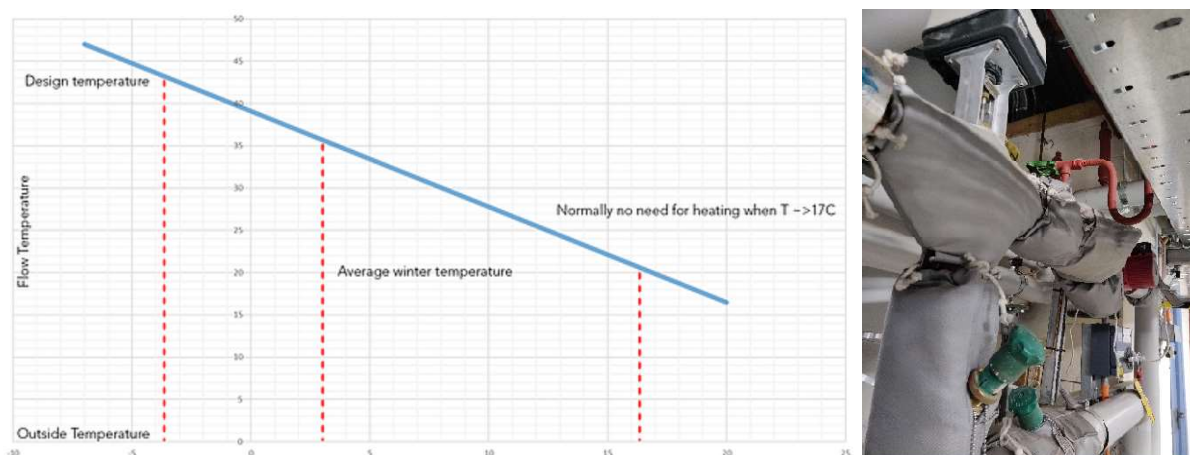


Figure 16. Weather compensation example for underfloor heating and VT heating zone mixing valve

The temperature of the VT system is achieved by mixing the hot water coming from the heat exchanger with the colder water coming back from the radiators. This is achieved with a mixing valve. Information regarding the temperature trend on the radiators, which can then be correlated with occupancy and outdoor temperature, also gives a good understanding of the system.

An overview of a typical hospital system is presented in Figure 17 below.

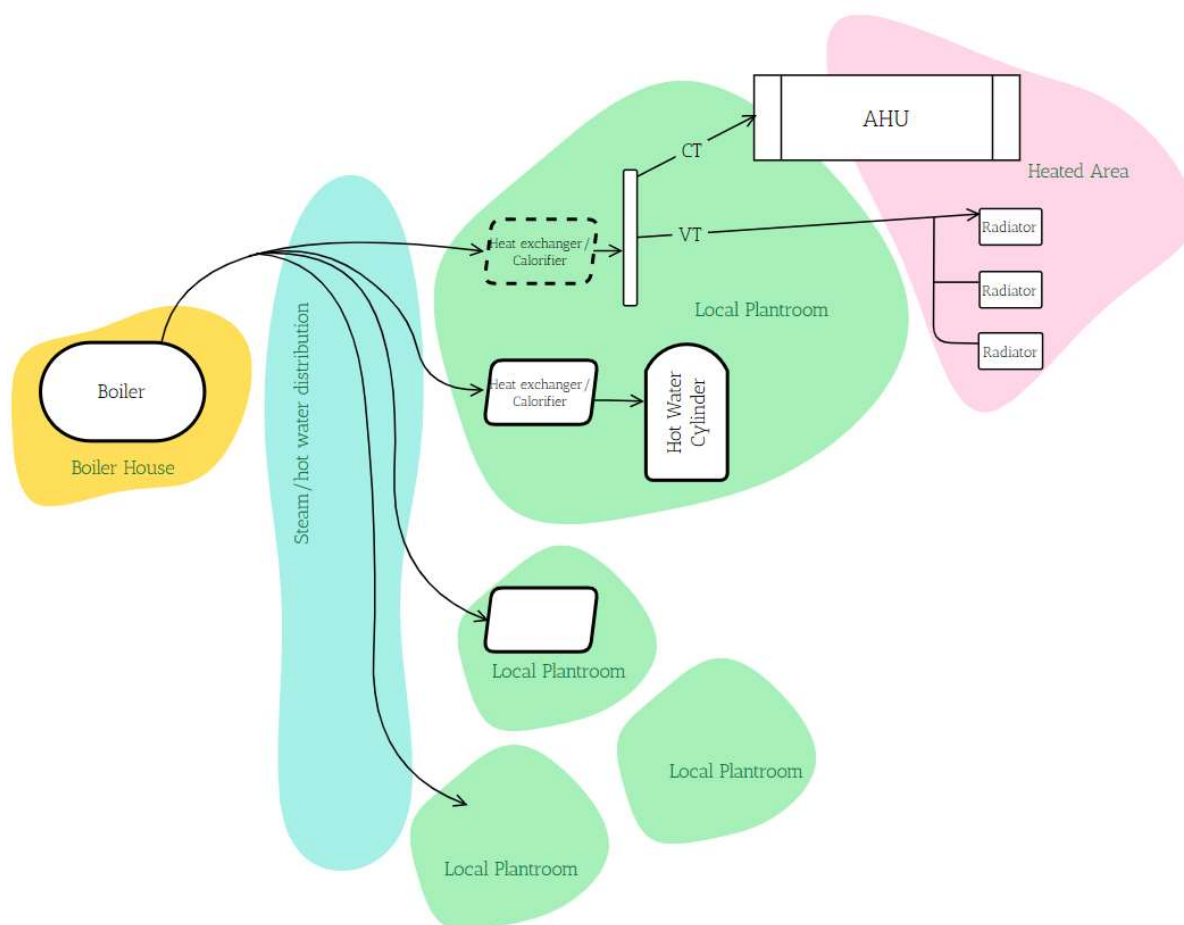


Figure 17. Simplified schematic of a typical heating system

For this first step, it is important to identify not only the operational information for the heat sources and mediums, but also the condition of the current services (age, maintenance, condition).

8.7.3 Identification of the needs

This step is the most crucial one, as fulfilling the heating needs is the reason for the existence of the systems described. Therefore, the exact systems, layout and operation can vary and change over time, but their focus will always remain on fulfilling the heating needs.

In most acute hospitals, there are three kinds of heating needs:

1. Space heating (including fresh air / make-up air ventilation),
2. Domestic hot water and
3. Sterilisation.

These three needs are very different, and each require a separate identification procedure.

Space heating usually requires a space to be kept at a temperature, usually in the range of 18°C to 25°C. The main drivers for heat demand are the heat losses of that space and the specific requirements for air changes per hour (rate at which the air of the room is replenished with fresh, filtered, clean air from outside), and sometimes requirements for humidity.

Domestic hot water is usually water delivered at the taps at a temperature of 40°C to 50°C. As there is usually hot water storage, in order for the water to be readily available when needed, the hot water is stored at higher

temperatures (>60°C) for legionella control. The volume of water needed is affected by the occupancy of the hospital and the presence of certain services like hydrotherapy pools.

Sterilisation uses steam, as temperatures over 100°C have to be reached for a certain amount of time in each cycle. Each of these uses is considered in more detail below.

Space heating

Space heating is a significant part of the heat demand in a hospital. Identifying it can be done in several ways:

- One is by estimating it from industry benchmarks, which can offer a good high-level idea of what it can be, but it's not accurate enough to be the basis of a heat decarbonisation plan.
- Another method commonly used is trying to derive it from the total gas consumption at the boilers. This is again not accurate enough as the split between the different heating needs is unknown, as are the losses of the system.
- Another way of calculating the heating need is by modelling the existing building. This can be quite complicated and in old buildings the values of some materials might be unknown. If there is confidence in the modelling, then the results can be very useful, especially when combined with the last, and recommended, method of identifying the heating needs.
- The recommended method is to measure the actual flows and temperatures of the circuits feeding each area. The heat measured this way (delivered heat), matches the heating need of the space when it is known that the space is not overheated or underheated. The measurements involve flows and temperatures of the CT and VT circuits, as depicted in Figure 19. The measurements can be carried out by installing temporary metering and logging equipment but in some cases the data already available in the BMS might be sufficient, as in the example depicted in Figure 18 below.

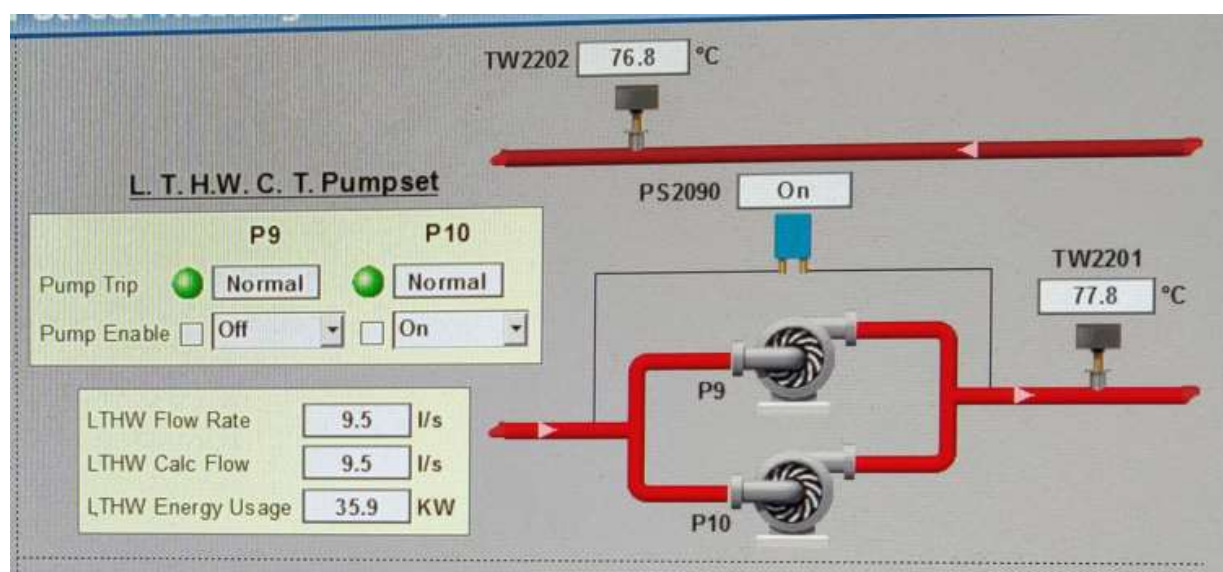


Figure 18. Example of heating needs being calculated already in the BMS

Another very important element that should not be missed when identifying the space heating needs is the condition of the building's fabric, as this is the main driver for heat demand. The required information for establishing the condition of the fabric conditions is described in section 6.1.

Domestic hot water

Similarly, the heating needs of the domestic hot water can be calculated, with a suggested measurement point being the input and output of the heat exchanger/calorifier.

Sterilisation

In sterilisation, the steam input to the sterilisers could be measured but there is an increased difficulty in measuring the flow. As the number of sterilisers in a hospital is low, an accurate estimation of their heating needs could be made by using their specification steam requirements and gathering information about how often each steriliser is used.

The red circles in Figure 19 depict the scope that needs to be included in the identification of the heating needs.

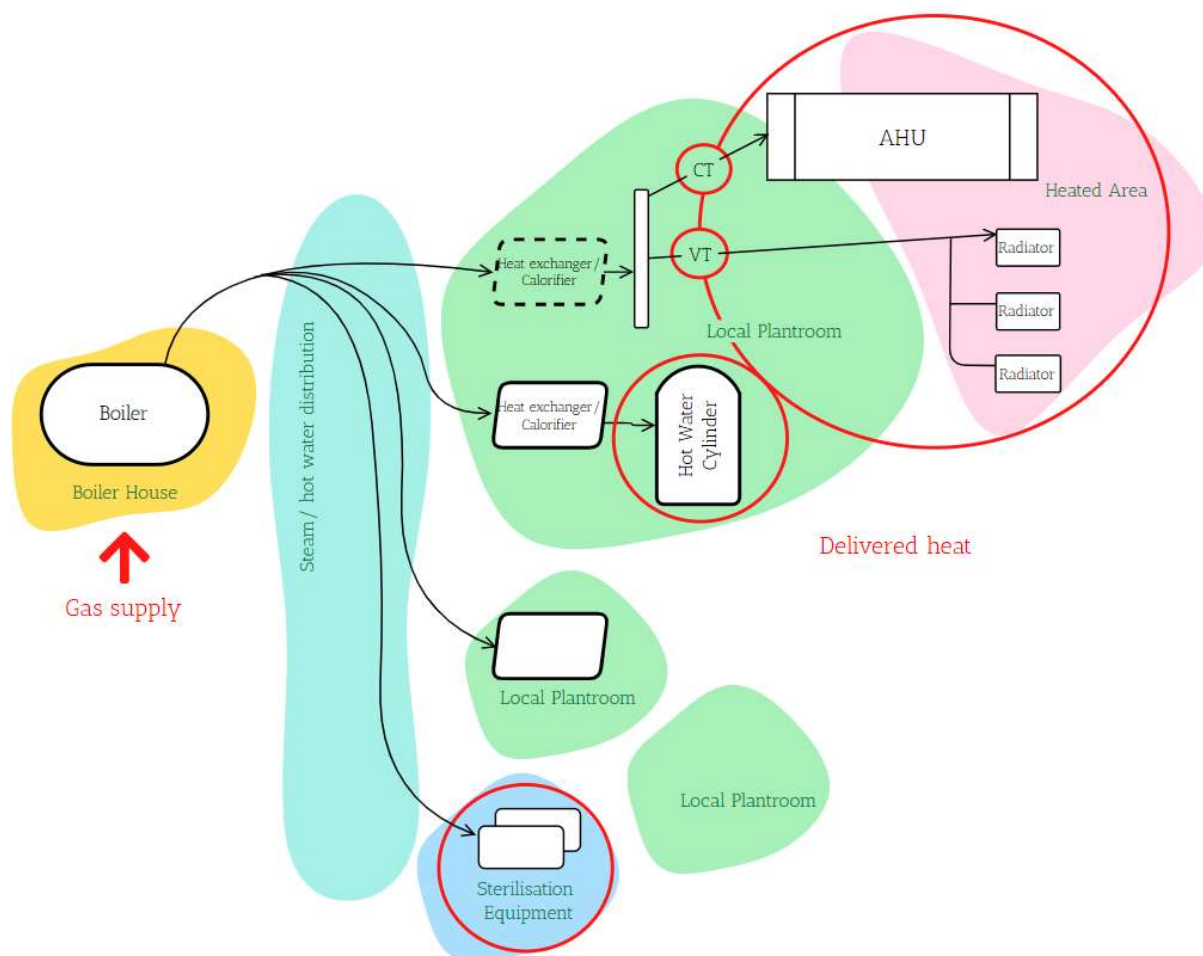


Figure 19. Simplified heating system schematic, showing scope of delivered heat monitoring

Having gathered this information, it is very informative to see how the delivered heat (fulfilling the heating needs) compares to the total energy imported to the site, usually through the gas supply. This comparison can give an idea of the losses of the system and whether the existing heat generation and distribution systems are oversized, showing the effect that this can have on energy consumption.

This information could be used in two ways:

Firstly, to identify energy savings that could be made by better matching of the heat source to the heating load. This could be done by, for example, replacing a boiler burner with another one with a better turn-down ratio, if suitable. Another example would be reducing over-pumping of hot water, saving on the energy of the pumps as well as the heat losses in the distribution systems.

Secondly, knowing that a system is oversized, would inform the calculations for replacement with low-carbon technologies, as these would then have to be based on the actual heating load, rather than the current installed capacity, or even the current energy consumption, as the latter often includes the inefficiencies of an oversized system. The delivered heat measurement can provide a baseline for the true demand for heating at the point of use. This would allow a more rational sizing of potentially decentralised systems.

Even though energy consumption data are not the main focus for the recommendations above, they are crucial for understanding the building operation and therefore are also used in the identification of the heating needs.

8.7.4 Information related to heating demand drivers – fabric condition

In order to assess the heating demand driven by the fabric condition of the building, condition surveys of the fabric and structural elements, already likely undertaken by NHS Wales at regular periods (annually), should ensure that such surveys assist in consequent steps in prioritising the most cost-efficient retrofit fabric upgrades.

As a best practice, the following documents should be available for a retrofit plan:

1. Detailed survey of fabric condition. This survey should report all different construction wall, roof and ground/exposed floor types alongside their condition in terms primarily of moisture content and their life expectancy. Also, where insulation is present (either through visual inspection or based on the age-band of the building or of the refurbishment), this should be reported in terms of its continuity, where this is technically feasible. A thermographic survey can contribute to identify these areas or other areas, such as where there are thermal bridges or air leakage paths. The thermographic survey can cover the following: a) insulation defect detection; b) air leakage detection; c) heat loss through window frames; d) dampness detection; e) examination of heating systems (e.g. damage to insulation); f) preventative maintenance; g) electrical defect detection.

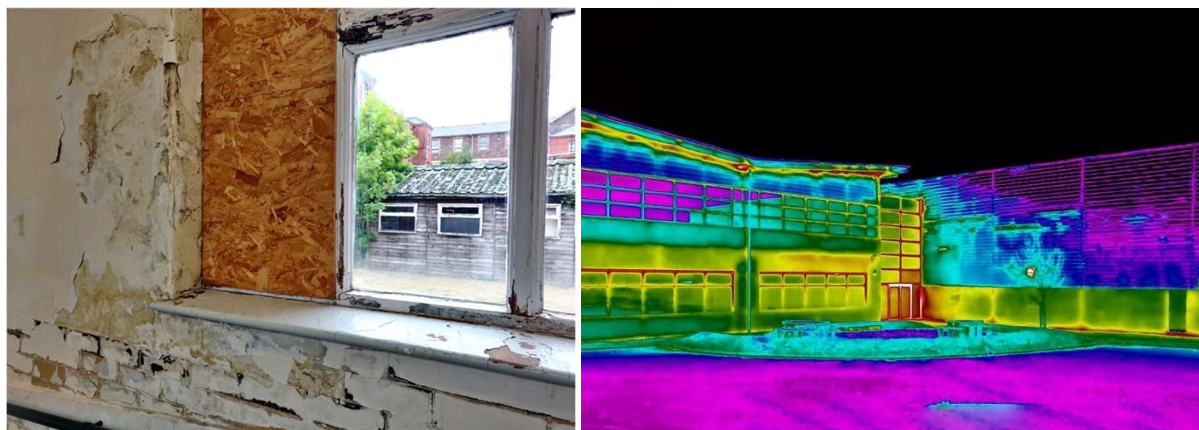


Figure 20. Condition of fabric and possibly a thermographic survey are part of a detailed survey of fabric condition⁷

2. Detailed survey of structural elements condition. All structural elements should be listed as per their type (and possibly size, if required) and tested in terms of their life expectancy and structural integrity. The ultimate outcome of this survey must be able to answer questions raised by the retrofit proposal on how each element will be affected by the proposed changes or additions or removals to/from the building. The structural integrity testing may require calculations of the existing structural elements, or even sample testing in some cases, i.e. timber framing structures. Any corrosion to the elements should also be reported and risks highlighted.

⁷ Image source <https://ww3.rics.org/uk/en/journals/built-environment-journal/conducting-a-successful-thermographic-survey.html>

3. Asbestos register survey. Asbestos is a mineral-based fibre, once used widely for insulation, now banned due to health risks. Before any works are taken place, it is recommended that an asbestos survey is carried out to identify any risks associated with its presence.
4. An airtightness test or “blower door test” will provide the level of air leakage from the building through the gaps or building fabric. The main leakages can be identified in the process and these findings can then be taken into account in the concept development of the retrofit plan.

8.7.5 Energy audits

An energy audit is an excellent way of gathering information regarding the delivered heat, but also identify opportunities for the next steps of decarbonisation. Hence the inclusion of an initiative to undertake audits in the NHS Wales Decarbonisation Strategic Delivery Plan.

In general, an energy audit can cover the whole site or individual buildings and should include the following steps:

- Data collection: the auditor starts collecting some preliminary information including:
 - energy consumption data including submetering,
 - heating systems control regime,
 - operating setpoints,
 - system drawings,
 - floor layouts,
 - equipment inventory.
- Field work: at least one on-site visit is required, with the aim of gathering all the information needed for the study depending on the defined scope. This information includes collecting details on the building and its uses, any energy consuming equipment, as well as the mode of control and hours of operation of the various systems. Some interviews with staff may also be required. Depending on the type of energy audit, some metering devices may be used. Previous projects that have taken place and major refurbishments are also audited.
- Analysis of energy consumption and performance of energy accounting. A first desired outcome of the energy audit is the understanding and quantification of energy flows within the scope. This will offer visibility and a basis on which the potential for reducing energy consumption can be determined and the energy saving measures can be quantified. The energy flow can be visualised in a Sankey diagram, as in Figure 21 below.

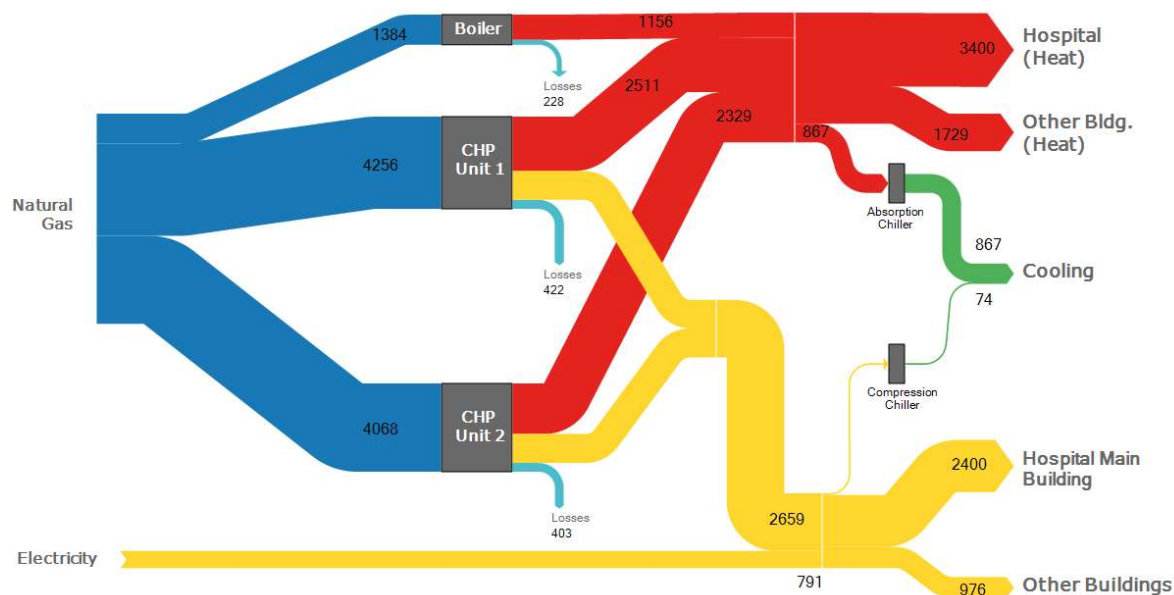


Figure 21. Example of a Sankey diagram for a hospital

- Analysis and development of energy saving measures: the most interesting outcome of the energy audit. The information collected and analysed enables the auditor to identify energy saving measures. Energy and cost savings of these measures will be assessed, together with the required investment and payback. At this stage some feedback from Estates or the Health Board can be helpful in commenting on possible obstacles to implementation.
- Energy audit report: All the previous steps are presented in a report.

8.7.6 Estate-wide overview

As a recommendation for items to be included within estates strategies and decarbonisation plans, having reliable information about the points below will give an informed overview on the whole estate and facilitate the smooth progress of the next decarbonisation steps.

- Size (floor areas).
- Age (year of construction and latest significant refurbishment).
- Fabric.
- Condition (of building fabric as well as building services).
- Heating / hot water system mediums (steam/LTHW/point of use electric DHW).
- Type of heat delivery (type of emitters / AHU/dual duct systems).
- Specification of heat delivery (theatres, imaging or other “high requirements” environments).
- Presence of steam sterilisation.
- Heating needs.
- Controls that are in place, presence and capabilities of the BMS.
- Availability of data (consumption data as well as delivered temperatures).

- Presence of high energy consuming equipment (in order to investigate potential for recovery of emitted heat in Step 3).
- Location and surrounding area (potential for PV and wind generation in Step 6, connection to a heat network)

8.8 Step 2 – Elimination of energy waste/reducing demand

Some of the ways that energy efficiency can be achieved in a typical hospital are described in the following paragraphs. Please note that this is not an exhaustive list, and an energy audit can assess which of these are applicable as well as identify further opportunities.

8.8.1 Fabric upgrade

The building fabric is the main moderator of thermal comfort and typically the main driver of heat energy usage in a building. When working on decarbonising heat, it is crucial to reduce the energy demand as much as technically and economically possible by implementing fabric improvements alongside any other energy efficient measures. This aligns with the rationale that for energy demand reduction, it is more feasible and cost effective to first consider energy reduction through passive design principles, then apply system efficiency measures to meet end use energy demand efficiently, before finally considering the use of renewable technologies which will offset any carbon emissions by generating energy onsite.

For new buildings, specifying fabric enhancements can be done during the early design stage with a standardised approach. On existing buildings, upgrading building fabric can be a challenging task, requiring a bespoke approach as upgrades are dependent on the listed status, age, form complexity, fabric condition and construction type of the building.

A feasibility study that assesses how best a building can be retrofitted is highly recommended. It will facilitate a well-informed decision for the next steps of delivering high performance healthcare buildings.

A well-planned retrofit is essential if the project is to succeed. This includes all aspects of the project, from the setting of initial performance requirements through to engagement of the relevant specialists for the detailed design and procurement of the works, and others. A robust retrofit plan will be based on the information described in section 5.1, with a strong focus on the information described in section 8.7.1c.

A fabric upgrade can include:

- a) roof insulation at rafters or joists/ceiling;
- b) wall insulation (external, internal or cavity);
- c) draughtproofing;
- d) windows upgrade;
- e) floor insulation;
- f) doors upgrade;
- g) lower g-values (the g-value is a measure of how much solar heat (infrared radiation) is allowed in through a particular part of a building. A low g-value indicates that a window lets through a low percentage of the solar heat);
- h) other passive measures like unconditioned buffer zones and adding external (or internal) shading devices.

An indication of the thermal transmittance (U-value) of the building fabric elements based on the age-bands when Building Regulations changed in Wales can be found in Table 17 below. The thermal transmittance (U-value) is a measure of the quantity of heat that will flow through a structure (per unit of area, time, and temperature differential of the environments on the two sides of the structure).

Table 17: U-values for thermal elements based on age bands applicable to Wales. Reference: NCM database through RdSAP

Building Age Band	External Wall U-value (W/m ² K)					Roof U-value (W/m ² K)	Ground floor U-value (W/m ² K)
	Stone: granite or whinstone	Stone: sandstone or limestone	Solid Brick	Cavity Wall	Timber Frame		
Before 1900	2.3-3.3	2.0-3.0	1.70	N/A	2.50	2.30	0.61
1900-1929	2.3-3.3	2.0-3.0	1.70	1.50	1.90	2.30	0.61
1930-1949	2.3-3.3	2.0-3.0	1.70	1.50	1.90	2.30	0.58
1950-1966	2.3-3.3	2.0-3.0	1.70	1.50	1.00	2.30	0.55
1967-1975	1.70			1.50	0.80	1.50	0.54
1976-1982	1.00				0.45	0.68	0.54
1983-1990	0.60				0.40	0.40	0.54
1991-1995	0.60				0.40	0.30	0.54
1996-2002	0.45				0.40	0.26	0.37
2003-2006	0.35					0.16	0.24
2007-2011	0.30					0.16	0.2
2012 onwards	0.28					0.16	0.2

The table shows that the heat losses through the fabric have dropped very sharply with newer construction methods and materials and therefore a fabric upgrade can bring a significant reduction in heating needs. This can be more than a 50% reduction in heating needs for buildings built before the 1990s, which form more than half of NHS Wales' portfolio.

Windows are as important as walls, regarding their thermal transmittance, and these too have improved in the last decades. Thermal transmittance of windows is listed in Table 18. Windows are more likely to have been replaced already in a building, therefore this report presents the thermal transmittance based on the window type and not age band. This table also present the g-value, which is a measure of how much solar heat (infrared radiation) is allowed in through the window. A low g-value indicates that a window lets through a low percentage of the solar heat.

Table 18: Default Window U-values, as referenced in the NCM database through RdSAP.

	Window U-value of existing (W/m ² K)	g-value	Current typical design values
Single glazing	4.8	0.85	N/A
Double pre-2002	2.6-3.1	0.76	N/A
Secondary glazing	2.4	0.76	N/A
Double post or during 2002	2	0.72	0.3-0.4
Triple glazing (Part L 2021 -consultation)	≤1.8	0.46-0.55	0.3-0.4

Apart from building fabric upgrades, there are other passive strategies that can reduce the energy demand of a building. These can be easily incorporated in the retrofit design. They are related to building form and include creating buffer zones in main entrances or other entrances with high use/ constant access. Another example, related to cooling rather than heating, is the addition of external effective shading devices to reduce solar gains during the summer. A general guideline suggests horizontal devices for south elevations and vertical for east and west orientation. Reduction of solar gains can also be achieved by adding films on the glazing of the windows that lower the g-value.

8.8.1.1 Setting the target for fabric performance

With a multitude of technologies and options, a pertinent question for fabric upgrade is "how far should we go?", with regards to setting the targets for the end result.

One approach could be adhering to the minimum requirements of Part L 2021 (under consultation during the writing of this report) as a retrofit target. According to this, when upgrading a thermal element, minimum U-values should be achieved. Table 19 presents these values, as well as the maximum insulation thickness required to achieve them if the construction is aged pre-1966.

Table 19: Minimum U-value targets based on Approved Document L 2022 for Wales and the maximum insulation thickness required to achieve them if the construction is aged pre-1966.

	Minimum U-values Required by Approved Document L 2022 Wales (under consultation)⁸	Maximum insulation depth in mm required when upgrading the relevant thermal element Against age band 'pre-1966'
External or Internal Wall U-value	0.30 W/m ² K	Option 1: 75mm with 0.027 thermal conductivity Option 2: 140mm with 0.04 thermal conductivity (timber cladded - thermal bridged) plus 15mm unventilated air cavity Option 3: 50mm with 0.036 thermal conductivity (filled cavity with polystyrene beads) PLUS 60mm insulation with 0.040 thermal conductivity
Cavity Wall U-value	0.55 W/m ² K	Option 1 (0.55W/m ² K): 50mm with 0.036 thermal conductivity (filled cavity with polystyrene beads)
Pitched roof – insulation at ceiling level U-value	0.16 W/m ² K	Option 1: 165mm with 0.027 thermal conductivity Option 2: 250mm with 0.040 thermal conductivity
Pitched roof – insulation at rafter level U-value	0.18 W/m ² K	Option 1: 150mm with 0.027 thermal conductivity unbridged Option 2: 140mm with 0.040 thermal conductivity with thermal bridges plus 110mm with 0.04W/mK unbridged
Flat roof or roof with integral insulation U-value	0.18 W/m ² K	Option 1: 150mm with 0.027 thermal conductivity unbridged Option 2: 220mm with 0.04 thermal conductivity
Ground floor U-value	0.25 W/m ² K	Option 1: 60mm with 0.040 thermal conductivity unbridged ⁹

⁸ Table 4.1 and Table 4.2 of Part L 2021 Wales Vol. 2 (draft) <https://gov.wales/sites/default/files/consultations/2021-10/consultation-stage-2B-draft-approved-document-l-vol-2.pdf>

⁹ Actual requirement will vary depending on ratio of floor area to exposed perimeter length

Table 20: Thermal conductivity of common insulation materials

Insulation material	Thermal conductivity (W/mK)
Mineral wool	0.040
Expanded polystyrene	
Glass fibre (Glass wool)	
Polystyrene beads	0.036
Extruded polystyrene	<0.027
Polyurethane	

The insulation thickness is determined according to the thermal conductivity of the material used. This ability doesn't change with the thickness of the material, therefore the U-values are used for a final structure, whereas the thermal conductivity is used for choosing the materials that will form this final structure.

When a fabric element is being upgraded, the selection of the most suitable insulation material should be based on the construction type of the fabric element, moisture content, any planning restrictions that may affect the location of the build-up (internal or external), the material's thermal conductivity, toxicity, and flammability. Thermal conductivities of some of the most common materials used as insulation are presented in

Table 20.

Another approach could be to set the target even higher and implement a more robust methodology. One approach which is currently one of the most robust methodologies for fabric specification, leading to very low operational energy for space heating, is Passivhaus (PH). It is also a reliable approach when it comes to the actual performance of the building, as there is published data which show that Passivhaus buildings perform as per the design intent.

8.8.1.2 Passivhaus and EnerPHit

Passivhaus is a building standard that is related to operational energy and occupant comfort. It can be applied, at least in part, to all building types both residential and commercial, new or refurbishment of existing.

Passivhaus deals with all aspects that influence the energy consumption of the building. It sets maximum performance criteria for space heating and cooling demand, total energy load and air permeability, rather than specifying technologies or materials. Its results can therefore be achieved using a range of construction methods and technologies, if the basic principles are followed.

Careful consideration needs to be given when applying Passivhaus levels of insulation and airtightness in acute 24/7 hospitals to avoid overheating.

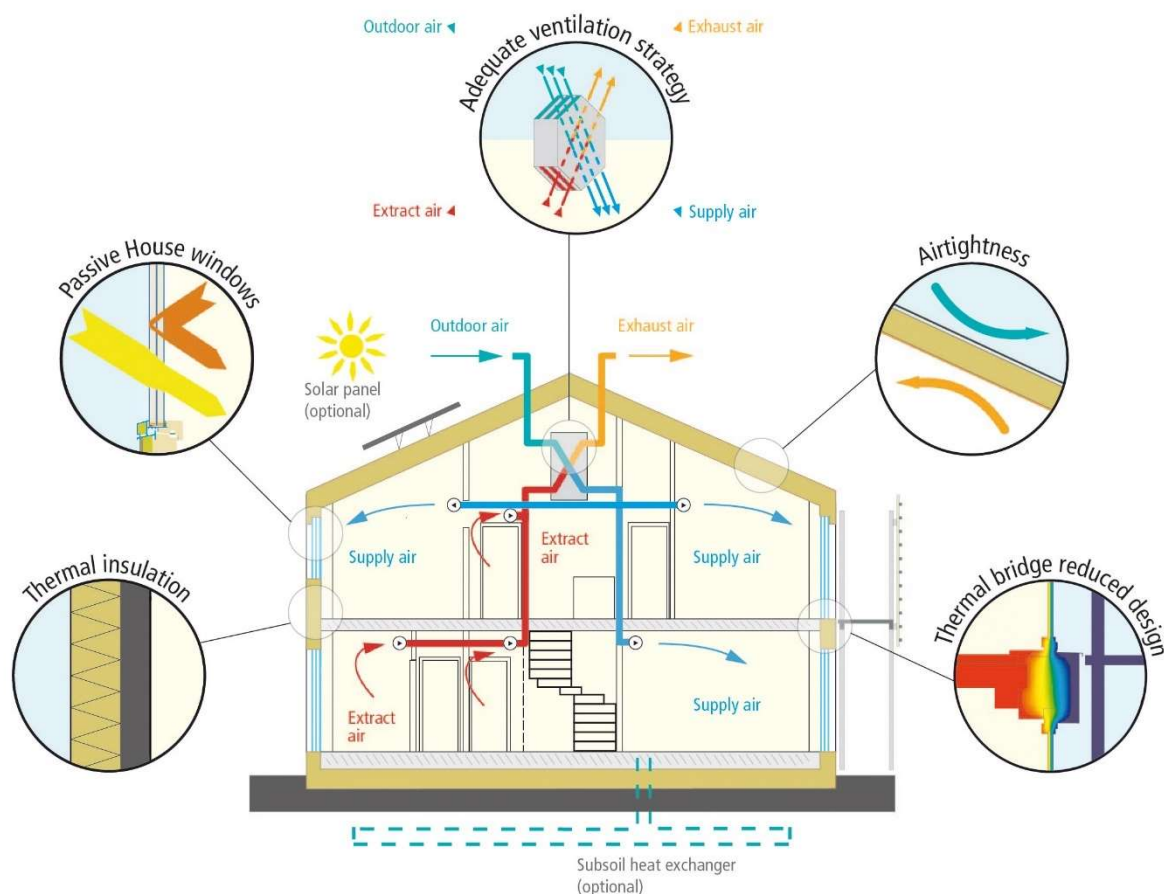


Figure 22. The five basic principles of Passivhaus¹⁰

As per Figure 22, the basic Passivhaus (PH) principles are:

- high level of thermal insulation;
- heat recovery in mechanical ventilation;
- triple-glazing with energy efficient framing which take advantage of free solar gains;
- the elimination of cold spots (or thermal bridges); and
- airtight shell.

As a rough guide, the values that are acceptable for achieving the PH certification are 15kWh/m²/yr for energy demand (space heating or cooling) or 10W/m² maximum load for space heating or cooling for standard building types¹¹. To achieve such low energy consumption, the PH design considers all energy consuming equipment in the building, as this can contribute to significant heat gains.

¹⁰ Passive House Institute Formal Website, https://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm

¹¹ In practice, more complex buildings such as healthcare ones, will be provided with a bespoke target by the Passivhaus Institute

8.8.1.2.1 EnerPHit Retrofit Plan: the Passivhaus equivalent for a Retrofit

The Passivhaus Institute, acknowledging that the orientation, form and location are already set in existing buildings (with all the restrictions associated with these), has developed EnerPHit for certified energy retrofits. EnerPHit is a slightly adapted Passivhaus standard that reflects the challenges of refurbishment / retrofit.

EnerPHit can be obtained through two certification routes. One requires meeting climate-zone-dependent requirements on heating and cooling demand and the other requires the consistent use of Passive House components and achieving the minimum comfort levels.

Table 21 shows the main requirements for both the Passivhaus and EnerPHit standard, in terms of space heating demand, airtightness and primary energy demand. Primary energy demand is the total demand of the building, including all equipment and services, irrelevant of the fuel they use. Certification can be achieved when either the primary energy demand or the heating load targets are met.

If a building is being served by an active cooling system, targets similar to the space heating demand apply and an allowance is available for areas where the cooling system needs to operate in high humidity levels, and therefore de-humidification is necessary.

Table 21: Minimum requirements to achieve Passivhaus or EnerPHit certification



	Passivhaus	EnerPHit
Primary energy demand	$\leq 120 \text{ kWh/m}^2 \cdot \text{yr}$	$\leq 120 \text{ kWh/m}^2 \cdot \text{yr} + \text{heat load factor}$
Space heating demand	$\leq 15 \text{ kWh/m}^2 \cdot \text{yr}$	$\leq 25 \text{ kWh/m}^2 \cdot \text{yr}$
Space cooling demand	$\leq 15 \text{ kWh/m}^2 \cdot \text{yr}$	$\leq 25 \text{ kWh/m}^2 \cdot \text{yr}$
Specific heating or cooling load	$\leq 10 \text{ W/m}^2$	
Airtightness¹²	$\leq 0.6 \text{ air changes/hr @ n50}$	$\leq 1.0 \text{ air changes/hr @ n50}$
Frequency of overheating (>25°C)	<10% of the year	
Mechanical ventilation heat recovery efficiency	$\eta_{\text{HR}} \geq 75\%$	
Mechanical ventilation electrical efficiency	$\leq 0.45 \text{ Wh/m}^3$	

More details regarding the EnerPHit requirements for certification based on components used for the retrofit can be found in Appendix 8.5.

8.8.1.2.2 Planning EnerPHit retrofit interventions

The challenges for a retrofit can vary. There may be cases where it is not feasible to complete a full retrofit in one go. To address these difficulties, the Passivhaus Institute introduced a step-by-step approach to an EnerPHit retrofit, namely the EnerPHit Retrofit Plan (ERP). These steps are not rigid in terms of type of retrofit or time. The

¹² For larger or more complex buildings a slightly different approach to the one shown is used for measuring air tightness

main aim behind it is that whatever is being retrofitted should be carried out at high standards and be part of a wider plan.

When energy retrofits are carried out in individual consecutive steps/stages, then pre-certification of the building as an EnerPHit (or Passive House) project is possible. Full EnerPHit certification can be targeted as a final step of the retrofit plan. For the NHS Wales building estate, the full certification may not be possible for all buildings. However, this robust methodology and the use of the Passive House Planning Package (PHPP) tool used for this approach can be utilised to facilitate other targets that can be set case-by-case.

The EnerPHit Retrofit Plan (ERP) includes a well-thought-out overall concept for a stepwise retrofit for an existing building, as it considers important interrelations between different energy saving measures. Thus, an optimal final result can be targeted through the execution of all steps with reasonable effort.

The first step is the specification of the building's current condition by inputting into PHPP all the information collected by the surveys mentioned in section 5.1. The more accurate these surveys are, the more reliable the PHPP outcome will be. The next step is to specify the targeted retrofit proposal. Interim stages can then be specified by taking into account other parameters like time, an element's current condition, budget or other institutional priorities.

The sequencing of the works needs to be carefully planned and this is what the EnerPHit Retrofit Plan can offer.

8.8.2 Variable speed fans/pumps and pipework insulation

Many heating systems in NHS Wales buildings operate on a constant temperature/flow basis. Wherever possible, moving to variable speed fans and pumps to avoid constant pumping of water at maximum rate is recommended. The same refers to Air Handling Units and switching off the system when it is not required.

A very common opportunity for heat energy savings is the insulation of pipework (steam and hot water), especially for the pipe runs that are outside the areas to be heated. It is believed that this is a major issue across the NHS Wales estate and tackling it could bring significant energy and carbon savings.

Uninsulated pipework also poses very high health and safety risks, obstructs and raises the cost of maintenance in the surrounding areas and, when indoors, the high temperatures can accelerate the degradation of surrounding equipment.



Figure 23. (left) Uninsulated steam pipe that causes significant energy waste and poses a great risk to nearby electrical installation

Figure 24. (right) Uninsulated steam pipe outdoors, even a small section can cause significant energy losses, especially when it's exposed to outside temperatures

8.8.3 Steam leaks

Steam leaks, as with uninsulated pipework, create energy waste and pose significant health and safety risks. A steam leak survey should be a regular routine as, even when a leak is fixed, it can fail again soon after, or a new one might appear.



Figure 25. Steam leaks and uninsulated pipework cause both energy waste and H&S risks

8.8.4 Condensate recovery

This is an opportunity only in heating systems using steam. Saturated steam used for heating gives up its latent heat (enthalpy of evaporation), which is a large proportion of the total heat it contains. The remainder of the heat in the steam is retained in the condensate as sensible heat (enthalpy of water).

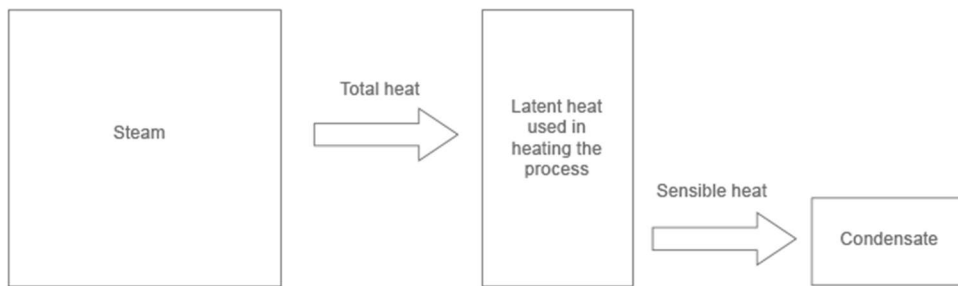


Figure 26. After giving up its latent heat to the process (space heating), steam turns to water containing only sensible heat

When a kilogram of steam condenses completely, a kilogram of condensate is formed at the same pressure and temperature. As well as having heat content, the condensate is basically distilled water, which is ideal for use as boiler feedwater. An efficient steam system will collect this condensate and return it to the boiler feed tank.

If the condensate is not reused, the system will need to be topped up with fresh water (make-up water) that needs to be chemically treated and preheated from an average of 15°C to about 85°C-90°C before it is fed to the boiler.

Where not already implemented, an effective condensate recovery system, collecting the hot condensate from the steam using equipment and returning it to the boiler feed system, can pay for itself in a short period of time.

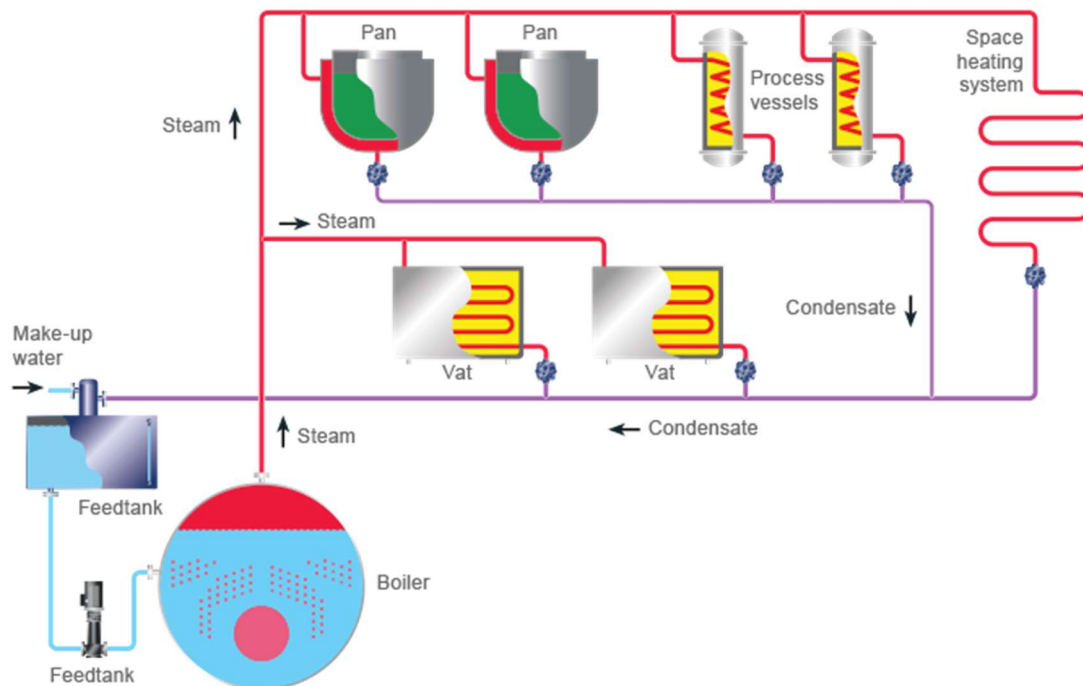


Figure 27. Typical steam and condensate circuit¹³

Figure 27 presents a typical steam system in an industrial site, where the main steam users are pans, vats, process vessels and space heating. In a hospital, the main steam users would be heat exchangers (for space heating and domestic hot water) and sterilisation units.

