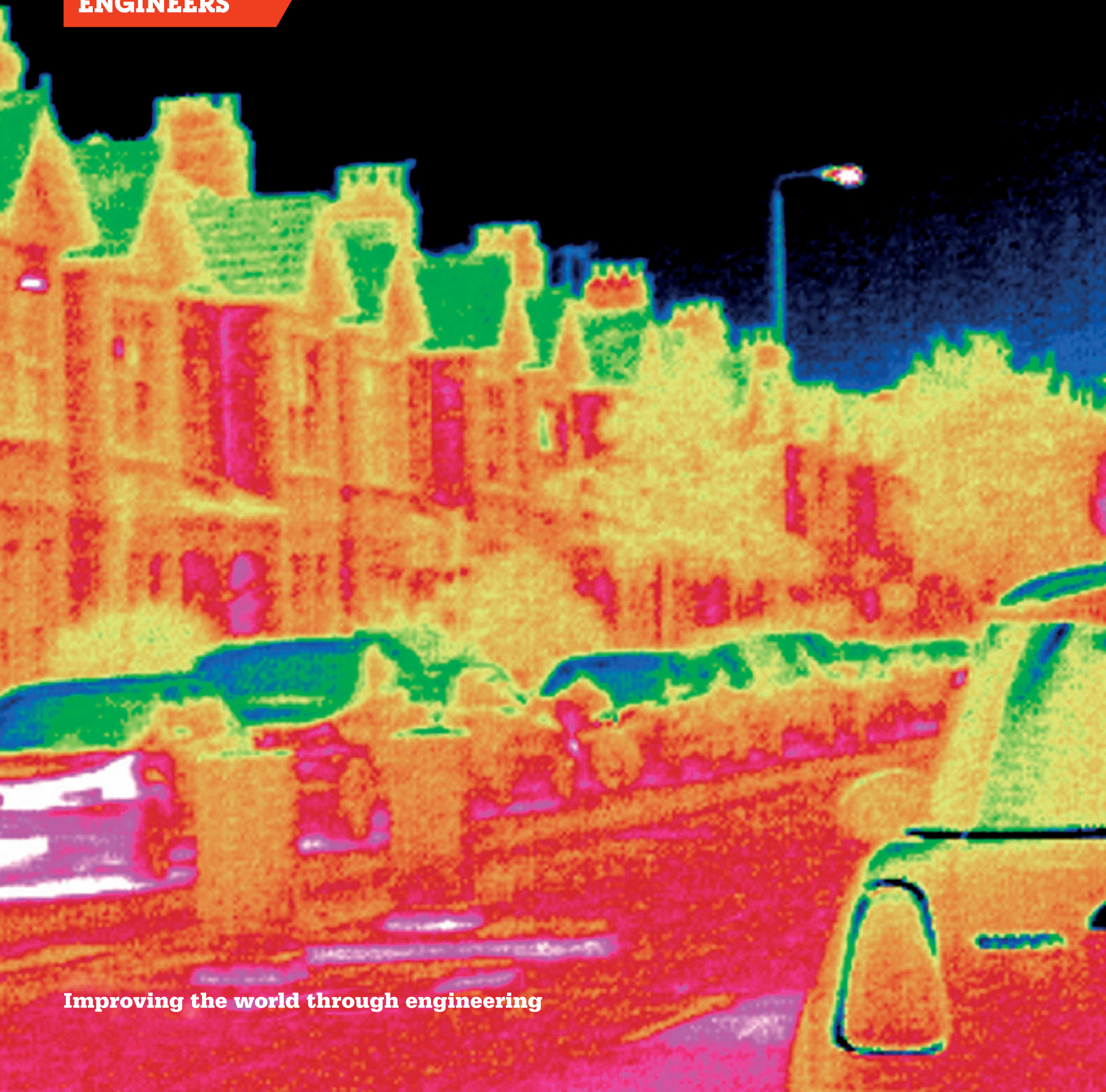
HEAT ENERGY: THE NATION'S FORGOTTEN CRISIS.

