THINKING OUTSIDE THE BOILER

How improved heat distribution systems could significantly reduce the cost of low carbon heating

October 2021

1.

Summary

A strategy to optimise control and efficient operation of UK residential heating systems could significantly reduce the amount of energy required for heating, and therefore the infrastructure cost of providing decarbonised heat.

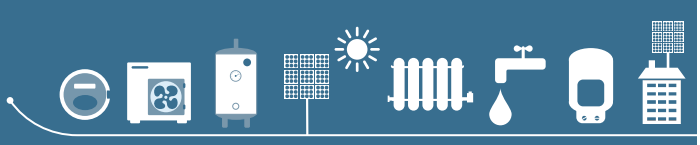
This paper shows that:

Measures to improve system efficiency have the potential to reduce current gas consumption for heating and hot water by **22%**

Allied to optimised fabric energy efficiency and a different approach for hot water the overall reduction in gas used for heating and hot water could be as much as **53%**

The same system measures would provide immediate benefits for the energy efficiency of existing homes.

A range of policy levers are also suggested in this paper that could be used alongside a roadmap for improved heating systems to achieve the potential benefits in practice.



2.

The relevance of heat distribution systems

The energy used by a heating appliance, such as a boiler, is largely dependent on the overall system that distributes heat to the building. In this context, the system comprises both the additional elements such as emitters and controls and the way it is designed and commissioned. While commissioning is required under the current Building Regulations it is known that practice is inconsistent and enforcement is weak.

A significant part of decarbonising heat in UK homes will be to change the 80% of homes that are currently heated by a natural gas boiler to an alternative low carbon form of heating, which is likely to be either a hydrogen boiler, an electric heat pump or connection to a district heat network. All these alternatives require the development or upgrading of infrastructure for production and distribution, and all will potentially be more expensive to consumers than using gas at its current unit price. This means that reducing the size of the heat demand from UK homes can offer a significant benefit by **reducing the infrastructure cost to Government** and **the end cost to consumers.**

There are two additional benefits from system improvements. Firstly, the improvements envisaged will immediately reduce carbon emissions from gas boiler systems in existing homes and help meet energy efficiency reduction targets. Secondly, these improvements can help make homes 'future ready' as they will deliver similar energy efficiency benefits with hydrogen boilers as they do with gas boilers and are largely consistent with the installation needs of heat pumps.

3.
Potential savings from systems

Figure 1 below shows the potential impact of applying a range of system improvement measures to all home heating and hot water systems on the overall energy required for gas heating and hot water:

The amount of natural gas used for heating and providing hot water to UK homes in 2019 was 25.7 million tonnes of oil equivalent (mtoe)[1]. The following actions have the potential to reduce this load by 22% overall, and are presented as a recommended hierarchy of actions against which to apply potential percentage savings.

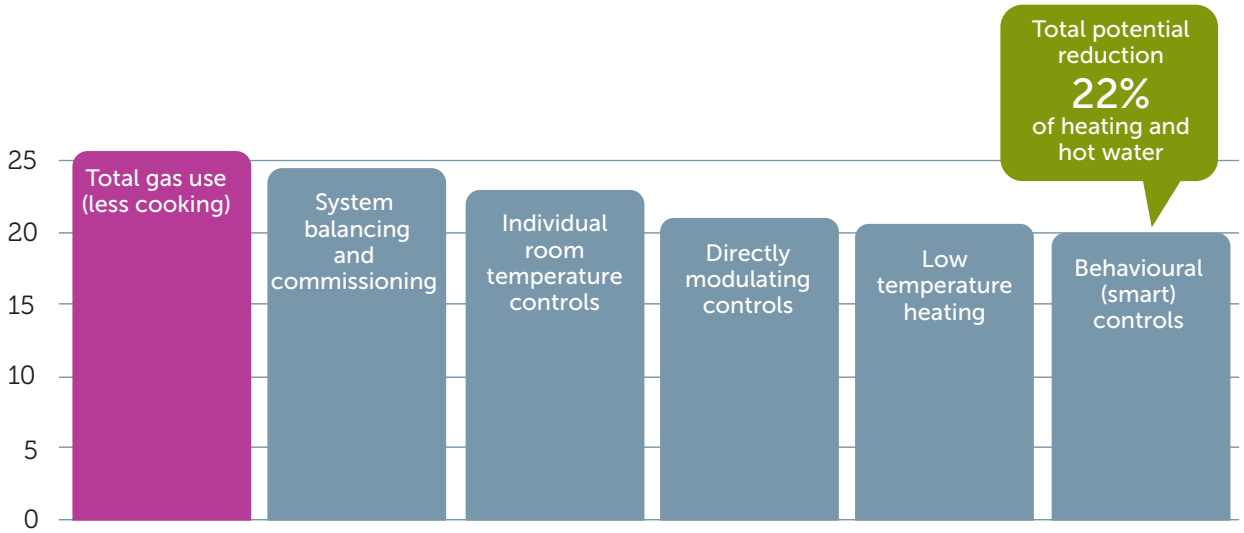


Figure 1: Potential UK residential gas use reductions through system improvements (mtoe)

3.1. System balancing and commissioning

Part L of the Building Regulations, which covers energy conservation, requires that fixed building services (such as central heating systems) are *"commissioned by testing and adjustment as necessary to ensure that they use no more fuel and power than is reasonable in the circumstances."* This should also include system balancing.

It is not necessarily the case that all aspects of effective commissioning are carried out as common practice by the majority of heating installers[2]. For example, the 2018 BEIS Boiler Plus consultation revealed that *"most installers do not have a common understanding of hydraulic balancing, with only 18% claiming to undertake it as a standard practice."* However, while recognising that this expected practice is not currently enforced, the subsequent Boiler Plus requirements that were introduced stopped short of taking measures to increase the level of enforcement of hydraulic balancing.

A detailed study carried out in 2015[3] calculated that optimising hydraulic systems in UK dwellings could reduce heat energy consumption by 1.1mtoe. This figure is used here.

As part of the test work described in section 3.3 it was identified that detailed set-up and

1 BEIS Energy Flow Chart 2019 https://www.gov.uk/government/statistics/energy-flow-chart-2019 corrected by removing 3.4% of the total to account for gas cooking using percentages of consumption in the UK Housing Energy Fact File 2013 (BEIS)

2 The 2021 BEIS Research Paper on Domestic Heat Distribution Systems also found evidence suggesting that hydraulic balancing is only found in 10% of European heating systems and can improve efficiency by 10%

3 C. Ahern, B. Norton, Energy savings across EU domestic building stock by optimizing hydraulic distribution in domestic space heating systems, Energy Buildings (2015), http://dx.doi.org/10.1016/j.enbuild.2015.01.014

commissioning work carried out on a boiler and heating system resulted in a significant improvement in the basic efficiency of the system. A difference from common commissioning practice was that boiler settings were based on the calculated heat loss of the building, something that it is not believed is the case with most boiler replacements currently carried out in the UK. The test regime did not allow for a quantitative assessment of these savings to be made, but they do identify that more work would be beneficial to identify the potential savings from this element of commissioning.

3.2. Individual room temperature controls

The role of TRVs (thermostatic radiator valves), and other forms of individual room temperature controls, is to reduce waste heat from rooms that can overheat where the only temperature control in a home is a single room thermostat. As such, it is a reasonable first step to take from a control perspective as it is simply reducing the amount of heat needed to keep homes at the desired temperature.

Tests carried out at the University of Salford[4] by BEAMA to a specification provided by BRE showed that the prevention of overheating by TRVs could reduce gas consumption by an average of 19% over the heating season. A study by the European Building Automation and Controls Association[5] estimated that a programme to replace manual radiator valves and older TRVs could lead to an overall reduction in UK energy consumption by 7%. These figures have been used alongside an assessment of the installed base of TRVs in the UKs to work out the overall savings potential from this measure

3.3. Directly modulating controls

Conventional room thermostats send a simple on/off signal to the boiler. They turn the boiler on when the temperature falls below the setpoint, and off again when it rises above setpoint. With load compensation the thermostat adjusts the output of the boiler in relation to the predicted heating needs. Weather compensation is similar but also includes outside temperature data in the calculation. Both result in closer control of temperature and more efficient boiler operation and this will be independent of any user interaction.

BEAMA have commissioned tests at the University of Salford on load and weather compensation. These show that such controls providing direct modulation of the boiler have an annual savings potential of up to 12% from the controls alone applied to an in-situ boiler when compared to a Class I thermostat. Industry figure have been used to estimate the current installed base of such controls and an estimate made of the total UK savings potential from upgrading the room thermostat in all other properties with gas central heating.

3.4. Converting systems to low temperature operation

As well as being a necessary element for future heat pump connections, it is well known that existing gas boiler systems will run more efficiently at low temperature operation. Most gas boilers are currently installed into high temperature systems so changing to low temperature emitters (e.g. larger radiators or underfloor heating) could be expected to make an overall saving of 2.4% consistent with the efficiency reduction for low temperature operation of a boiler in table 4c of SAP2012[6]. Recent research shows that around 10% of current wet heating systems in UK homes could operate at a low temperatures (55°C) without any changes to the existing system needing to be made.[7]

3.5. Smart (behavioural) controls

This category covers the commonly accepted definition of a smart control laid out in the BEIS Boiler Plus FAQs[8] as products that let consumers remotely control their home temperature via a

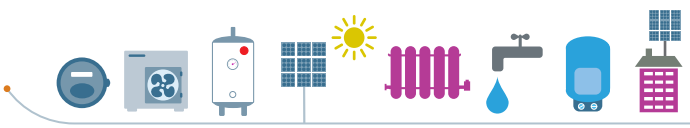
4 https://www.beama.org.uk/resourceLibrary/salford-university-tests-to-establish-the-energy-savings-from-trvs---2018-pdf.html

5 https://www.eubac.org/cms/upload/downloads/position_papers/White_Paper_on_Room_Temperature_Controls_-_eu.bac_July_2017_FINAL.pdf

6 https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf

7 Domestic Heat Distribution Systems Evidence Gathering – Final report - BEIS Research Paper Number: 2021/015 – February 2021

8 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/718569/Boiler_Plus_Factsheet_v3.pdf



tablet, smartphone or desktop, with a common understanding that a 'smart' product requires some form of wider connectivity.

Acknowledging the above, it is also clear that the widest uptake of smart controls currently is with devices that act to more closely match overall on/off operation of the heating system with occupancy, either by allowing users to adjust the operation when they are not home, or by sensing and responding to occupancy. Within this proposed hierarchy of system measures this would be the last step; limiting the operating time of a system already optimised for efficiency.

Field trials on smart thermostats[9] indicate overall potential savings in gas consumption of 6%. There are likely to be some element of savings within this for the improved control accuracy of a replacement thermostat, as well as optimum start functionality which currently gets a credit within SAP 2012. There is also some uncertainty over the impact with an optimised low temperature system running for longer periods. However, we believe it is reasonable to assume a saving potential of 5% across dwellings that don't currently have a smart thermostat[10] – particularly with a clearer definition of required functionality.

3.6. Smart (flexibility) controls

These are not included in the calculations as the focus is on gas, but it should be noted that there are potential benefits from smart controls for heat pumps, and other electric heating, that allow heating appliances to take advantage of variable time of use tariffs to reduce the cost and carbon intensity of the electricity used. There is some evidence that UK heat pump users scheduling their heat pumps to avoid peak hours have seen average prices of less than 8p/kWh compared to the average of 15p/kWh[11]. A long-term strategy for heat should include the role of such controls, both for the consumer benefits and the beneficial impact of grid flexibility.

3.7. Occupant behaviour and usage of controls

While not included in these calculations it is assumed that steps would be taken to ensure that householders use their heating controls as intended and therefore can realise in practice the savings demonstrated in test case. This could be achieved through better information as future versions of the Building Regulations aim to deliver, and this should include better enforcement of, and support for, the current legal requirement for installers to explain to occupants how to use their systems to reduce energy consumption. No additional energy savings due to occupant behaviour (e.g. actively setting a lower room temperature than current comfort levels) has been assumed.

3.8 Water treatment

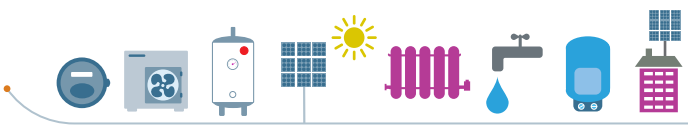
Water treatment for central heating maintains the long term performance and efficiency of a heating system. Water treatment products include chemical inhibitors, chemical system cleaners, biocides, anti-freeze and in-line filters/ separators. The application of water treatment products to the standard BS7593 is required under current Building Regulations when heating systems are installed or boilers replaced, but the performance of heat distribution systems can deteriorate over time. Without regular system maintenance problems can build up. A recent BEIS research paper[12] showed that build up of sludge can reduce the efficiency of a central heating systems by 15%, limescale on the inside of pipes can reduce a boiler's efficiency by 12%, and air in a system can reduce its performance by 6%. While the degree to which these problems are limiting the efficiency of existing systems in the UK is not quantified in this report, it is clear that the potential impacts could be significant. Government should therefore consider policy levers to drive regular maintenance of heat distribution systems and application of water treatment products to limit deterioration over time.

9 Study by the Behavioural Insights Team on the savings from smart thermostats, 2017: https://www.bi.team/publications/evaluating-the-nest-learning-thermostat/2

10 Estimated from industry data that 8% of existing housing with a gas boiler currently has a room thermostat with smart functionality

11 The pathway to Net Zero heating in the UK – A UKERC policy brief (2020)

12 Domestic Heat Distribution Systems Evidence Gathering – Final report – BEIS Research Paper Number: 2021/015 – February 2021



4.
The wider context for systems

As described in section 3, improving heating systems can have a significant impact by reducing the amount of energy required for residential heating. However, this approach should be part of a wider strategic focus.

As mentioned above, the total annual gas consumption for residential heating and hot water is about 25.7 mtoe and figure 2 below shows how this could be reduced by around 53% by implementing system improvements on top of a different approach for hot water and achieving the Committee on Climate Change's recommendations for fabric energy efficiency improvements.

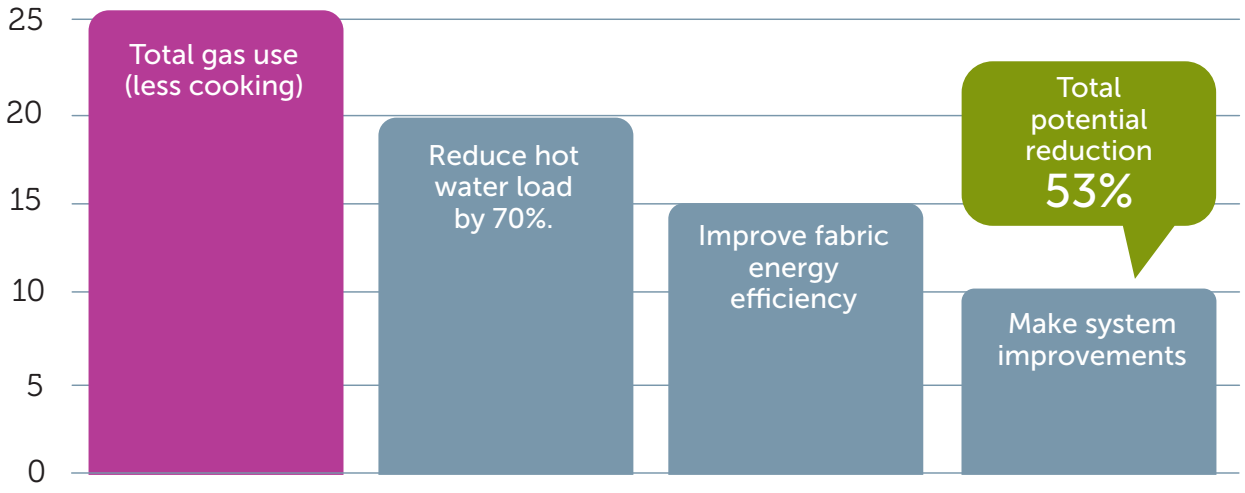


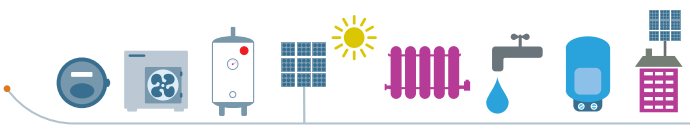
Figure 2: Potential UK residential gas use reductions through overall improvements (mtoe)

4.1. Hot water

Of the total gas used in homes by boilers, approximately 23% of that is to provide hot water[13]. The predominant trend currently is for combination boilers delivering instantaneous hot water, but there are other options that may be preferable for a low carbon future and a key component of this would be the re-incorporation of hot water storage in homes.

With a hot water cylinder, or alternative form of storage, a home can utilise renewable energy to provide hot water (either on-building or local) alongside an immersion heater connected to time of use tariffs to heat water tank when low cost, zero carbon electricity is available. Correctly controlled, this could then minimise the contribution of main heat generator in the home (either hydrogen boiler or heat pump) and reduce the hot water component of the current heating load.