¹³ Image source : Spirax Sarco

The condensate is extracted from the system through steam traps. These are depicted in Figure 27 as the blue symbols after each steam user. Correct sizing of the steam traps and regular checks to make sure they are not failing are essential for the efficiency of the system.

8.8.5 Reassess heating requirements

This is a recommendation to periodically check that the heating systems operate at the required specification for each area in terms of temperature, humidity and air changes. It is often found that some areas are heated (or cooled) beyond their specified requirements, leading to increased energy consumption.

8.8.6 Heating and Ventilation and Air Conditioning (HVAC) Optimisation

Air handling units (AHUs) ensure that clean air is introduced into the areas they serve. Using fans, they extract the air from a space and force filtered, clean air from outside into the space. The main reason for these air changes is to replenish the oxygen and remove carbon dioxide, especially in spaces with no natural ventilation, but also to remove potential harmful particles that can occur in a hospital environment.

8.8.6.1 Heating Zoning

A lot of energy waste occurs when areas of the hospital are heated outside their operational hours. This often happens when these are in the same heating zone with adjacent areas that are occupied for longer hours, therefore the heating system cannot be turned off. Further breakdown of the heating zones can resolve this issue and it's now possible and easier with 2-port valve variable flow, automatic valves and dampers and BMS control.

8.8.6.2 Optimal Scheduling

Another reason causing heating of non-occupied areas is BMS schedule override. These are sometimes caused by a past complaint (for example the room was not warm enough at the beginning of the day) which was quickly resolved by overriding the system to being on all day, to ensure user comfort on arrival. These overrides should be lifted and rectified with a more sophisticated schedule, that can start pre-heating the room according to current and forecasted outside temperatures. With correct zoning, the preheating can be achieved by the wet system instead of the AHUs, as there is no need for air changes.

Energy waste is also often related to the HVAC plant serving operating theatres when these are not being used, as observed during site visits. Operating theatres HVAC systems are very energy intensive because these have high standards for temperature, humidity, and air changes per hour. As the schedule of operations can change from one day to another, it is essential to have a system that will stop the ventilation when the theatres are not used.

8.8.6.3 Avoiding simultaneous heating and cooling

There are cases where energy waste occurs by simultaneous heating and cooling. Their identification requires detailed energy audit, but some common cases are described below.

Different systems fighting each other

As described in section 6.1, in most buildings there are two separate systems for heating:

- a "wet system", which is the hot water running in the radiators fed by the VT system and
- a tempered air system, which is the air that the AHUs supply to the areas. The AHUs have capability to heat the air, as well as cool it.

These two systems, even though they are carefully designed for the building, usually feed the building through a different breakdown of zones, with AHUs usually feeding larger zones than the wet systems. In addition, they have separate temperature controls and schedules.

This can result in cases where the one system is fighting the other, usually with the AHU trying to cool the space, whilst the wet system is still heating it through the radiators.

- In addition to these two systems, split systems (local air conditioning units) are also installed throughout buildings, according to local needs – usually for cooling, as their installation is usually much simpler than modifying the AHU ductwork.

The local control of the split units is again not connected to the control of any of the previous two systems, resulting again in situations of simultaneous heating and cooling, which has negative effects on energy consumption and often also on occupant comfort.

Such cases of energy waste through simultaneous heating and cooling can be resolved through careful zoning and integration of all controls under one system (BMS).

Systems working against natural ventilation

Openable windows and doors left open can create circumstances where heat, or cooled air escapes directly outside. These are very wasteful practices and are often a sign of space users not knowing how to correctly operate the heating and cooling controls.

These issues can be resolved by:

- informing staff on all the available controls and heating strategies (behavioural change),
- greater automation, for example the heating/cooling systems turning off if a door or window is left open for a while,
- or by a combination of the two.



Figure 28. Perimeter heating operating with doors wedged open during winter

Conflicting setpoints

There are some cases where simultaneous heating and cooling occurs within the same system, when the setpoints are conflicting. These cases are more difficult to identify as they often occur only in certain conditions and can therefore go unnoticed for long periods of time, having a significant impact on energy consumption.

An example of such an incident is the one below, occurring in AHUs serving theatres with heat recovery and humidity control.

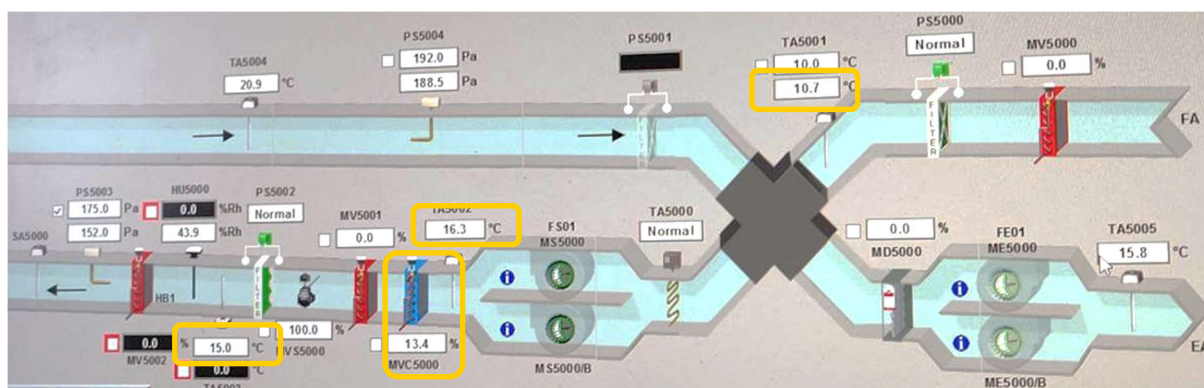


Figure 29. AHU with heat recovery and dehumidifier

In Figure 29 one can observe that the setpoint of the cooling coil serving for de-humidification does not consider the fact that there is heat recovery in the AHU. The setpoint is at 15°C, as typically, outside air warmer than that can contain excess humidity. The cooling coil will cool the air so that the excess humidity condenses, and the air with the desired level of humidity will then be reheated.

The conflict of the setpoints in the AHU depicted in Figure 29, is in that it doesn't consider that the 15°C is not the outside air temperature, but the temperature of the air after it has passed through the heat recovery. The outside temperature is 10°C in this case (a temperature in which absolute humidity is low, so there is no need for dehumidification).

Therefore, in the above operation, which was observed in two different occasions, not only some of the heat recovered is wasted, but it is done so using the chilled water system, increasing the energy consumption of the chillers. In the end, the air needs to be heated again before it is delivered to the theatres.

Cases like that can be identified by periodically checking the BMS controls, as part of a BMS service when other issues can also be identified, like manual overrides and sensors obviously in need of calibration.

Another way to identify issues like this is by detailed energy management, checking hot and chilled water use against weather data.

8.8.7 Decentralisation and separation of heating and hot water loads

Decentralisation of heat supply is often considered together with low carbon heating options for multiple reasons:

- It can lead to a reduction of distribution losses, especially when the heating demand varies in different areas within the same system.
- The above reduction in distribution losses and the generally lower demand in some areas enables lower temperature water to be used for heating. With these lower temperatures, heat pumps are more feasible and efficient.
- Areas with lower heating demands can be served by an appropriately sized system.

Decentralisation is not a current practice in hospitals. While energy costs were low and carbon emissions were not considered to be an issue, the abundance of affordable fossil fuels led to designs with centralised energy centres. This had the advantage of reduced complexity and easy addition of resilience to the system. From this centralised energy centre, a network of hot water or steam would circulate throughout the site, at a temperature and pressure high enough to cover the most energy intensive loads. A “degrading” of heat would happen in calorifiers, heat exchangers and mixing valves, to then deliver the right amount of heat for each use.

These networks of hot water and steam can have high distribution losses and require a heat source that can easily and cheaply deliver high grade heat. Gas boilers are ideal for that, but there is currently no low carbon equivalent for them. Electric resistance boilers could deliver high grade heat but feeding with them a network with such high losses would be very expensive and unsustainable. Such levels of electrical capacity might also not even be available with the current electrical infrastructure, both within the site but also on a national transmission and distribution level.

The constraints of the cost and availability of electricity and the lower temperatures in which heat pumps currently operate efficiently make the case for decentralisation and rationalisation of heat generation.

In contrast to the benefits of a centralised system mentioned above, decentralisation increases complexity, both in control and in maintenance. It includes many more pieces of equipment that operate in slightly different setpoints and schedules and all need to be maintained.

Manual operation and maintenance is an impossible task in decentralised systems, which can therefore only be possible with a robust system of automated control, monitoring and reporting, such as a BMS.

The need for extensive and robust BMS across all sites has been highlighted in the NHS Wales Decarbonisation Strategic Plan as the Initiative 9.

Centralised systems can still be considered, as the problem with the existing centralised systems is not the concept as such, but the high distribution losses and the lack of modulation capability. The heat losses can be minimised through improved pipework insulation and low distribution temperatures. In efficient centralised systems the main heat sources should have the capacity to modulate their output and match the exact heating needs.

There is also the possibility to have a combination of a centralised/decentralised system, such as an ambient loop system, described in section 8.11.1.6.

8.8.7.1 Decentralisation of uses

Decentralisation can also occur in terms of uses, so depending on whether the heat is used for space heating, domestic hot water, or sterilisation processes. This segregation can even expand to type of heating, whether it is conditioning of fresh air with a CT circuit, or a wet system with a VT circuit.

The segregation of domestic hot water can have further benefits. Typically, domestic hot water is generated and stored at 60°C for legionella control but is rarely needed in temperatures above 40°C. These excess 20°C can significantly increase the heat losses during storage and distribution. The replacement of calorifiers with point-of-use electric boilers could reduce or eliminate the need for legionella treatment. Of course, that increases significantly both the initial equipment cost and the maintenance cost, so it won't be a suitable solution in some settings.

Sterilisation processes are the best example of the benefits from decentralisation of uses, as decentralising them allows for the heating system to de-steam and operate in lower temperatures, with lower distribution losses. Furthermore, it allows for heat sources to be better matched to the heat demand.

8.9 Step 3 – Closing the loops / heat recovery

8.9.1 AHU Heat recovery

As the AHUs extract the air at room temperature, the heat in that air is lost.

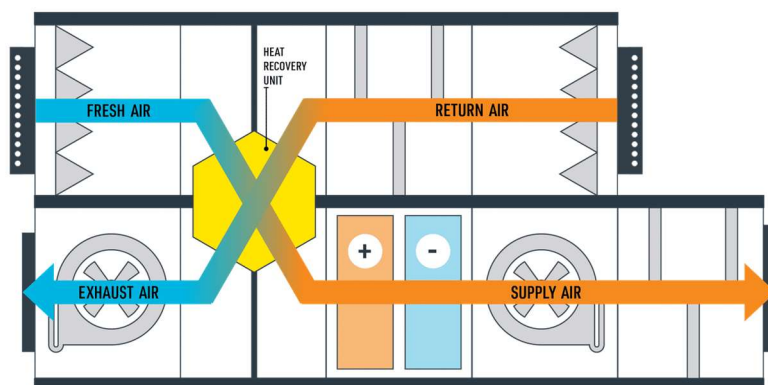


Figure 30. Schematic of an air handling unit with heat recovery¹⁴

A heat recovery unit transfers heat from the exhaust air stream over to the supply air stream, thus reducing the heat loss due to ventilation and reducing the need to condition the cold supply air. Conversely, in hot conditions, a heat recovery unit can keep heat outside, thus reducing cooling costs.

It is estimated that up to approximately 75-80% of heat can be recovered with such units, as required in the PassivHaus certification.

There are different technologies used for heat recovery, mainly divided into regenerative heat recovery (e.g. thermal wheel) and recuperative heat recovery (e.g. plate heat exchanger).

Recuperative heat exchangers transfer heat across a dividing plate by means of thermal conduction (plate or tube heat exchanger), or with an intermediate fluid (run-around heat exchanger, heat pipe or heat pump). Since the two air streams are kept separate, these exchangers can theoretically have zero transfer of odours, though in practice, plate heat exchangers, which are the most common type, typically have 1–3% recirculation due to internal leakage.

Plate heat exchangers

Plate heat exchangers consist of parallel plates (flat or corrugated) that separate the supply and exhaust air streams. If the plates' temperature drops below 0°C, ice can grow in the exhaust air paths in the exchanger, and it will eventually become blocked. When heat recovery is not desirable, in summer, a bypass damper may be used. Due to condensation in the exchanger during winter, a condensate drain must be provided.

¹⁴ Image source : AECOM

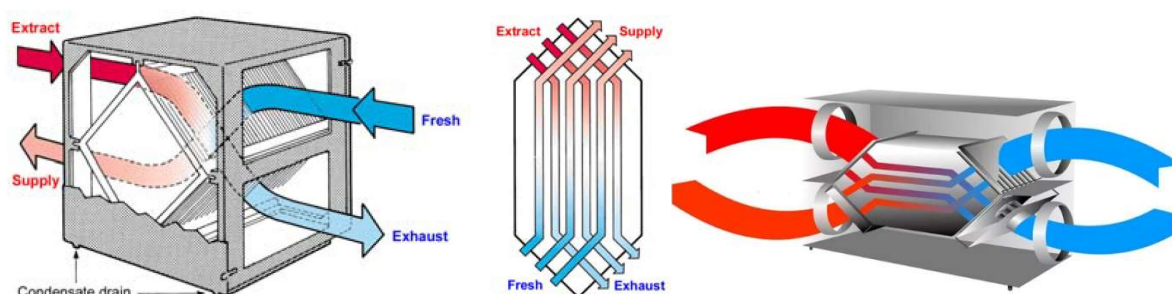


Figure 31. Cross-flow (left) and hexagonal counter-flow (middle and right) plate heat exchanger¹⁵

Traditionally, cross-flow heat exchangers are the most common. Counter-flow heat exchangers are a more recent development they have higher recovery efficiency but are more susceptible to frosting.

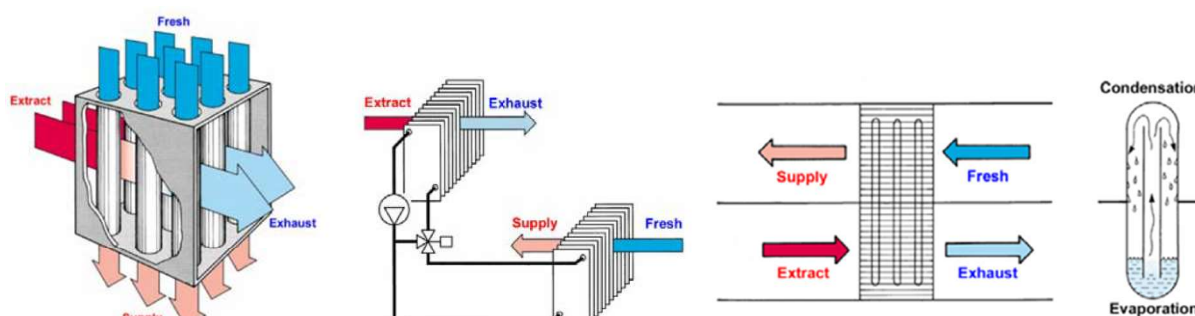


Figure 32. Other types of heat exchangers from left to right: tube, run-around, heat pipe heat exchanger

Tube heat exchangers

These function in a similar way to plate heat exchangers, where tubes replace plates.

These are easier to clean than plate heat exchangers and can be equipped with an automatic washing mechanism. The tubes can be made of glass, giving good corrosion resistance. The risk of becoming blocked due to frosting is less than plate heat exchangers and the internal leakage is generally less.

Run-around heat exchangers

These consist of two batteries (coils), one in each air stream, connected by a fluid circuit of water/glycol or water/alcohol (for frost protection). The heat recovery efficiency is reduced with increasing glycol concentration. In large systems, brine is used instead of water/glycol.

The advantage with this type of heat exchanger is that there can be a large distance between the supply and exhaust ducts, and heat can be reclaimed from multiple exhaust ducts by means of individual batteries. This system is appropriate in cases with heavily polluted extract air since there is no risk of air leakage from the exhaust to supply air streams (stainless steel, copper or plastic batteries give corrosion resistance).

Heat pipe

These function in a similar way to run-around heat exchangers. The working medium is a refrigerant that evaporates under heat and condenses when cooled. No pump is needed as natural circulation is achieved by a wick inside the tube, along which the condensate is conducted. The heat recovery efficiency is higher in colder weather. Heat recovery is controlled, if necessary, by a bypass.

Heat pump-based heat recovery

¹⁵ Image source of Figure 31 and Figure 32 : INIVE EEG, Ventilation Information Paper No6, June 2004

AHUs can have an in-built heat pump. The heat pump consists of two batteries (one in each air stream, just as a run-around) connected by a refrigerant circuit with a motorized compressor and a pressure reduction valve. The compressor's power consumption is also released as heat in the supply air stream. Heat pumps do not transfer moisture. The heat recovery efficiency is normally controlled by regulating the compressor speed or by diverting gas from the compressor's pressure side to its suction side.

More information about air source heat pumps can be found in section 8.11.1.3.

8.9.2 Wastewater heat recovery

As hospitals have high and relatively constant domestic hot water usage and occupancy, there is a great opportunity for heat recovery from wastewater, both from taps and showers and from sewers. It is estimated, even though the temperature of wastewater fluctuates, it can be as high as 25°C and remains always above the water mains temperature, so approx. 15°C. This makes it a very good source of heat, especially when combined with a heat pump to raise the temperature and deliver higher grade heat that can be used either for heating or hot water.

Spiral heat exchangers are recommended for this application, as they are very robust and less likely to clog up on the effluent side.

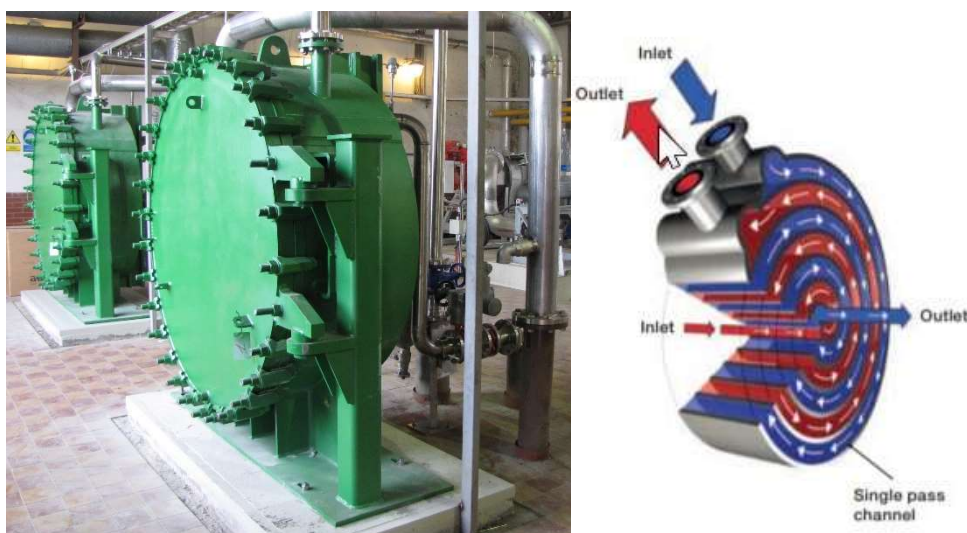


Figure 33. Spiral heat exchangers are suitable for recovering heat from effluent¹⁶

Wastewater heat recovery hasn't been implemented so far widely on a building level, but in the light of energy efficiency and decarbonisation, it is considered an attractive opportunity, if there are central wastewater outlets.

8.10 Step 4 – process change

This step is mainly applicable to sterilisation processes and laundries, rather than space heating. This step requires in-depth expertise on the processes and their requirements, so this report refrains from making any technical suggestions (see 8.7.4)

¹⁶ Image source : <https://www.nexson-group.com/products/spiral-plate-heat-exchanger/sludge-heat-exchanger/> and <https://www.alfalaval.ca/service-and-support/local/canada/heat-exchanger-repair/recondition-spiral-heat-exchanger/>

8.11 Step 5 – Fuel switch / Alternative fuels and heat sources

8.11.1 Heat pumps

Heat pumps use electricity to extract heat from ambient sources such as: the air, the ground, water bodies or sewers.

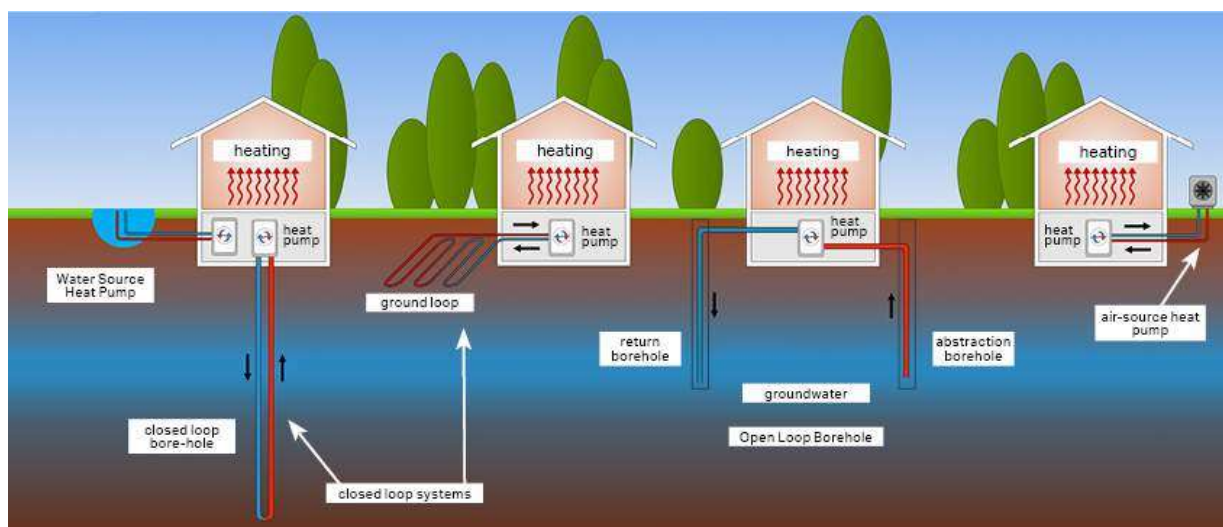


Figure 34. Schematic of different heat pump setups¹⁷

Heat pump efficiency increases the warmer the heat source that heat is being extracted from or the cooler the required supply temperature in the building.

In winter, the ground may be warmer than the air so ground source heat pumps would be more efficient than air source heat pumps. In summer, air temperatures may be warmer than the ground. A combination of heat sources can help to optimise efficiency.

Unlike gas Combined Heat and Power (CHP) engines the efficiency of heat pumps does not increase significantly with capacity so they can provide a low carbon heating solution at any scale.

Securing the required electricity reinforcement for the power needs of heat pumps should be considered early in the development planning process.

The expected shift to electric heating and electric vehicles will place much greater demands on the electricity grid, as explained in 6.1. Electricity also has a higher cost per unit than gas. Increasing efficiency standards for buildings will help to reduce power demands, costs and the level of grid reinforcement required.

The operation of a heat pump is based on the refrigeration cycle, where heat is removed from a medium, for example cooling water and is released to the air, through cooling towers or condensers, making the cold water colder and the warm air warmer. These systems use refrigerant to carry the heat from one medium to the other. Heat pumps operate on the exact same principle, but in reverse, drawing the heat from the air (or another source of heat) and releasing it into a medium, usually warm water.

¹⁷ Image source : <https://www.herold.at/blog/waermepumpe/>

There are types of heat pumps that do not operate based on the refrigeration cycle, e.g., gas absorption heat pumps, but in the context of healthcare buildings these are likely to be very rare, therefore the report will not focus on them.

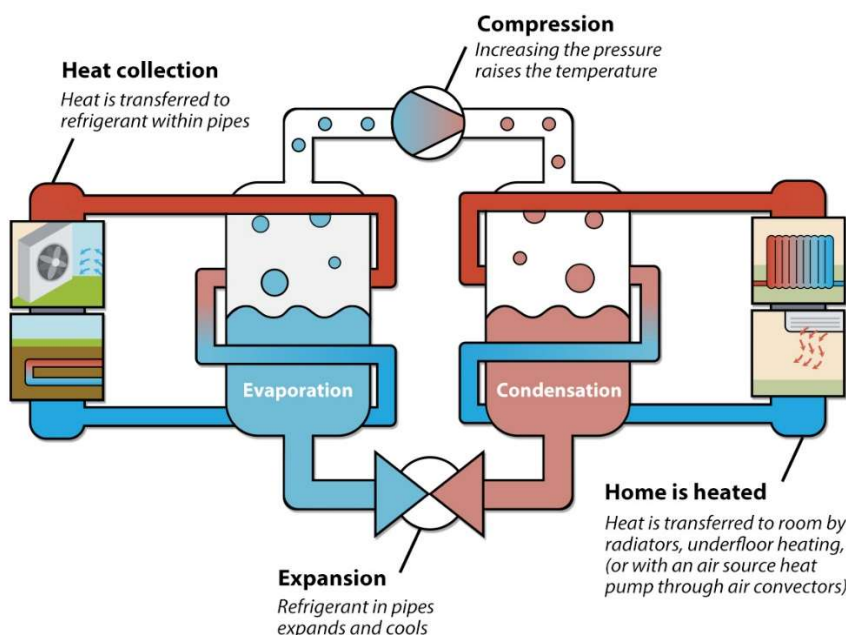


Figure 35. Schematic of heat pump operating in heating mode¹⁸

In the paragraphs below, different kinds of heat pumps are explained but in all schematics the heat pumps are in heating mode. In heating mode, the outdoor heat exchanger works as an evaporator (draws heat into the heat pump) and the indoor heat exchanger works as a condenser (releases the heat out). It should be noted that heat pumps can also work in cooling mode (just as a VRF or a split unit). In cooling mode, a reversing valve forces the outdoor heat exchanger to work as a condenser and the indoor heat exchanger to work as an evaporator.

For any use of heat pumps, careful consideration should be given to use of low global warming potential (GWP) refrigerant otherwise there is high risk of increasing scope 1 fugitive emissions, see 2.2.

8.11.1.1 Efficiency and carbon performance of heat pumps

Currently a gas fuelled solution (i.e. boilers) is considered to be less carbon intensive way of providing heat than a direct electric system. However, because of the high efficiency of heat pumps, heat pumps currently provide a much lower carbon solution. Furthermore, as the grid decarbonises even further, heat pumps will get even closer to being a net zero solution.

The high efficiency, more than 100%, might sound unrealistic, and contradicting the laws of physics, as the energy output of the system cannot be greater than the input. In reality, the equation of efficiency only takes into account certain elements.

$$\text{Efficiency} = \frac{\text{Energy Output}}{\text{Energy Input}}$$

$$= \frac{\text{Heat delivered by the heat pump}}{\text{Heat that was drawn from air, water, ground} + \text{Electricity needed to draw this heat (compressor, recirculation pumps etc.)}}$$

¹⁸ Source: <http://www.airsourceuk.org/air-source-heat-pumps.html>

Even though the heat drawn from the air, water and ground is very significant in amount, comparable to the heat delivered by the heat pump, it is considered to be free and abundant and is therefore not taken into account in the calculation. The equation then becomes the coefficient of performance (CoP):

$$CoP = \frac{\text{Heat delivered by the heat pump}}{\text{Electricity needed to draw and deliver this heat (for the compressor, recirculation pumps etc.)}}$$

which is significantly higher than 1 (100%), usually above 3 (300%).

The COP refers to the fact that the heat pumps do not produce heat themselves, like a direct electric heater would do by transforming electricity to heat. Heat pumps use electricity to draw heat from air, ground, or water.

The cost of electricity is approximately four times that of gas in a hospital setting. This often leads to direct electric systems not being suitable for heating due to the high costs of operation. However, heat pumps operate typically at an efficiency (or Coefficient of Performance) between 2.8 and 6, meaning that for every kilowatt hour (kWh) of electricity used, the heat pump can deliver up to 6kWh of thermal energy. However, it should be noted that the COP can drop as low as 1 in the winter months, and seasonal CoPs can be as low as 1.8. On average, air source heat pumps provide the lowest efficiencies due to the less constant temperatures of outside air throughout the year. Ground source offers the highest efficiency due to the relatively constant year-round below ground temperatures.

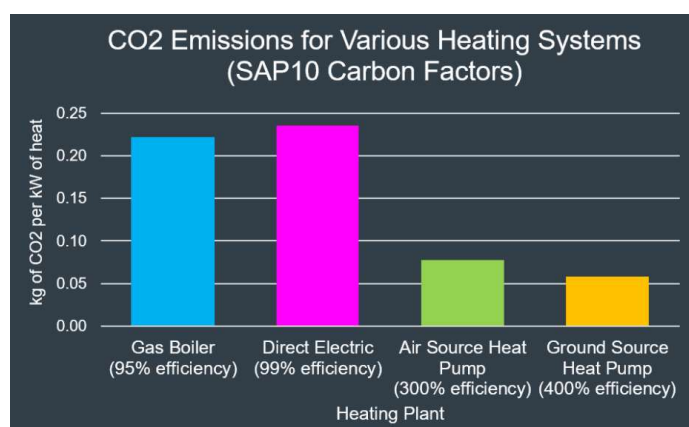


Figure 36. Comparison of CO₂e emissions for gas, electric and heat pump heating systems¹⁹

Although some technologies can allow heat pumps to provide temperatures of up to 90°C, the majority of cost-efficient heat pumps perform most efficiently at heating flow temperatures below 50°C. Therefore, the first way to ensure the best carbon performance of the heating system is to lower the heating system circulation temperature. In most cases, this will mean changing the heat emitters and AHU heater batteries in the building for bigger ones or significantly reducing the heat losses of the building.

8.11.1.2 Ground source heat pumps

Ground source heat pumps utilise the constant temperature below the ground and sometimes aquifers (underground bodies of water). Ground source heat pumps typically have relatively high efficiencies as the ground temperature (11-14°C at approximately 100m depth) is typically warmer in winter than air or water bodies.

Heat pumps can be either "closed loop" systems that circulate a heat exchange fluid either through ground coils buried beneath the ground surface or through vertical piles drilled deep into the ground, or "open loop" where heat is exchanged with water abstracted from a borehole before being returned to the ground via a second borehole.

¹⁹ Image by AECOM

The feasibility of ground source systems is dependent on location. Considerations include soil structure, contaminated land, available space for boreholes and ground loops and underground obstructions from utility and transport networks, environmental concerns (especially for open loop systems) and cost.