Institution of MECHANICAL ENGINEERS



Improving the world through engineering

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IN THE UK, THE PROVISION OF HEAT REPRESENTS 40% OF THE TOTAL ANNUAL ENERGY DEMAND.

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This report has been produced in the context of the Institution’s strategic themes of Energy, Environment, Education, Manufacturing and Transport and its vision of ‘Improving the world through engineering’.

Cover image: Thermogram of housing and cars in a suburban street. Thermography records surface temperatures by detecting the long-wavelength radiation emitted by an object.

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EXECUTIVE SUMMARY

For the past decade, successive UK Governments have focused energy policy initiatives almost exclusively on creating an environment to drive renewal of the nation's electricity infrastructure. The challenge has been substantial, not least because of the difficult task of balancing the competing demands of the energy trilemma (cost, security of supply and sustainability), while simultaneously trying to attract large-scale financial investment in the sector from domestic consumers, the private sector and overseas. A similar challenge now awaits the UK's new Government, but this time an order of magnitude more complex: renewal of the nation's heat infrastructure.

The provision of heat in the UK for domestic, commercial and industrial applications is largely based on the consumption of gas and delivered through an infrastructure developed at the end of the last century. This infrastructure was designed and engineered to exploit abundant gas reserves located under the North Sea. However, these are depleting rapidly and, as the nation'st gas imports rise through our undersea pipeline connections and via our LNG receiving terminals to maintain supply, the time to focus attention on how best to transition to new energy sources for heat is long overdue.

One option is, of course, to seek an alternative indigenous gas supply, and to this end the UK Government, together with a number of energy companies, is exploring the possibility of using the nation's untapped shale gas resources. Although the latter are known to be substantial, there is significant uncertainty regarding the economic viability of exploitation, and therefore the actual size and potential of the nation's productive reserves. In order to resolve this uncertainty, a programme of exploration is required, and though the companies involved are working towards undertaking the necessary investigations, public resistance to the use of the hydraulic fracturing technique means that progress has been slow in recent years. Despite the finding of a recent ICM survey for the Institution that just over 60% of those polled would be in favour of a North Sea replacement based on obtaining gas from shale rocks, if importing gas were more costly and less predictable, 66% believed that the companies have lost the public opinion battle and 61% that Government has not handled the issue well. In general, when asked in the same survey what we should do about our provision of heat in response to depleting North Sea gas reserves, 55% thought converting our domestic and business heating systems to an alternative to gas should be prioritised.

Given that in the UK the provision of heat represents over 40% of the total annual energy demand (nearly double that of electricity), and winter demand is about three times that of the summer months, the engineering and commercial challenge of providing an alternative to gas is substantial. The scale of this task is increased significantly by the fact that the UK's extensive heat supply infrastructure is a product of 1980s' thinking, founded on the use of individual gas boilers, each dedicated to a single domestic or commercial property with its own gas supply line. This has effectively created fully independent systems for each consumer, in contrast to the rest of Northern Europe, where district heating schemes based on shared community and industrial sources of heat are much more prevalent. Gas-based technology, processes and customer expectations are deeply embedded in the UK, for both domestic and commercial space and water heating, as well as cooking, and as a result the nation faces a significant technical, social and political challenge in shifting to a secure, sustainable alternative to meet current and future heat demand. The first step on this difficult journey is to recognise the scale of heat demand in the UK and take action to reduce it.

PUSHING AGAINST AN OPEN DOOR

For heat, as with all forms of energy usage, stopping unnecessary waste and reducing demand are the priority in a shift to a more sustainable and secure future. To help achieve this, all new and existing domestic, commercial and industrial buildings should be insulated to meet current Building Regulation standards and have leakage paths and draughts eliminated. Additionally, these buildings should be equipped with genuinely SMART energy management systems, that include optimised control of heat usage to meet the consumer's needs and preferences. