Mitsubishi Electric Guide to Whole Life Carbon in the Built Environment

Information Guide 81

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Mitsubishi Electric Guide to Whole Life Carbon in the Built Environment

This is an independent guide produced by Mitsubishi Electric to enhance the knowledge of its customers and provide a view of the key issues facing our industry today.

This guide accompanies a series of seminars, all of which are CPD certified.

Contents

Introduction - Whole Life Carbon in the Built Environment

Whole Life Carbon (WLC) is increasingly referenced in the built environment today due to growing concerns about the environmental impact of buildings and the UK's 2050 target for net zero greenhouse gas emissions.

The term 'whole life carbon' in the built environment generally describes the carbon emissions associated with a building throughout its entire life cycle. This includes embodied carbon which covers the emissions associated with the materials and construction of the building, as well as the operational carbon resulting from the energy used during its occupation and use. Whole life carbon is also closely linked to the concept of the circular economy, which considers the potential for buildings to be refurbished and reused rather than demolished and replaced. This approach can help to reduce the impact of embodied carbon by extending a building's lifetime use.

One of the driving forces behind the growing interest in the whole life carbon impact of buildings is client demand, who are focusing more on carbon measurement and abatement across their organisations. As a result, public and private sector building owners and tenants are committing to organisational environmental goals, which extend to the buildings they occupy and operate. However, despite the growing interest in measuring and addressing whole life carbon emissions from the built environment, there is currently limited UK legislation and guidance on whole life carbon calculations. And while we have become familiar with the concept of operational carbon and energy efficiency, embodied carbon and its impacts on specification and design are less clear.

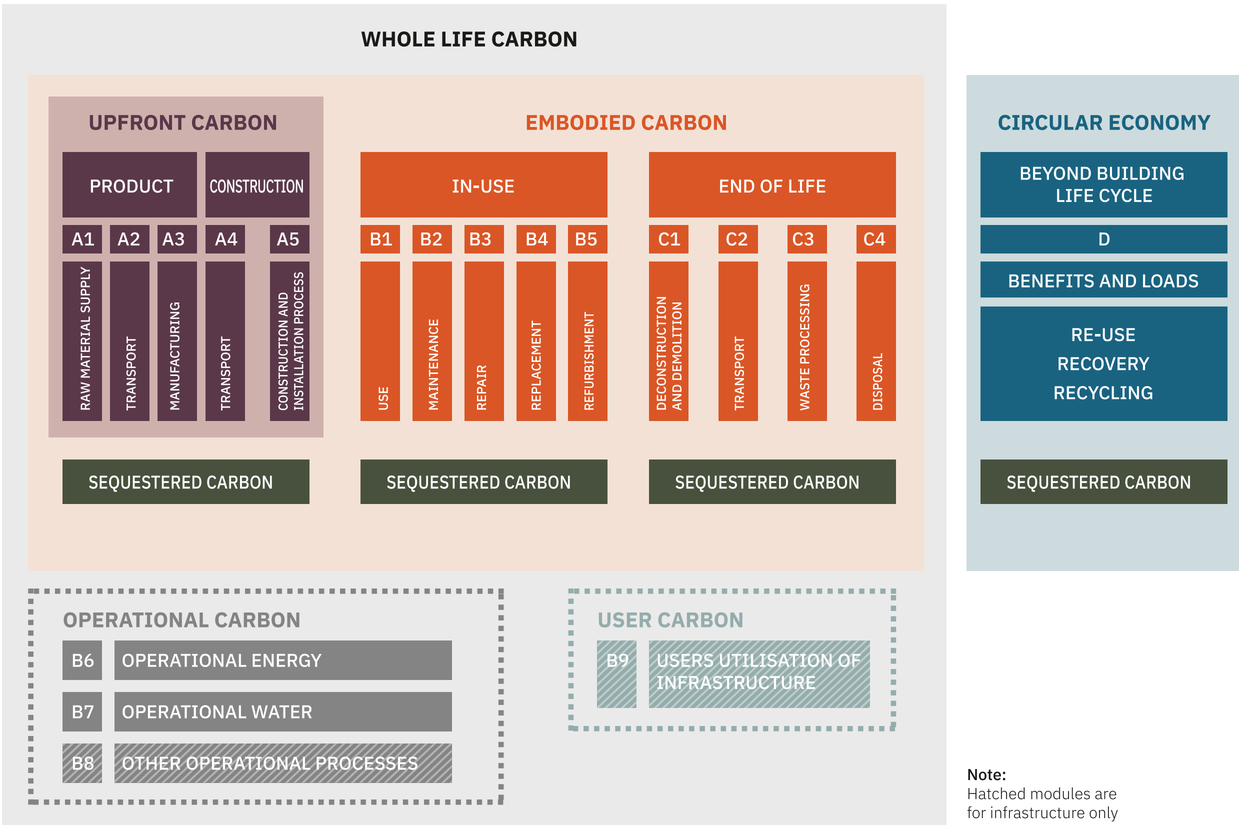
As a result, construction professionals, including engineers face the challenge of meeting client expectations at a time when there is often limited data available to them to make precise calculations. This Guide examines the impact of WLC considerations on specification decisions, looking at some of the critical areas designers and installers should take into account and questions they should ask when making decisions around building services.

Carbon emissions - some definitions

One of the challenges of addressing whole life carbon in the built environment is establishing definitions. As already noted, there is currently little legislation in this area, so terms such as 'net zero building' or 'carbon neutral' may be used differently across the industry, leading to confusion. A useful source of definitions has been drawn up by the **Whole Life Carbon Network** (WLCN) and **LETI** (Low Energy Transformation Initiative)[1]

The definitions described here were introduced by LETI and CIBSE (April 2022)[2] and are a 'work in progress', but the intention is that they will eventually be included in the RICS Professional Statement update, which is widely regarded as an important basis for future whole life carbon standards in the UK.