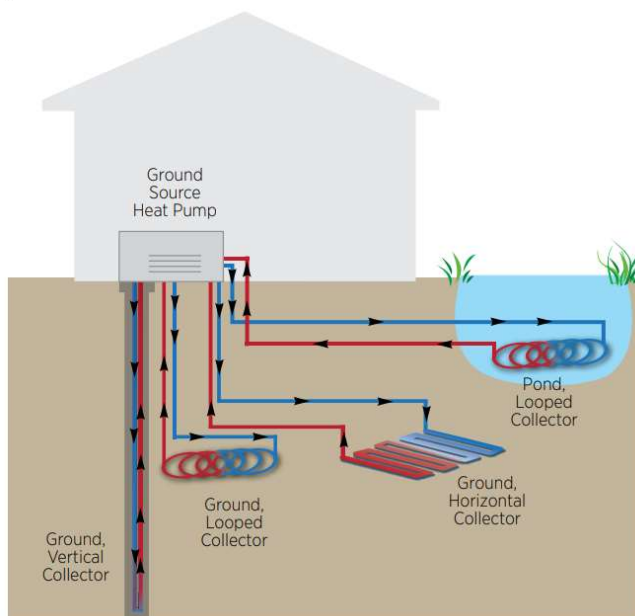


Figure 37. Schematic of different collector configurations for closed-loop ground source heat pumps²⁰



Figure 38. Installation of ground coils²¹

Further guidance on ground source heat pumps can be found in the following:

- The CIBSE CP3: Open-loop groundwater source heat pumps: Code of Practice for the UK. 2019

²⁰ Source https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/hvac_guide.pdf

²¹ Source <https://www.insulationsuperstore.co.uk/help-and-advice/product-guides/plumbing-heating/everything-you-need-to-know-about-ground-source-heat-pumps/>

- Environmental good practice guide for ground source heating and cooling. Environment Agency. GEHO0311BTPA-E-E

8.11.1.3 Air source heat pumps

Air source heat pumps can provide a cost-effective option for high efficiency heat from electrical energy, with a relatively easy installation. However, due to the range of external air temperatures throughout the year, the system is not as efficient as a ground or water source. The system is also limited by external space and acoustic constraints which can lead to increased construction costs and logistics.

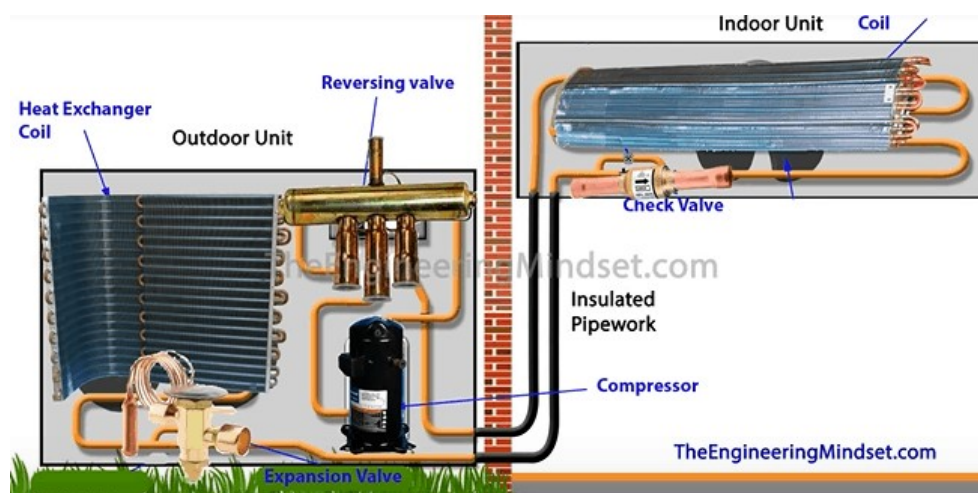


Figure 39. Basic schematic of an air source heat pump where the heat is delivered indoors as warm air



Figure 40. An air source heat pump is very much like a VRF unit²²

8.11.1.4 Water source heat pumps

A water source system will be more efficient than an air source, but usually less than a ground source, depending on the body of water used. For smaller water sources (i.e. ponds) it is essential to not draw or dump too much heat into the water body, so much that it significantly affects the temperature of the whole body of water.

²² Image source: <https://www.ukalternativeenergy.co.uk/projects/air-source-heat-pumps-solar-pv-cranwell-lincoln/>

Obviously, the main constraint is having a water source nearby, hence their use is very location specific. Suitable water bodies can include docks, lakes, rivers, canals, the sea or sewers. Environmental aspects can also be of concern, particularly if the water source has living organisms. Abstraction and discharge licensing may be required with NRW and ongoing monitoring of the water source to ensure temperatures of the water are not significantly altered by the heat pump system. Detailed design consideration for water inlet and extract infrastructure is also required.



Figure 41. Outdoor heat exchanger coil installations for water source heat pumps²³

A water source heat pump can utilise the heat from the hospital's wastewater, see also 6.3, page 37.

Further guidance on water source heat pumps can be found in The CIBSE CP2: Surface water source heat pumps: Code of Practice. May 2016.

8.11.1.5 Hybrid systems (Heat pump with condensing gas boiler)

The efficiencies mentioned in section 8.11.1.1 refer to the optimal operating temperatures of the heat pump. Currently, most commercially available air source heat pumps operate at the most efficient when they deliver hot water at 40°C, which is much lower than the 70°C that the current heating systems usually operate at in cold weather.

The lower delivery temperatures would require changing the heat emitters on site, but when that is not possible, hybrid or bivalent systems can be considered. These can be configured in different ways.

In one possible configuration, the heat pump delivers water in higher temperatures, albeit with lower efficiency, closer to a COP of 1.5 in mild weather ($>4^{\circ}\text{C}$). To maintain the level of heating and optimise efficiency in colder weather, a condensing boiler is installed together with the heat pump. The two can work together, controlled by a system that aims for the maximum efficiency on any given outside temperature. In very low temperatures, for example sub-zero, the heat pump efficiency drops so much that the control system favours the sole use of the gas boiler.

Another configuration can have the heat pump and boiler working simultaneously, with the heat pump heating the return water from e.g., 45°C to 55°C and the boiler heating the water further to 65°C. For this configuration to operate efficiently, it is important to make sure that the return temperature drops low enough (to 45°C in this example) so that the heat pump can deliver a considerable portion of total delivered heat. If in this example the return temperature is closer to 55°C, then the heat pump does not come on and all the heat is delivered by the gas boiler.

²³ Image sources: <https://energy-tec.co.uk/case-studies/14-water-source-heat-pump-for-commercial-rhi> and <https://www.thebigraise.fr/2018/01/23/towards-permaculture-energy-strategy/hpim0552-jpg/>

In a conservative estimation, hybrid systems can operate with an overall efficiency in the range of 1.2-1.5. This is much better than the 0.9 efficiency of a gas boiler, but, as electricity is more expensive than gas, the overall system will be more costly to operate.

A detailed study for each site will determine the best solution (sizes of heat pumps, boilers and their configuration and control), the expected COP of the system and the expected carbon reduction.

8.11.1.6 Ambient loop system

Several heat pumps can be integrated in a heating system in different setups. The ambient loop setup is a system where low-grade heat (water in relatively low temperature, typically 10°C - 30°C but can be lower) is circulated across the whole building, or even in a network of several buildings. Within each different area of the building, a water-to-water heat pump draws heat from the ambient loop and upgrades this (through a process of compression of refrigerant acting as the working fluid, using the same principal as refrigeration) to a usable temperature for heating and/or domestic hot water.

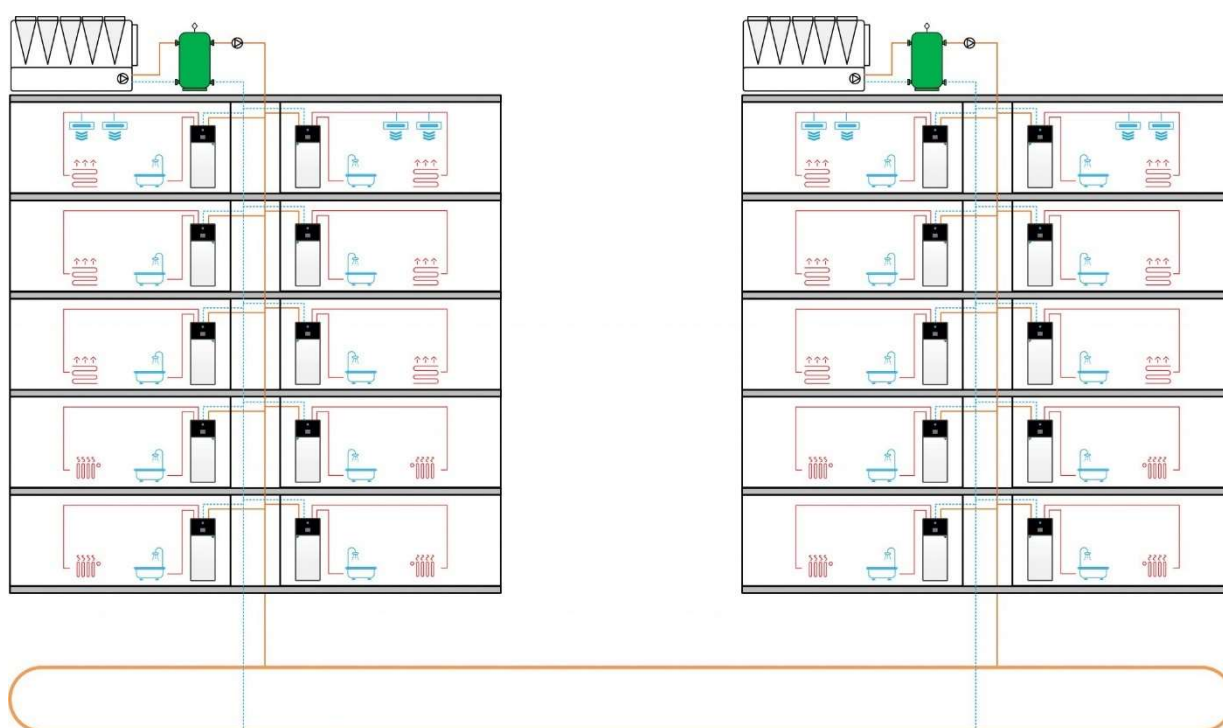


Figure 42. Schematic of an ambient loop system²⁴

Benefits of the ambient loop system include:

- i. With such low temperatures of the circulating water, the distribution losses are very low.
- ii. The same loop can accommodate heat pumps operating in cooling mode. The heat ejected by them in the ambient loop can then be used by another heat pump for heating or hot water. This is a form of excellent heat recovery and can contribute to increased efficiency.
- iii. The main loop can be fed from different kinds of heat pumps, or even directly from borehole water, depending on what is more suitable to the site. It can also be part of a district heating network, (see 8.11.5).

²⁴ Image source: <https://cpd.building.co.uk/courses/cpd-1-2020-ambient-loop-carbon-zero/>

8.11.1.7 High temperature heat pumps for hot water and sterilisation

As mentioned above, most of the available air source heat pumps currently deliver water in relatively low temperatures. Nevertheless, as heat pumps are in the spotlight of decarbonisation, their technology is evolving rapidly. As a result, there are heat pumps available today, which, using carbon dioxide (CO₂) as a refrigerant, can deliver hot water at temperatures between 55°C and 90°C with a COP of 3.88. As they require a significant temperature differential between input and output, they are best used in applications where the incoming water temperature is low. Therefore, they are not best suited for space heating, but they offer a very attractive solution for domestic hot water generation.

Even though not widespread, there are heat pumps that could possibly generate steam to fulfil the sterilisation needs of hospitals. These are typically a series of heat pumps in a cascade setup.

8.11.2 Solar thermal hot water (STHW)

STHW is a form of energy and a technology for harnessing solar energy to generate thermal energy.

The two main types of solar thermal collectors that are more suitable for use in hospitals are flat plate collectors and evacuated tube collectors.

Flat panel collectors

A flat plate panel looks similar to a panel in a photovoltaic system. Its design includes an absorber panel attached to multiple copper pipes through which the water or transfer fluid passes. These copper pipes are encased in a metal frame that is surrounded by insulation to support the retainment of the collected heat. A sheet of glass or glazing protects this frame, which, at the same time, provides a space of air that works as insulation.



Figure 43. Flat plate collector²⁵

Evacuated tube collectors

In comparison to flat plate panels, evacuated tube collectors are more efficient, especially in cold climates. On the downside, they lose efficiency in warmer seasons due to the risk of overheating. This is due to the vacuum tubes that are designed to avoid heat loss and therefore differ to flat plate panels that tend to lose some heat.

An evacuated tube collector is usually made of a heat pipe surrounded by a glass tube. These are under a vacuum. Having something under vacuum is a better insulator than having an air space. In addition, the heat pipe is depressurised, which allows the fluid to boil rapidly.

²⁵ Image source: <https://sciencebanquet.blogspot.com/2019/03/flat-plate-solar-energy-collector.html> and <https://wiki.bath.ac.uk/display/ebwmaristow/Solar+Collector>

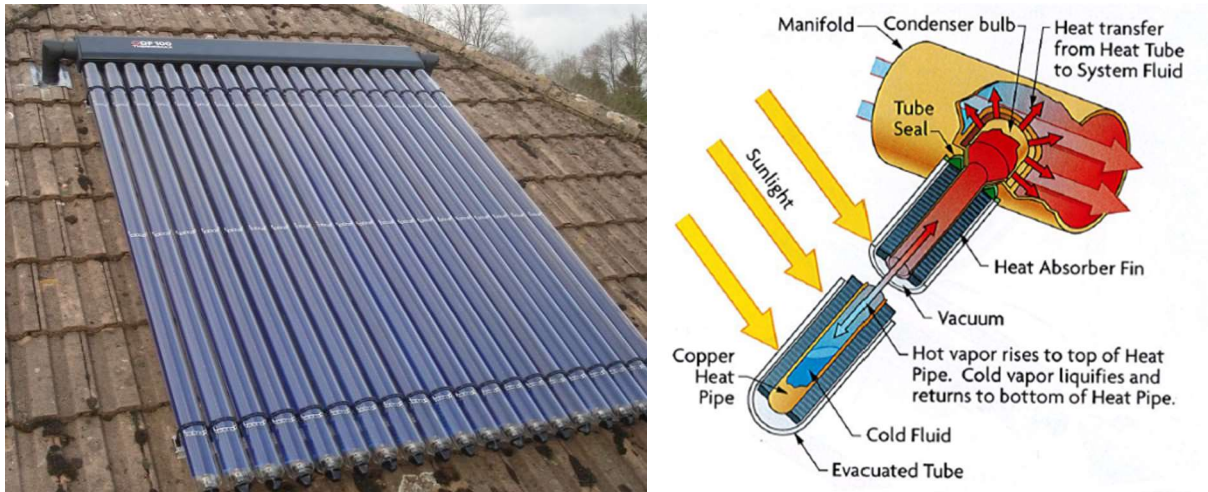


Figure 44. Evacuated tube collector²⁶

As the output of solar thermal is intermittent and weather dependant, it is better used for meeting the hot water needs, rather than heating, as it is more likely that hot water systems will already have some water storage capability. Solar thermal can provide heat to the stored water and, if this heat is not sufficient or available, another source of heat (electric immersion, heat pump or gas boiler) can top it up.