[13] UK Housing Energy Fact File 2013 (BEIS)



Field trials have shown that solar water heating systems can provide 60% of a household's hot water needs[14]. With advances in technology, particularly in photovoltaics, it is likely that this can increase. The degree to which energy storage and flexible tariffs can offset water heating load required from the heat generator is yet to be determined but it is known that BEIS are funding a trial working towards the gradual electrification of water heating through a combination of home solar PV, and flexible tariffs[15]. Reductions in tank and pipe losses could also play a small part. In this document we have assumed that a 70% reduction in the current gas usage for domestic hot water is possible.

The major difficulty with this approach would be the need to incorporate hot water cylinders in homes when many of these have been removed. It is estimated that 70-80% of homes no longer have a cylinder[16] and occupants could be resistant to loss of space. However, there are many challenges to decarbonise homes and this could be one of the more practical to resolve. In addition, provision of hot water storage would make homes heat pump ready and could provide a clear cost benefit to householders when hot water becomes increasingly significant in well insulated homes and where the future cost of zero-carbon energy sources is uncertain. While there is an implication on the electricity network, this could in theory remove a large part of the current heat generator load and should be analysed.

4.2. Fabric energy efficiency measures

The Committee on Climate Change's Further Ambition scenario show the potential for a 25% reduction in energy demand as a result of fabric efficiency measures[17]. Given that fabric measures are about insulating and improving the airtightness of buildings their impact is to directly reduce the heat load of homes and are therefore included in this analysis.

14 Here comes the sun: a field trial of solar water heating systems - The Energy Saving Trust (2011)

15 https://octopus.energy/blog/powervault/

16 Based on installed base and rate of change recorded in the UK Housing Energy Fact File 2013 (BEIS)

17 Net Zero –Technical report, Committee on Climate Change (2019)

5.
Potential policy levers

The aim should be for all system upgrades to be done by 2040. This would ensure that efficient and future ready systems are available for the final stages of heat decarbonisation as well as maximising the carbon saving benefits of these measures within the existing housing stock.

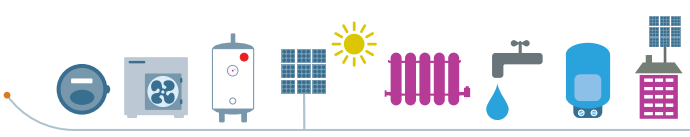
The following policy levers have potential to help deliver these measures:

5.1. Building Regulations Part L

Heating systems are one of the significant areas that can be influenced by Building Regulations as there are about 1.6 million boiler replacements each year where the regulations will apply. Increasing the regulatory requirements at the time of boiler replacements too far could have obvious negative effects. The majority of boiler replacements, approximately 70%[18], could be described as a 'distressed purchase' where the boiler has failed or is not working properly so adding costs to a necessary purchase will be a burden to consumers and could potentially delay the replacement of inefficient appliances. However, there are reasonable improvements that could be made immediately within the regulations for existing homes due to come into force in 2022:

- Ensure that the proposed introduction of the requirements to add 'self-regulating devices' (i.e. individual room temperature controls) when replacing a boiler is implemented. This is extremely cost effective for consumers with a payback of less than 2 years and an average return on investment of 9:1[19].
- One of the common reasons why adding TRVs to an existing system may not prove to be practical is a lack of compatibility with older radiator fittings, or simply the condition of those radiators. It should at least be covered as good practice to renew such radiators, both to facilitate the fitting of a TRV and also to remove a radiator that is likely to have poor performance (compared to newer emitters) and/or sludge build up.
- The 'Boiler Plus' requirements with options for better controls in England, including load and weather compensation, could be applied to all boilers, rather than just combination boilers in existing homes. In addition, the smart controls option could be adjusted so that these devices must include load or weather compensation – at present a consumer could continue to receive a standard on/off 'smart' thermostat.
- Commissioning of a boiler is already a legal requirement in the Building Regulations but this needs to be laid out as a set of specific requirements and properly enforced to ensure that a boiler is correctly set-up for the building it is installed in and the system balanced. Greater emphasis should be placed on customers receiving and keeping a commissioning certificate.
- Boiler replacements could be recommended as 'like for like' to discourage further removal of hot water cylinders for instantaneous hot water through a combination boiler.
- An obligation to carry out a heat loss calculation when fitting a boiler is proposed for the next Building Regulations and this should be brought into force and fully enforced. This should be seen as an opportunity to upskill installers and to improve the tools available to help them do this work. Calculating the heat loss will be increasingly necessary with low carbon heating systems.