The first stage of defining carbon across the whole life of a building is to break down that lifecycle into identified stages. The diagram below is based on BS EN 15978 (*Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method*).



Source: WLCN-LETI adaptation from BS EN 15978

Carbon emissions - some definitions

Net Zero (Whole Life) Carbon Building

A Net Zero (whole life) carbon building is one where the total of all asset-related greenhouse gas emissions (embodied and operational) over its life cycle (A1 to C4) amounts to zero. This means that emissions are minimised, meet local carbon, energy and water targets and any residual emissions are offset. A building which is 'net zero whole life carbon' must achieve both net zero embodied and operational carbon.

Net Zero Embodied Carbon Building

A Net Zero embodied carbon building is one where its total greenhouse gas emissions are zero because they have been minimised, meet local carbon targets, and any residuals are offset. This applies across the building's lifecycle from A1 to C4.

Net Zero Upfront Carbon

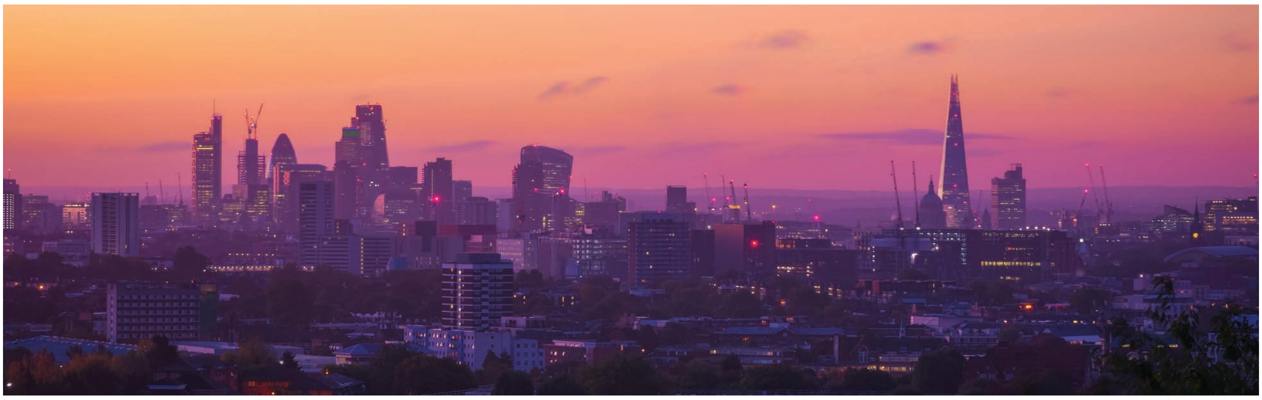
Net Zero upfront carbon means that the GHG emissions from a building in stages A1 to A5 are minimised, meet local carbon targets and equal zero when offsets are included.

Net Zero Carbon - Operational Energy

A building which is Net Zero carbon - operational energy is defined as one where no fossil fuels are used, and all energy consumption is minimised. The definition of 'no fossil fuels' is strict, in that even a building which is connected to a district energy scheme which uses fossil fuels would not be considered 'Net zero carbon - operational energy'. The building must also meet any local energy targets. All energy used must be generated on or off-site using renewables that demonstrate additionality.

This definition is important for designers making early-stage heating and cooling systems decisions. For example, using heat pumps instead of gas boilers becomes a better option for reducing on-site emissions. It also has implications for community or district energy schemes. For example, where the energy centre uses fossil fuels, this will impact the building's net zero carbon - operational energy. Here, heat pumps could also be considered as an alternative heat source.

Meeting local energy targets is also necessary since buildings cannot use more 'green' energy. They must also be energy efficient if they are truly net zero. The report by CIBSE and LETI notes: "Buildings cannot be considered in isolation; achieving Net Zero needs the whole system."



Whole life carbon and the existing stock challenge

When considering the issue of whole life carbon in the built environment, it is imperative to examine the existing building stock, which offers both opportunities and challenges.

At a RICS webinar[3] in June 2022, Institution senior vice president Tina Paillet noted: "Constructing new buildings is extremely carbon intensive. For everything that goes into a new building, more embodied carbon is being produced. If we are serious about achieving net zero while meeting the need for high-performing and affordable space, retrofit has a key role to play."

There are around 30 million buildings in the UK, and most of these will still be around in 2050. This means that reducing the WLC of the existing building stock is essential to achieving the UK's net zero greenhouse gas emissions target.

The table below is taken from the *RICS Professional Statement on Whole life carbon assessment for the built environment (2017)*[4]. The figures assume a 60-year lifecycle for each building, with embodied and operational emissions estimated at the design stage. Embodied carbon emissions account for a significant proportion of the total over a building's lifetime. From the point of view of new buildings, these figures illustrate the importance of taking embodied carbon into account when designing and constructing buildings, and specifying equipment.

		Spec office; Cat A fit out; central London	Warehouse shed with 15% office space, London	Residential block, basic internal fit-out, Oxford
Embodied Carbon Emissions	Carbon emissions to practical completion	35%	47%	51%
	Carbon emissions in use	32%	29%	18%
Operational Carbon Emissions	Operational emissions - regulated	18%	11%	24%
	Operational emissions - unregulated	15%	13%	7%

Figures from: Professional Statement on Whole life carbon assessment for the built environment (2017) and Sturgis Carbon Profiling

Whole life carbon and the existing stock challenge

But for existing stock, these figures spotlight the challenges ahead for building owners and managers. Because while the increased focus on reducing carbon emissions is welcome, it can have negative implications for older buildings, including reduced marketability and loss of commercial value. As a result, buildings with high carbon emissions may become “stranded assets” that are less attractive to investors and buyers. (For more information, see the Mitsubishi Electric Guide to Stranded Assets[5].)

The commercial property market is already responding to issues around building value and ESG (environmental, social and governance) considerations. For example, some lenders view this market as an opportunity and offer ‘green’ loans for refurbishing commercial buildings to higher sustainability standards[6].

In addition, the “demolish and rebuild” approach for older buildings is increasingly being discouraged. The principle has been put into action by some regional planning authorities. For example, the Greater London Authority (GLA) guidance on Whole Life-Cycle Carbon Assessments[7] states as its first principle: “Retaining existing built structures for reuse and retrofit, in part or as a whole, should be prioritised before considering substantial demolition as this is typically the lowest-carbon option.”

This trend is likely to continue as the UK focuses on reducing carbon emissions and improving the energy efficiency of existing buildings. The UK Green Building Council[8] predicts that there will be a wave of retrofitting in non-residential property, as owners seek to meet energy efficiency and carbon targets: “Much of the sector will have to undergo some form of retrofit by 2050.”

As the property and construction sectors undertake more refurbishments, the internal fit-out of a project contributes a significant proportion of embodied carbon. This means designers must consider the embodied carbon implications of their system specifications, while balancing these with energy savings achievable through system updates which will improve the operational carbon post-refurbishment.

As noted in the CIBSE Journal[9], the Greater London Authority (GLA) benchmarks for a typical office allocate 21% of the WLC to building services: “As an item that is replaced regularly during a building’s life, and that is directly linked to operational energy consumption and fugitive emissions (refrigerant leaks and irregular releases), building services can have a major impact on the WLC of a development.”

> **This raises another important point about the specification of building services with whole life carbon in mind. As the embodied carbon impact of a building reduces over time, the embodied carbon of building services equipment becomes a larger proportion of the building’s carbon footprint as a whole.**

Whole life carbon and building services systems - specifying for balance

A focus on whole life carbon means that specifiers face the challenge of balancing embodied and operational carbon when designing building services systems. For example, a component with low carbon operational emissions over its lifetime may have higher embodied carbon. On the other hand, low embodied carbon products may lead to higher operational emissions.

A further vital issue for designers is that while data on the energy performance (hence operational carbon emissions) of HVAC products is relatively easy to access, information on embodied carbon is harder to find. The Building Regulations do not require embodied carbon calculations for building services systems. As a result, there is currently no standard methodology. However, information is gradually becoming more available. Manufacturers can provide an Environmental Product Declaration (EPD) to convey information about the embodied carbon of their products in a standard format. EPDs must comply with BS EN 15804 and supply information on carbon emissions associated with the product's manufacturing process and its end-of-life and recovery.

Currently, many manufacturers are still developing EPDs for building services products, so they are not consistently available. To address this data gap, the Chartered Institution of Building Services Engineers (CIBSE) issued a technical memorandum in 2021 to help engineers make the calculations. **TM65: Embodied carbon in building services: A calculation methodology**[10] offers guidance on embodied carbon measurement and reporting for MEP (mechanical, electrical and plumbing) systems.

CIBSE advises that engineers should request EPDs as a first step to understanding embodied carbon in MEP equipment and describes the purpose of TM65 as a 'stop gap' as the building services industry grows its skills in the field of embodied carbon.

For new build projects, TM65 emphasises the importance of 'lean' MEP, where the building is designed and constructed to reduce requirements for services such as heating and cooling through the building fabric, thermal performance and shading.

Where MEP plant is used, CIBSE advises specifying equipment with low-GWP refrigerant (and low leakage rates), long lifetimes and with products that are easily accessible for inspection maintenance and replacement.

Whole life carbon and building services systems - specifying for balance

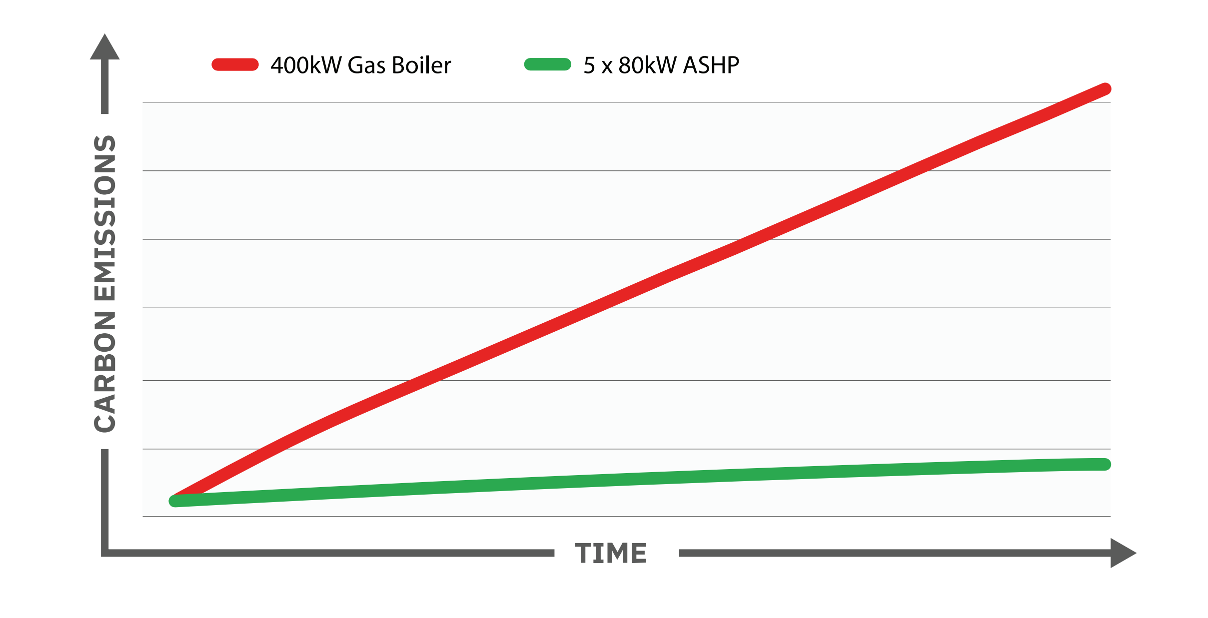
Building services systems can also be the subject of upgrades in projects that aim to reduce building operational carbon emissions. These can be cost-effective capital projects, and since HVAC systems are significant energy users, updating them can significantly reduce a building's operational carbon footprint, while also improving the indoor environment for occupants.

The graphs that follow show comparisons between a modular gas boiler and equivalent modular air source heat pump (ASHP).

A note on our graphs

These graphs are compiled using information on **embodied carbon and efficiency performance of Mitsubishi Electric systems.** The X and Y axes are generalised for Time and Carbon to illustrate the relationship between embodied carbon and operational carbon. Exact figures would depend on the actual performance of the system, which is unique to each building. This highlights another challenge around predicting the balance between embodied and operational carbon considerations.

Graph 1: Whole Life Carbon Comparison



General Assumptions:

- Annual heat delivered is calculated in accordance with EN14825 at 826,400 kWh/annum (FLEQ of 2066).
- Grid emission factor for gas is assumed at 210gCO_2/kWh.
- Grid emission factor for electricity assumed in accordance with UK Greenbook, decreasing over time. For comparison, a fixed factor of 233gCO_2/kWh was also calculated and provided as an alternative to indicated emissions if the UK electricity grid does not decarbonise as planned, but remains static with today's levels as per Part L of the Building Regulations 2021.

Assumptions: Gas boiler

- A modular gas boiler delivering 400kW of capacity with an efficiency of 90%.
- Gas boiler weight is approximately 500kg.
- Assumed embodied carbon taken from CIBSE TM65 average data sets as reported in CIBSE Journal, October 2021: 7kgCO_2e / kg for a gas boiler.
- Amounts to: 500kg x 7 = 3,500kg CO_2e embodied carbon for the gas boiler.

Assumptions: Modular air source heat pump

- ASHP delivering 395kW of heat capacity (in this example, 5 x MEHP-iS-Go7 112) at SCOP of 3.43.
- Delivering 55ºC flow temperature calculated in accordance with EN14825.
- Using TM65 mid-level calculation of ASHP units carried at 13,915kgCO_2e.
- Resulting in a total of 69,575kgCO_2e embodied carbon for 5 units.

These assumptions give us a whole life carbon saving when comparing a 400kW capacity air source heat pump against a gas boiler. This represents around 2,700 tonnes of CO_2 over 15 years. The embodied carbon difference on day one of installation of 66,075kgCO_2e is paid back through operational carbon savings within the first year of operation.

Whole life carbon and building services systems - specifying for balance

So, specification decisions may be more complex than selecting a gas boiler or heat pump. In one example, a group of engineers undertook a study (reported in the CIBSE Journal[9]) to quantify the whole life carbon (WLC) of three options for typical office heating and cooling systems: air source heat pump (ASHP) four-pipe fan coil unit (FCU), variable refrigerant flow (VRF), and hybrid variable refrigerant flow (HVRF). They used CIBSE's TM65 to carry out the calculations.

The study is based on an eight-storey office block providing about 12,500m^2 of commercial office space. The operational energy performance of each system has been estimated using IES-VE ApacheHVAC software, and the VRF system was found to be the most efficient at 21.5kWh.m^2.

When converted to carbon emissions, the VRF system was also the best performer, with emissions of 44kg CO_2e.m^2, compared with 47kg CO_2e.m^2 for the HVRF system and 58kg CO_2e.m^2 for the ASHP system.

The study also looked at the impact of refrigerant leakage, which significantly impacted the embodied carbon of the VRF system, making it the worst performer. The study concludes that strategies to reduce the impact of refrigerant leakage, such as using lower global warming potential refrigerants, should be considered to improve the WLC of VRF systems.

Practical questions about WLC and system choice

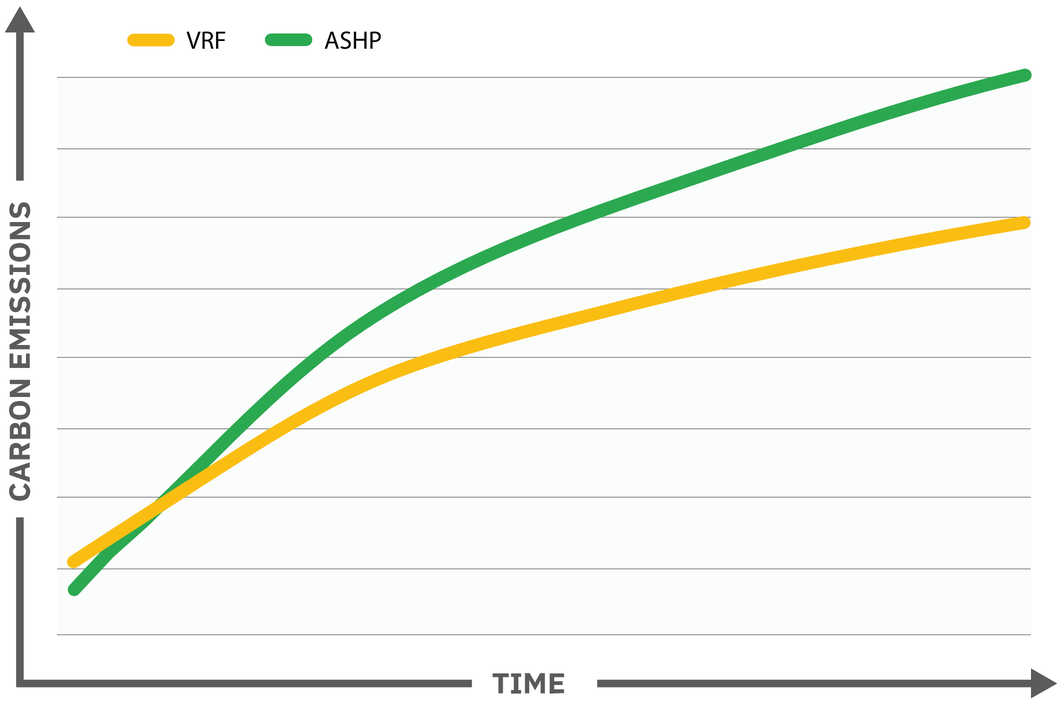
The previous examples highlight that when designers are considering a choice of building services equipment in light of issues around embodied and operational carbon, they are faced with several questions. For instance, at what point does the equipment's operational efficiency outweigh higher embodied carbon? Or, how long does a high efficiency product with high embodied carbon have to operate before its WLC balances against a lower-efficiency product with lower embodied carbon?

For example, a VRF system has the benefit of high efficiency compared to other systems such as heat pump chillers or Hybrid VRF (HVRF). However, the larger refrigerant volumes and refrigerant Global Warming Potential (GWP) along with assumed leakage rates, mean that VRF has a higher embodied carbon.

Graph 2 on the next page shows an example using Mitsubishi Electric equipment of 5 x 25kW VRF systems against a single 129kW air source heat pump (ASHP) in heating-only mode.

Practical questions about WLC and system choice

Graph 2: 5 x City Multi PURY-M200 VRF Heat Recovery Outdoor Units + Additional Refrigerant vs an EAHV-M1500 Heating Only Air Source Heat Pump



Assumptions:

- 5 x City Multi PURY-M200 R32 VRF heat recovery outdoor units operating in heating only mode, delivering annual heat of 266,514 kWh.
- 1 x EAHV-M1500 R32 Modular ASHP unit operating in heating only mode delivering the same annual heat demand.
- Efficiencies calculated in accordance with EN14825 to be VRF = 4.4 and ASHP = 2.88.
- ASHP operating at 55ºC flow temperature.
- VRF system excludes indoor units.
- ASHP also excludes heat emitters.
- VRF system, including additional site-added refrigerant charge of 11.9kg of R32 with an annual leakage rate of 6% to match TM65 assumptions.
- Embodied carbon of both units calculated in accordance with CIBSE TM65
  - VRF: 5,612kgCO_2e (x5 for five units)
  - ASHP: 28,831kgCO_2e (1 unit)
- Grid emissions factor for electricity assumed in accordance with UK Greenbook cleaning grid over time.
- Embodied carbon difference of 11,698kgCO_2e on day one of installation (Note: this includes additional site refrigerant for VRF).
- This is paid back within three years due to the higher operational efficiency of the VRF system.

The graphs highlight the complexities required to make specification decisions around whole life carbon. For example, a designer may ask if the figures would look different if they include necessities such as fan coils, pumps and pipework in the calculations. Perhaps the overriding consideration is which option would be the best for the client and the project.

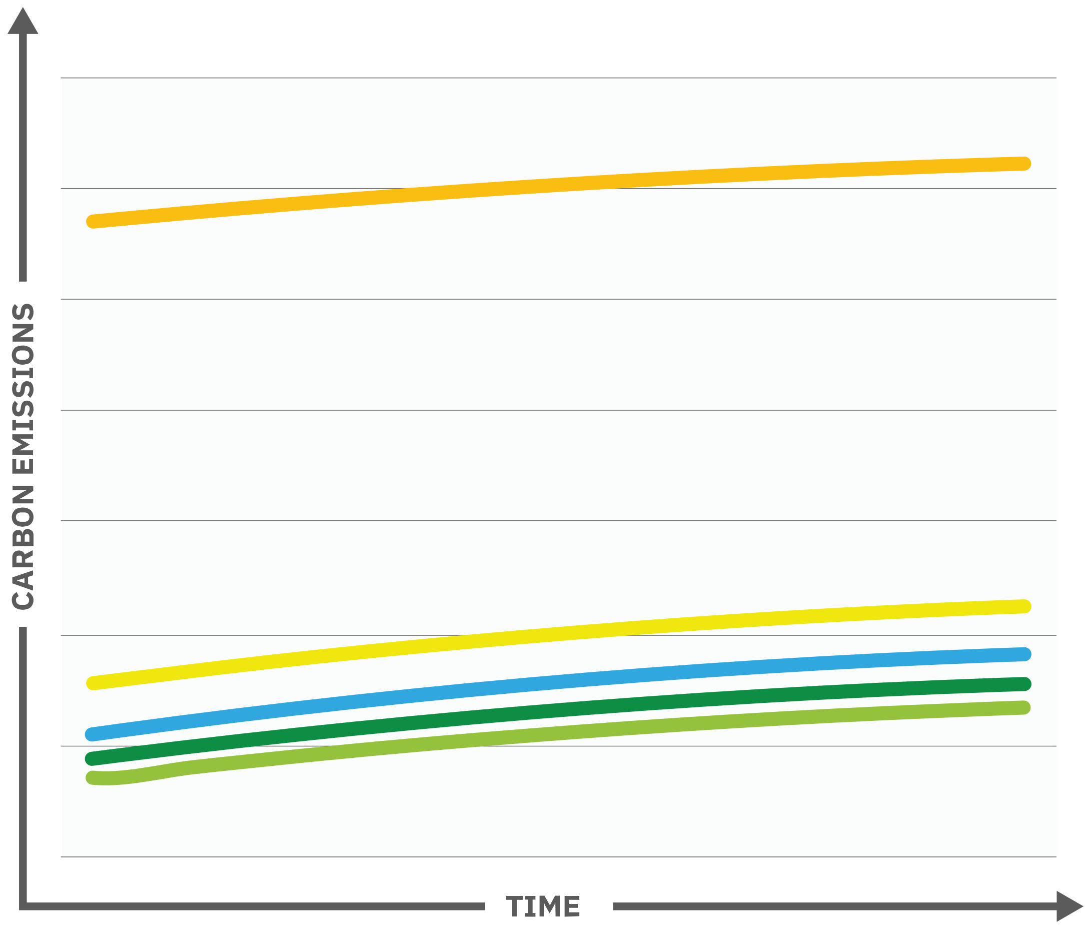
In a more extended example, we can consider a building which requires 500kW of cooling and approximately 350kW of heating, using assumptions from EN 14825 on the delivery and efficiency of heating and cooling. Applying TM65 mid-level assumptions, we can consider four equipment options for the building:

SYSTEM TYPE	REFRIGERANT & GWP	NUMBER OF UNITS	kW PER UNIT	DETAILS
R410A VRF (PURY-P500)	R410A GWP 2088	10 No	50 kW	Variable Refrigerant Flow (VRF) heat recovery system
R32 Hybrid VRF (PURY-EM500)	R32 GWP 675	10 No	50 kW	Hybrid Variable Refrigerant Flow (HVRF) heat recovery system
Centralised ASHP (i-FX-N)	R513a GWP 631	1 No	500 kW	Air Source Heat Pump with inverter driven compressor delivering 55ºC flow water temperature
Modular ASHP (MEHP-iS-G07 0102)	R32 GWP 675	6 No	85 kW	Modular ASHP with inverter driven compressors delivering 55ºC flow water temperature
Modular ASHP (EAHV-M1800)	R32 GWP675	3 No	180 kW	Modular ASHP with inverter driven compressors delivering 55º flow water temperature

If we compare these systems based on embodied and operational carbon, the results highlight some interesting points. Firstly, that cooling has less impact over a twenty-year lifecycle. This assumes a lower annual kWh of cooling delivered, based on calculations from the methodology from EN 14825:2022 (Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling, commercial and process cooling. Testing and rating at part load conditions and calculation of seasonal performance methodology). This means that if the embodied carbon at the point of installation is much higher, it is unlikely to be paid back over the lifespan of the system as shown in Graph 3 on the next page.

Practical questions about WLC and system choice

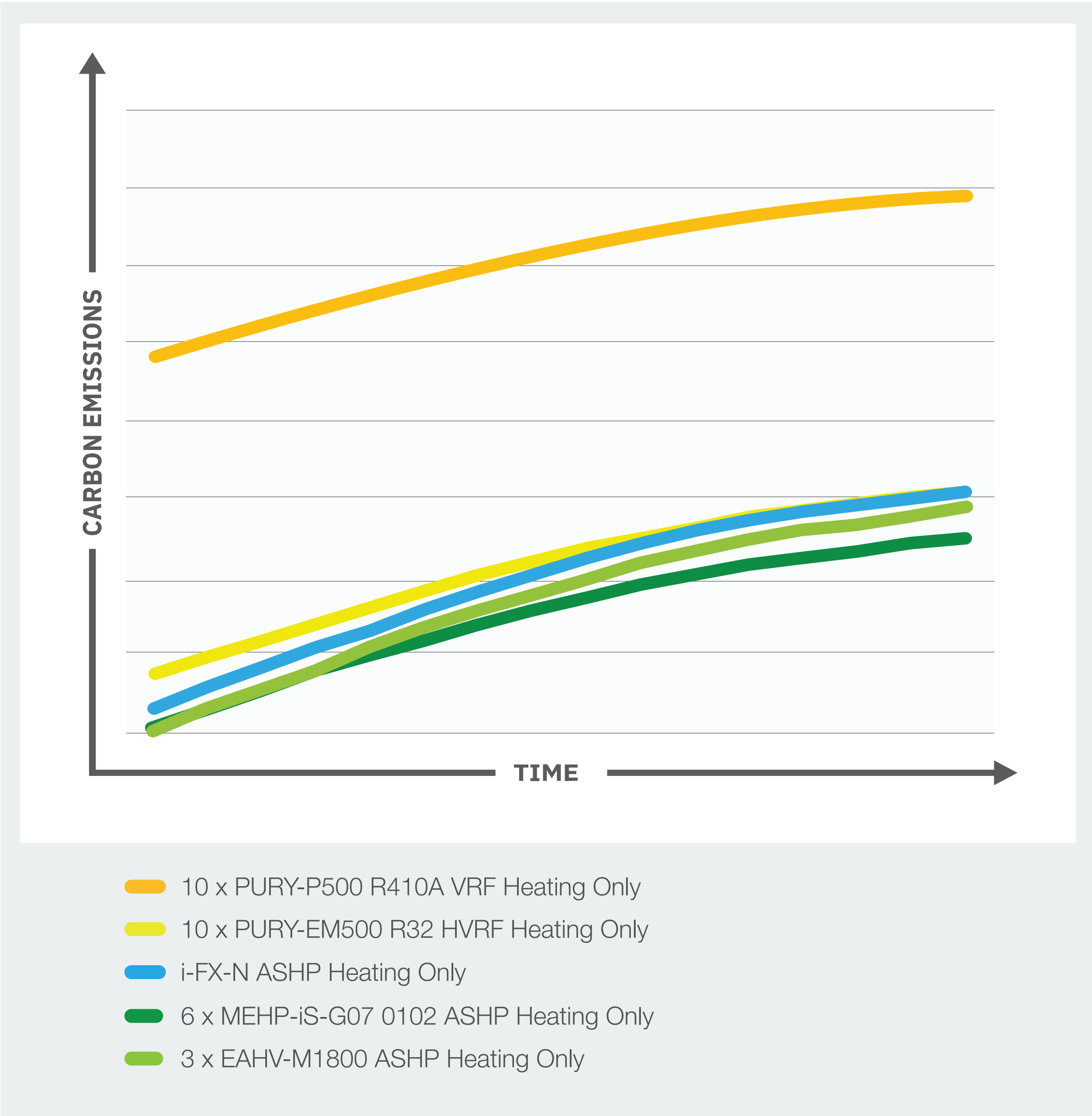
Graph 3: Cooling Only Whole Life Carbon Comparison