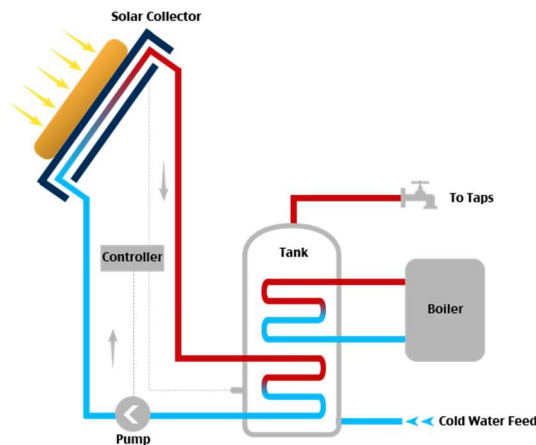


Figure 45. Simplified schematic of solar thermal integrated with another heat source²⁷

Solar thermal is strongly recommended for large hospital buildings as usually there is the space available for their installation and for hot water storage. It is impossible for them to satisfy fully the hot water load, but their contribution in a hybrid system can be important, with a low payback period.

8.11.3 Hydrogen

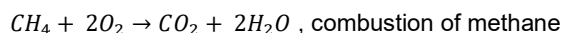
Hydrogen is considered a potential alternative to natural gas for decarbonisation because it can be combusted in a similar way to hydrocarbons currently used for heating. This means that there would be little need for changing the heating infrastructure of a building, apart from replacing the boilers, or boiler burners, to ones compatible with burning hydrogen, or a mix of natural gas and hydrogen. It is assumed that the current gas network will have the capability and capacity to deliver hydrogen or hydrogen-natural gas mix. Although the early value of hydrogen

²⁶ Images sources : <https://sussexsolar.com/solar-thermal/> and <https://hydrosolar.ca/blogs/news/how-do-vacuum-tubes-collector-work>

²⁷ Image source : <https://www.eeweb.com/solar-thermal-energy/>

seems to be to address the intermittency of large renewables and use hydrogen for transport / industrial process, pilot projects are imminent for delivering a hydrogen blend through the existing gas network. Other projects are investigating the viability of pure hydrogen networks in certain locations.

The combustion of hydrogen does not produce any carbon dioxide (or other greenhouse gases), only water vapour, as opposed to methane combustion (methane is the main constituent of natural gas).



Regarding the heat released, combustion of one mole of hydrogen releases 286kJ whereas one mole of methane releases 890kJ (these are HHV - Higher heating values). In terms of the calorific value per mass (kilograms) and volume (cubic meters), Table 22 gives a comparison of the two fuels.

Table 22: Comparison of calorific values of hydrogen and methane in terms of mass and volume

	Density (@0°C, 1 bar)	Gross Calorific value	Gross Calorific value
	kg/m ³	kWh/kg	kWh/m ³
Hydrogen (H₂)	0.090	39.5	3.555
Methane (CH₄)	0.716	15.4	11.0264

Having a much lower calorific value, higher volumes of hydrogen will be needed in order to provide the same amount of heat as methane and therefore the grid and relevant equipment will need to operate at higher pressures.

Giving out no direct greenhouse gas gases, hydrogen use would count as Scope 2 emissions, and the related emissions would depend on the greenhouse gas emissions during the production of hydrogen.

There are several ways to produce hydrogen, and a “colour coding” of hydrogen is currently used to show how it was produced.

There are two main ways to produce hydrogen:

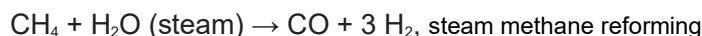
1. From fossil fuels, using heat (steam reforming).
2. From water, using electricity (electrolysis).

These are described in the following paragraphs.

8.11.3.1 Hydrogen from fossil fuels

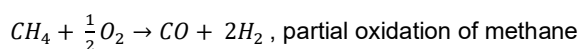
Grey hydrogen

Before gaining popularity for its potential as a fuel, hydrogen has been crucial in the manufacturing of several products in the chemical industry, notably ammonia (NH₃) that is used in fertilisers. The most common method of producing hydrogen currently is from methane, through **steam methane reforming (SMR)** or **autothermal reforming (ATR)**.



The mixture of hydrogen and carbon monoxide produced is a type of syngas (synthetic gas) and can be used as fuel, as both molecules can be combusted.

Partial oxidation of methane is another way of producing syngas, although much less used.



As a second stage in hydrogen generation, the carbon monoxide in syngas reacts with water to produce more hydrogen, but also carbon dioxide:

$CO + H_2O \rightarrow CO_2 + H_2$, hydrogen and carbon dioxide production from syngas (water shift gas reaction)

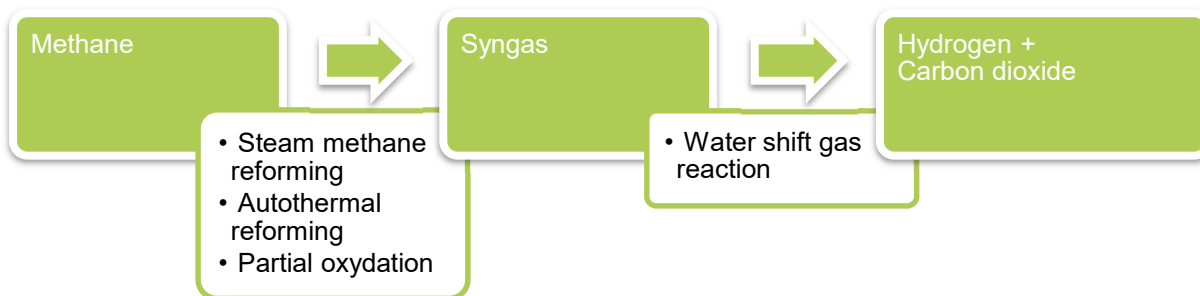


Figure 46. Grey hydrogen production process

Both processes described above require high volumes of heat, as well as methane as feedstock.

Therefore, the current way of producing hydrogen uses a potent greenhouse gas (methane) and emits carbon. Emissions factors for different hydrogen production methods are presented in Table 24 below.

Blue hydrogen

Blue hydrogen refers to hydrogen produced from a feedstock of natural gas by steam methane reforming or autothermal reforming (ATR), as described above, but coupled with carbon capture, and storage (CCS) of the resulting carbon dioxide emissions. It is therefore “filtered” grey hydrogen. Blue hydrogen has lower emissions but as steam or high temperature is needed for most of the above-mentioned processes, it is unclear how energy efficient it is, which means that maybe the original source of heat would be better if used directly, instead of using the produced hydrogen for space heating.

‘CCS’ is preferred to the more general ‘CCUS’ (i.e. carbon capture, utilisation, and storage), in reading this report, the term CCS is intended to also referring to forms of CO₂ utilisation that can ensure permanent sequestration.

For details in further methods of hydrogen production based on fossil fuels (“brown”, “black” and turquoise hydrogen) please see appendix 8.6.

8.11.3.2 Hydrogen from electrolysis

Electrolysis is the process of “splitting” water into oxygen and hydrogen using electricity. This process usually requires some heat and an electrolyte to facilitate the reaction.

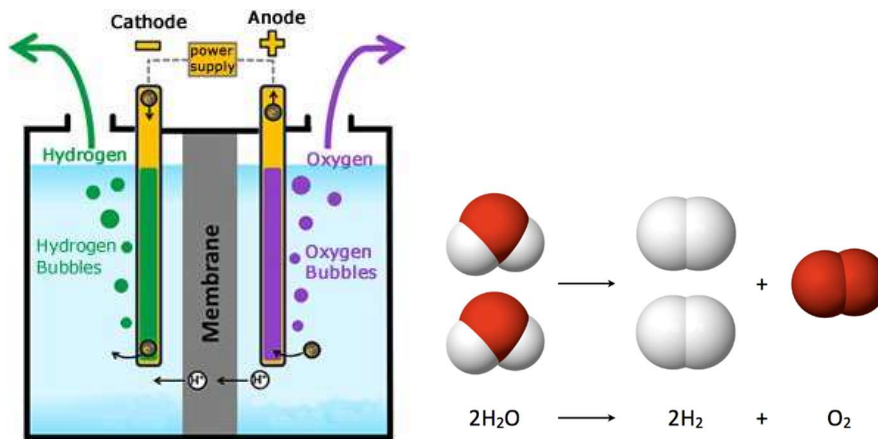


Figure 47. Schematic of water electrolysis²⁸

Green hydrogen

Green hydrogen refers to hydrogen produced through water electrolysis using renewable electricity.

For more types of hydrogen, please see appendix 8.6.

Table 23: Carbon intensity of different hydrogen production methods²⁹

Production method	Definition	Carbon Intensity estimates ¹⁸	Levelised Costs ¹⁹	Role to 2030 / 2050	Next steps
Steam methane reformation without carbon capture	Natural gas with methane reformation, mostly for use in petro-chemical sector	83.6 gCO ₂ e/MJ H ₂ (LHV)	SMR (300MW) 2020: £64/MWh 2050: £130/MWh	Small amounts of existing supply have helped prove end use case in tests / trials.	Decarbonise existing use in industry
Steam methane reformation (SMR) or autothermal reformation (ATR) with carbon capture	Natural gas with methane reformation, but with CO ₂ emissions captured and stored or reused	ATR with CCS: 16.0 gCO ₂ e/MJ H ₂ (LHV) SMR with CCS: 21.4 gCO ₂ e/MJ H ₂ (LHV)	ATR (300MW): 2020: £62/MWh 2050: £65/MWh SMR (300MW): 2020: £59/MWh 2050: £67/MWh	Large scale projects expected from mid-2020s, bulk supply to kick start UK hydrogen economy	Carbon capture and storage infrastructure needs to be in place
Grid electrolysis	Using electricity from the grid to electrolyse water, splitting it into hydrogen and oxygen.	78.4 gCO ₂ e/MJ H ₂ (note this is a blended figure using grid averages to calculate)	PEM (10MW): 2020: £197/MWh 2050: £155/MWh	To be determined based on further policy development	Further engagement and analysis required, e.g. via the consultation on the UK Low Carbon Hydrogen Standard
Renewable electrolysis	Using clean electricity to electrolyse water, splitting it into hydrogen and oxygen	0.1 gCO ₂ e/MJ H ₂ (LHV)	PEM (10MW) (with dedicated offshore wind): 2025: £112/MWh 2050: £71/MWh	Small projects expected to be ready to build in early 2020s	Scale up technology, reduce costs over time

²⁸ Images source: <https://www.pemteco.com/pfsaionmembrane/pem-water-electrolysis.html> and https://en.wikipedia.org/wiki/Electrolysis_of_water#/media/File:Electrolysis_of_Water.png

²⁹ UK Hydrogen Strategy, August 2021

Production method	Definition	Carbon Intensity estimates ¹⁸	Levelised Costs ¹⁹	Role to 2030 / 2050	Next steps
Low temperature nuclear electrolysis	Low temperature electrolysis from existing nuclear facilities	Not modelled but expected low GHG emissions.	Not modelled by BEIS	Can apply existing technologies to current plants in the 2020s.	Further developments expected in 2020s.
High temperature nuclear electrolysis	High temperature nuclear power to electrolyse water	High temperature electrolysis: 4.8 gCO ₂ e/MJ H ₂ (LHV)	Not modelled by BEIS	Could develop hydrogen from advanced nuclear for 2030s	Further innovation and developments expected in 2020s.
Bioenergy with carbon capture and storage (BECCS)	Biomass gasification with carbon capture and storage	-168.7 gCO ₂ e/MJ H ₂ (LHV)	BECCS (473MW) 2030: £95/MWh (excl. carbon) £41/MWh (incl. carbon) 2050: £89/MWh (excl. carbon) -£28/MWh (incl. carbon)	Could begin production in 2030s	Further innovation and developments expected in 2020s. Developing position further in forthcoming Biomass Strategy
Thermochemical water splitting	Direct splitting of water using very high temperature heat from advanced modular nuclear facilities	Not modelled but expected low GHG emissions.	Not modelled by BEIS	Could develop hydrogen from advanced nuclear for mid-late 2030s	Further innovation work to develop to commercial technology
Methane Pyrolysis	Heat splits natural gas into hydrogen and solid carbon	Not modelled, but expected low GHG emissions	Not modelled by BEIS	Nascent technology still to be proven at scale	R&D / Innovation

Table 24: Energy efficiency of different hydrogen production technologies³⁰

technology	energy efficiency in transformation (%)	energy efficiency with CCS (%)
coal gasification	60	43
steam methane reforming	75	60
biomass gasification	35–50	
thermochemical water splitting	20–45	
water electrolysis	50–70	
methane pyrolysis	58	58

8.11.3.3 Advantages, disadvantages, and potential role in healthcare buildings

The current information on hydrogen and the possible ways of hydrogen production result in a list of advantages and disadvantages, presented in Table 25. From these we can conclude that the role of hydrogen in heat decarbonisation of hospitals is limited.

³⁰ Methane Pyrolysis for Zero-Emission Hydrogen Production: A Potential Bridge Technology from Fossil Fuels to a Renewable and Sustainable Hydrogen Economy,

Nuria Sánchez-Bastardo, Robert Schlögl, and Holger Ruland

Industrial & Engineering Chemistry Research 2021 60 (32), 11855-11881

DOI: 10.1021/acs.iecr.1c01679

As green hydrogen for heating is less efficient than directly using the electricity generated by renewables (see Figure 48 below), it appears that it is currently unlikely that it will become the main fuel for heating, based on these efficiencies.

In general, hydrogen's role will be more important in applications that are difficult to decarbonise otherwise, such as transport (especially trucks) and industrial heat, where high grade heat cannot be delivered by any other low-carbon technology.

Although it hasn't been ruled out by the UK government, it seems unlikely that hydrogen will be used in low grade heat applications such as space heating. A graph of suggested priorities for the uses of green hydrogen is presented in Figure 48 below.

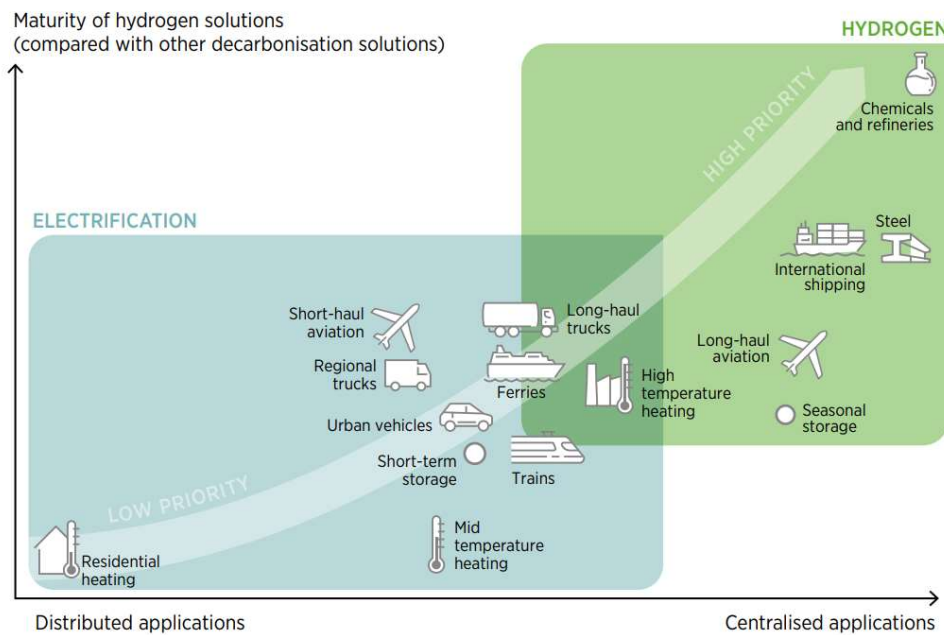


Figure 48. Green hydrogen policy priority³¹

Hydrogen can be used as energy storage of excess renewable generation that might be available to the hospital (this is in case the hospital has got space for photovoltaics or wind generation). This excess generation being intermittent and unpredictable, hydrogen as energy storage can only work as a back-up fuel in a hospital. Considering the 60% efficiency in transforming electrical energy to heating potential in hydrogen, batteries will be more efficient than hydrogen in storing that excess renewable electrical energy.