[18] Research report – Homeowners' Willingness to Take Up More Efficient Heating Systems By Ipsos MORI and the Energy Saving Trust for DECC (2013)
[19] https://www.eubac.org/news/eu.bac-press-release-poor-heating-controls-are-failing-european-consumers.html



The Heat and Buildings strategy should lay out a plan for progressive increases in the minimum standards that will be required when a boiler (or other element of a heating system) is replaced. In addition it would be helpful to have higher levels of 'good practice' defined in parallel to the minimum standards, with an insistence that these higher levels are applied when any financial incentives (such as a Government funded grant scheme) are being used for the work.

5.2. Defined heating measures for incorporation into financial incentives

One of the issues for incentives, such as the Green Homes Grant scheme in England, is that heating system measures can be quite poorly defined.

With a clear roadmap for system improvements, and a defined list of packages of measures Government would be in a better position to incentivise these heating improvements either on their own or alongside boiler replacements. The BEAMA Manifesto for Heating Controls[20] sets out suitable definitions of 'good practice' and 'best practice' that would be appropriate for heating control measures.

5.3. Support for open communication standards

One of the barriers to the wider application of directly modulating load and weather compensation controls that communicate with the boiler (see section 3.2) is that there are different approaches within industry over the application of communication protocols. This can make it harder for installers to ensure compatibility and can create a significant barrier where installers want to combine controls and boilers from different manufacturers, which is a common scenario in the current heating installation market.

An open communication protocol that is used by all controls and boilers would provide installers and consumers with freedom of choice on products and allow equipment manufacturers to participate equally in driving the market to more efficient heating systems. Industry needs to develop and/or agree an open communication protocol that is suitable for the application of Directly Modulating Room Thermostats and will ideally also be applicable for integrating future heating systems, particularly heat pumps and hybrids, within smart buildings. Once in place, Government could support this with information requirements on interoperability.

There are examples where an open communications protocol specifically for boilers and compensation controls have driven the uptake of communicating controls, most notably in the Netherlands where around 90% of boilers installed have a communicating compensating control facilitated by a standard communication.

[20] https://www.beama.org.uk/portfolios/heating-controls.html

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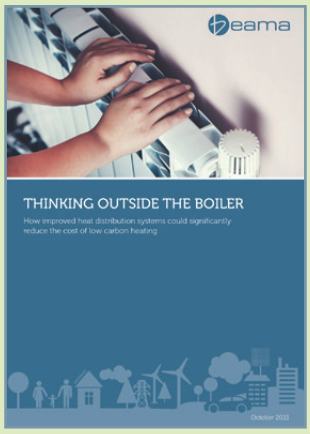

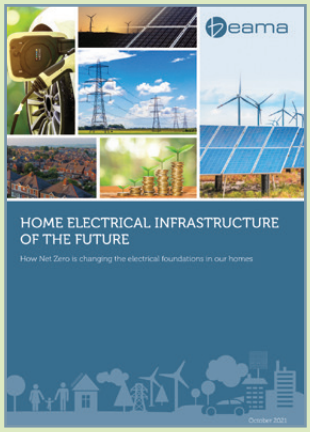

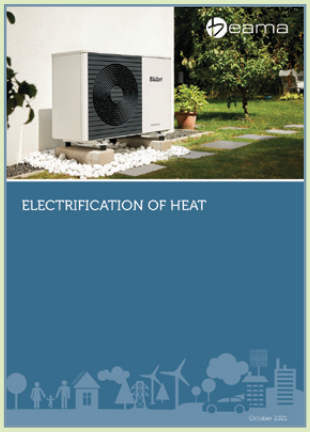

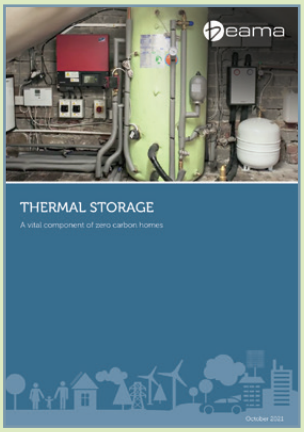

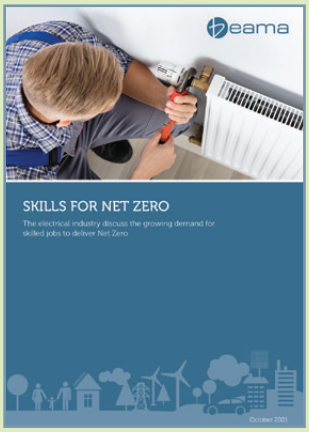

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