- 10 x PURY-P500 R410A VRF Cooling Only
- 10 x PURY-EM500 R32 HVRF Cooling Only
- i-FX-N ASHP Cooling Only
- 6 x MEHP-iS-G07 0102 ASHP Cooling Only
- 3 x EAHV-M1800 ASHP Cooling Only

In heating only operation, there is a greater impact on the whole life carbon of the system, with some solutions regaining their embodied carbon deficits over time, as illustrated by Graph 4 below.

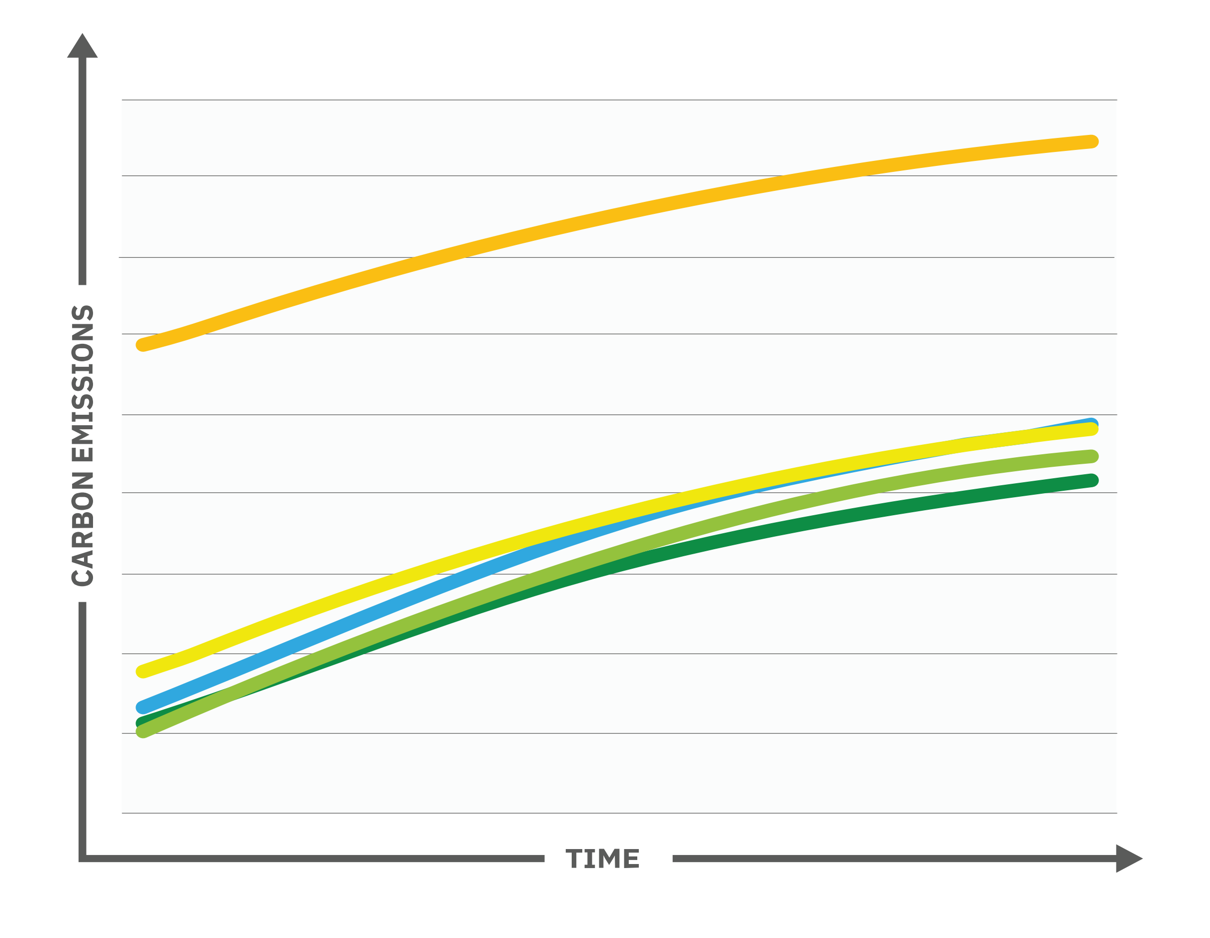
Graph 4: Heating Only Whole Life Carbon Comparison



Practical questions about WLC and system choice

And if we consider heating and cooling operation together, the system profiles change again as shown in Graph 5 below.