There is a potential role for hydrogen in Welsh hospitals when combined with hydrogen generation based on capturing methane and ammonia from local agricultural processes and wastewater treatment plants. These technologies are still under development and there are no examples of large-scale implementation at this moment.

³¹ Source: IRENA (2022), *Green hydrogen for industry: A guide to policy making*, International Renewable Energy Agency, Abu Dhabi.

Table 25: Advantages and disadvantages of hydrogen³²

Advantages	Disadvantages
Hydrogen provides us with flexibility to meet demand. It can be stored and used in electricity generation, helping to manage peak demand when fossil fuels are no longer available.	Characteristics of hydrogen, like its energy density and molecular structure, have implications for transportation and storage . Pipes may need to be upgraded and salt cavern storage modified to store hydrogen.
Hydrogen can replace natural gas in heat applications, with comparatively simple modifications to appliances (both domestic and industrial).	Currently there are no regulations nor market for hydrogen supply at scale, both of which are fundamental to the growth of hydrogen use.
The existing national gas pipe network could be repurposed for hydrogen.	Due to the process of producing, transporting and storing both hydrogen and CO ₂ , hydrogen is a less energy efficient way of heating, compared to natural gas.
Hydrogen can also be blended into the natural gas network (approximately 20% by volume) to reduce its carbon impact. This could be done on a regional basis as hydrogen production is gradually increased.	Given higher production costs for hydrogen in comparison to natural gas, the final product to the customer will be more expensive.
Electrolysis could produce green hydrogen using surplus renewable electricity at times of low demand. This avoids shutting off wind generation, which incurs costs to end-consumers.	The costs of producing hydrogen vary greatly, dependent on factors such as the wholesale cost of electricity and the cost of electrolyzers and methane reformers.
With careful placing of electrolyzers and associated hydrogen infrastructure, some electricity network constraints could be significantly reduced.	If the location of electrolyzers is not carefully considered, they could add to network constraint issues caused by the increase in renewable electricity.
Producing hydrogen from the UK's natural gas supplies and renewable electricity would reduce our dependency on energy imports.	There is uncertainty about worldwide plans for hydrogen. A global hydrogen market may develop, which could supplement demand but also leave us exposed to hydrogen price volatility.

8.11.3.4 Hydrogen hubs in Wales

There is a lot of activity related to the hydrogen energy sector around Wales, as shown in the results of the consultation of the Welsh Government, published in the “Hydrogen development in Wales” baselining report³³. These activities span from research projects to hydrogen production plant, refuelling and distribution hubs.

8.11.4 Liquid biofuels and biomass

Biomass is plant-based material used as fuel to produce heat or electricity. Since such feedstock material can be replenished readily, biofuel can be considered to as a source of renewable energy, unlike fossil fuels such as petroleum, coal, and natural gas.

Biomass can be considered a renewable form of energy and electricity generation as its growth (e.g., of plants or trees) removes greenhouse gases like carbon dioxide from the atmosphere and stores it in soil, trees and other vegetation. Nevertheless, the carbon balance for liquid biofuel production (e.g., ethanol/ biodiesel) is not always neutral due to high inputs of fertiliser.

Even though sometimes the terms biomass and biofuels are used interchangeably, a common approach is to use the term “biofuel” for liquid and gaseous fuels derived from biomass and the term “biomass” for solid fuels, such as

³² Future Energy Scenarios, July 2021, National Grid ESO

³³ <https://gov.wales/sites/default/files/consultations/2021-01/baselining-report-hydrogen-development-in-wales.pdf>

firewood, wood chips and wood pellets and processed municipal solid waste. Firewood, wood chips and wood pellets are also referred to very often as “woody biomass”.

The liquid biofuel in greatest production is ethanol (ethyl alcohol), which is made by fermenting starch (primarily from corn grain) or sugar and it is typically blended with gasoline to produce “gasohol,” a fuel that is 10 percent ethanol. Biofuels from crops grown on arable land are “first-generation” biofuels and they are not established in the UK, possibly because of the economic and environmental costs associated with the refining process and the potential removal of vast areas of arable land from food production.

Second generation biofuels are of greater interest for this report.

Second-generation biofuels are fuels made from lignocellulosic or woody biomass, or agricultural residues/waste. The feedstock used to make the fuels either grows on arable land but are by-products of the main crop, or they are grown on marginal land. Second-generation feedstocks include straw, bagasse, perennial grasses, waste vegetable oil and municipal solid waste.

Third generation biofuels are the ones made by processing algae and fourth generation biofuels are electrofuels and solar fuels. Electrofuels are fuels that are produced using electricity and their primary use is for storage of energy from renewable sources. Hydrogen can be included under this category and it is examined in detail in section 8.6. Other fuels in the fourth generation include photobiological process, where the hydrogen is produced using photosynthetic microorganisms (green microalgae and cyanobacteria) in photobioreactors. As these are still under development and not available for widespread use, the report will focus on the following biofuels:

8.11.4.1 Biomethane

Biomethane is a naturally occurring gas that is generated from anaerobic digestion (AD). AD is a biological process where microorganisms break down organic matter such as sewage, plant material and food waste in the absence of oxygen to produce biomethane. The unrefined product is usually referred to as biogas. It is not suitable for injection into gas networks but can be used for on-site electricity generation and heating. When biogas is refined to make it suitable for network injection, we refer to it as biomethane.

8.11.4.2 Bio substitute natural gas (BioSNG)

Bio substitute natural gas (BioSNG) is a gas that is derived from household waste. The process uses high temperatures to produce a synthetic natural gas which, after cleaning and refining, can be injected into a gas network. BioSNG is in the early stages of development. A commercial demonstration plant has been under development with funding from Ofgem’s Network Innovation Competition (NIC).

8.11.4.3 Woody biomass

Biomass boilers harvest the energy from materials of recent biological origins (mainly wood pellets or chips) through either combustion or, less commonly in small-scale applications, gasification. Biomass is only renewable if the materials harvested are replaced at the same rate they are removed. When considering the use of biomass, it is important to consider the source of fuel and ensure it is likely to be sustainable in the long term. Ideally, biomass would be sourced locally to limit emissions associated with transport and to support local economies.

Biomass has a much lower energy density than fossil fuels so a much larger quantity of fuel must be burnt to produce the same amount of energy. This will typically require significant space for fuel storage with sizing dependent on the frequency of delivery.

An increased focus on air-quality means that biomass is unlikely to be a favoured solution in areas where good air quality is important, due to high NO_x and particulate emissions. It may be a very effective low carbon solution in less urban areas and where local biomass supply chains exist.

It should also be noted that biomass boilers have limited capability of modulating their heat output and require some time to start-up and turn off. As a result, they are not suitable for variable loads and are more efficient when satisfying a constant baseload, or in combination with significant thermal storage.

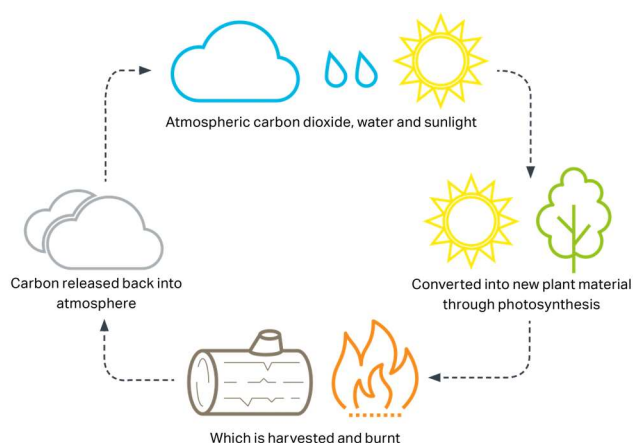


Figure 49. Biomass fuel carbon cycle

Considerations for installing a biomass boiler should include:

- On-site fuel storage space is required, also posing a significant fire risk.
- Access must be planned for regular fuel deliveries.
- An air-quality assessment may be required particularly in Air Quality Management Areas (AQMAs).
- Regular maintenance and ash removal is required.
- Correct sizing is key to efficiency, due to slow modulation capability.

The two most common types of biomass fuel are wood pellets and wood chips.



Figure 50. Biomass wood pellets and chips

Wood pellets

Biomass wood pellets are normally about 10mm x 30mm in size and are manufactured from waste wood products. These compacted offcuts (from saw milling, wood manufactured products and waste wood found after logging), are compressed down into pellets along with a binding agent, often flour or corn starch, to prevent the breakup of individual pellets.

They are a high-density, low moisture content biomass fuel, which enables them to be transported and stored efficiently and easily, with 1 tonne of the pellets only taking up 1.5 cubic meters of space.

Since they are of uniform shape and size, they can be automatically fed into the heating system through an attached hopper.

Wood chips

The major advantage of wood chips over the other fuels is that they require minimal processing. Debarked logs are fed into specialised wood chipping machines, a less complex procedure than the manufacturing of pellets, making them cheaper.

Due to their relatively high moisture content, they do not tend to be as efficient in terms of transportation and storage as wood pellets, with 1 tonne of wood chips taking up a space of more than 2 cubic meters.

8.11.4.4 Design considerations for biomass

Special design considerations should be considered when suggesting biomass as the main low carbon fuel of a hospital. Experience has shown the following:

- Sizing of the biomass boiler should focus on serving the baseload, rather than the maximum load.
- Fuel quality is variable, due to a variable moisture content.
- A special delivery and storage system is required, including hoppers and skip conveyors. These create room for failure, either in failure of equipment or of water ingress that deteriorates the fuel quality.

8.11.5 Low carbon District Heat Networks (DHN)

A District Heating Network (DHN) refers to a distribution system providing multiple individual buildings with heat generated from one or more centralised sources. The heat generation plant is generally housed in a building known as an energy centre. DHNs comprise a system of insulated pipes, known as heat mains, which distribute hot water from the energy centre to several different buildings to provide space heating and hot water. Each building has a heat interface unit (HIU) that supplies heat from the network to the local building distribution system instead of individual boilers. Controllers operate the system (very similar to those fitted and linked with gas boilers), and buildings can usually retain their internal distribution system (e.g., radiators) when the network provides high grade heat. Heat is metered and billed to consumers in much the same way that gas or electricity is. This is combined with a service charge to cover maintenance of the shared distribution system (electricity and gas bills also incorporate a charge for these services). Schemes can range in size from simply linking two buildings together to spanning entire cities.

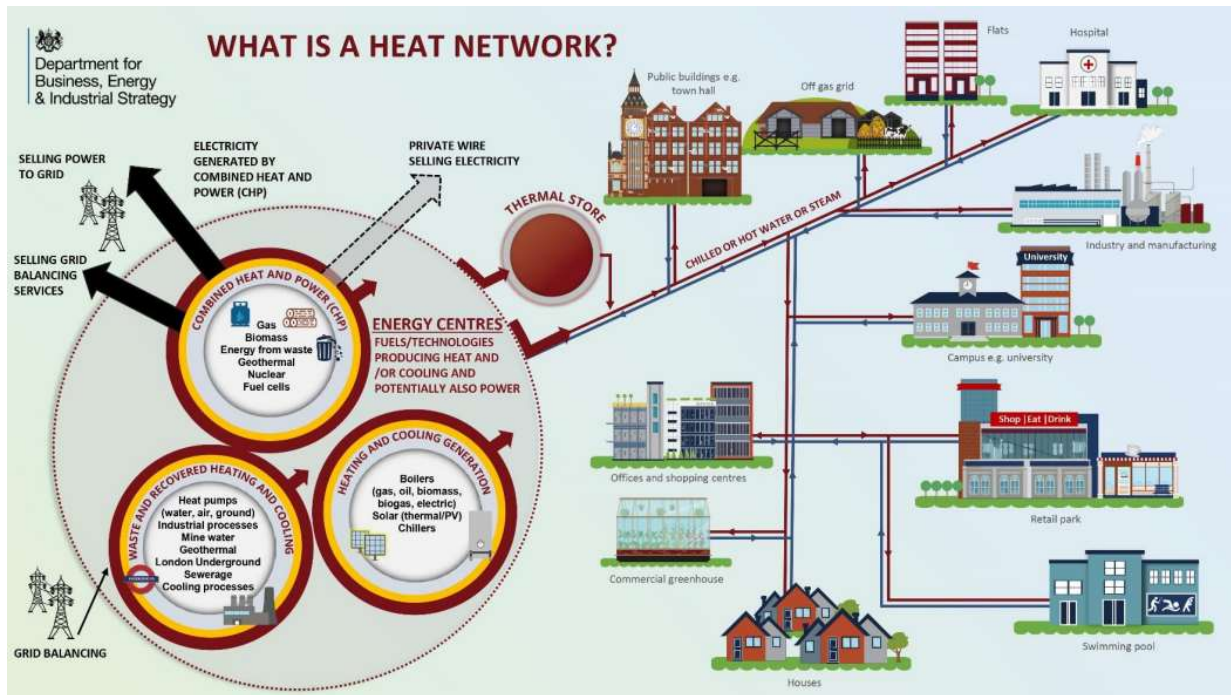


Figure 51. Diagram of a heat network

District heat offers an alternative to the typical decentralised arrangement, offering efficiencies of scale by generating and distributing heat to a number of buildings or utilising a source of heat that would otherwise be wasted. This would include access to otherwise wasted forms of heat, not viable at a building scale, including the use of waste heat from local power generation or energy from waste plants, local rivers, industrial sites, bodies of water or mines. Waste heat can be considered a low carbon option as it offsets the new end-users' needs for additional heating fuel. Deployment of low-carbon technologies at a network level can also utilise large thermal storage allowing for wider energy system balancing at a cost far lower than many chemical or alternative batteries.

Being part of a low carbon DHN would be suitable for hospitals that are either in an urban environment, close to an existing planned heat network or part of an industrial estate, where significant waste heat might be available. In the latter case, attention should be given to verify that the industrial processes providing the waste heat will be operating long-term. DHN are often designed around hospitals, as these have very large heating demands that can form the baseload of the network.

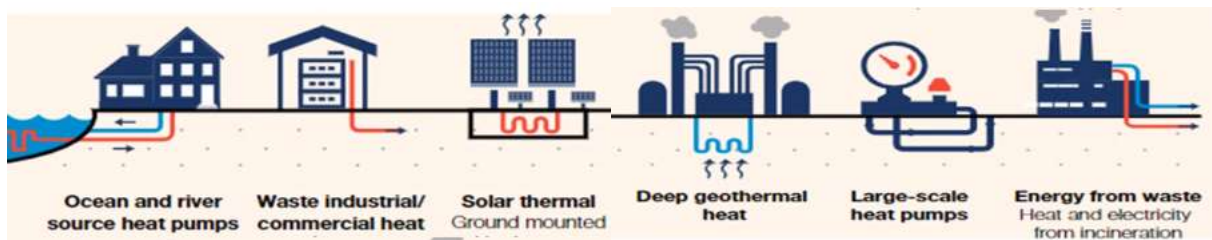


Figure 52. Heat networks can be both lower carbon and cheaper for consumers than a building level solution. They can take advantage of natural and waste heat sources that individual solutions cannot³⁴.

In Wales, ambitions and planned schemes include various areas, such as Bridgend, Cardiff, Newport, and Swansea. Currently, advanced plans are in place for Bridgend and Cardiff.

³⁴ Image source: Department for Business, Energy & Industrial Strategy