Graph 5: Combined Heating and Cooling Whole Life Carbon Comparison



- 10 x PURY-P500 R410A VRF Cooling & Heating
- 10 x PURY-EM500 R32 HVRF Cooling & Heating
- i-FX-N ASHP Cooling & Heating
- 6 x MEHP-iS-G07 0102 ASHP Cooling & Heating
- 3 x EAHV-M1800 ASHP Cooling & Heating

These examples highlight the type of analysis required as the construction sector moves to greater consideration of the whole life carbon of buildings. And the figures will be impacted by the UK's heat decarbonisation programme. As we transition to heat pumps, for example, and away from gas boilers, heating system efficiency will have a significant impact on whole life carbon. It is important to bear in mind that the ability of a highly energy efficient system to offset any extra embodied carbon must be a consideration for designers.

One way to frame this balance is to think less about 'low' or 'high' embodied and operational carbon, and to focus instead on system comparisons. For example, if the decision has been made to specify centralised plant for engineering reasons, then the comparison for whole life carbon calculations should be between large, single units or smaller, modular units. And if the decision is to use VRF, then the comparison should look at VRF or Hybrid VRF. Another crucial point to bear in mind is the impact of targets for building performance or rating systems that might be required by a client. For example, an Energy Performance Certificate (EPC) in its current format will focus on delivery of low energy usage intensity measured as kWh/m^2. Using the examples in our graphs, the best solution would be VRF.

However, if the target is focused on reduced embodied carbon and measured as $kgCO_2e/m^2$ then the most appropriate solution is likely to be a modular air source heat pump. On the other hand, if we consider trying to balance whole life carbon (i.e., a combination of embodied and operational carbon) the best choice could be Hybrid VRF which offers a high operational efficiency and relatively low embodied carbon.

We can see that considerations of whole life carbon require careful questioning and analysis of carbon impacts over time. Even though there is no legislation in place on accounting for embodied carbon in the built environment, it is a topic which is certainly set to have an impact soon.

Future focus on whole life carbon

A proposed Carbon Emissions (Buildings) Bill which was introduced in November 2022, and which reached a second reading in Parliament in December 2022.

The Bill, as introduced, will: **"Require the whole life carbon emissions of buildings to be reported; set limits on embodied carbon emissions in the construction of buildings".** However, while the government has also acknowledged that the Bill is necessary, it has delayed introduction to bring clarity around definitions and mechanisms.

Speaking in the House of Commons in December 2022, Dehenna Davison, Minister for Levelling Up, Housing and Communities noted: **"One of the biggest challenges to tackling embodied carbon right now is a lack of data because consideration of embodied carbon is relatively new compared to operational carbon for both industry and government".**

"Without enough information at both product and building level, industry cannot make informed decisions about design and construction. And the government cannot establish the right benchmarks or targets."

The Net Zero Carbon Standard[13] is another important development by a group of industry organisations, including CIBSE, RICS, RIBA, UKGBC, BRE and LETI. Its goal is to establish definitions around the terminology of net zero while establishing the metrics used to determine net zero carbon performance for buildings. This is essential work, as it will give clients and the construction industry a 'common language' around net zero buildings, which is currently lacking.

The proposed Standard will also include performance targets likely to include energy use, embodied carbon and lifecycle embodied carbon. The NZCBS group also wants to develop benchmarks for operational energy use and embodied carbon in today's buildings to set future targets for a decarbonisation strategy. Given that the government is keen to introduce legislation around the issue of embodied carbon, construction professionals must be aware of this important topic and start to consider how they will achieve the balance between operational and embodied carbon in building services.

Conclusion

If the UK is to reach its Net Zero 2050 target, then whole life carbon assessments of buildings must become standard practice. With the industry itself driving the way, there can be little doubt that designers, contractors and installers must become familiar with discussions around the embodied carbon of building services equipment - as we have become used to detailed consideration of energy efficiency.

And the UK is not alone in these requirements. The International Energy Agency (IEA) highlighted the importance of whole life carbon in the built environment worldwide. Its February 2022 report noted that a key milestone in transforming the global building sector is that all new and retrofitted buildings are 'zero-carbon-ready' by 2030.

Professionals involved in specifying building services systems will have to incorporate 'carbon thinking' into their calculations and balance the requirements of clients and buildings with embodied and operational carbon for each piece of equipment. This is a significant challenge, but there is now a wide range of low-carbon and energy efficient equipment for building services already on the market. The next step will be to grasp the opportunities presented as a growing number of clients seek to improve the whole life carbon performance of their buildings.

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Note: The fuse rating is for guidance only. Please refer to the relevant databook for detailed specification. It is the responsibility of a qualified electrician/electrical engineer to select the correct cable size and fuse rating based on current regulation and site specific conditions. Mitsubishi Electric's air conditioning equipment and heat pump systems contain a fluorinated greenhouse gas, R410A (GWP:2088), R32 (GWP:675), R407C (GWP:1774), R134a (GWP:1430), R513A (GWP:631), R454B (GWP:466), R1234ze (GWP:7) or R1234yf (GWP:4). *These GWP values are based on Regulation (EU) No 517/2014 from IPCC 4th edition. In case of Regulation (EU) No.626/2011 from IPCC 3rd edition, these are as follows. R410A (GWP:1975), R32 (GWP:550), R407C (GWP:1650) or R134a (GWP:1300).

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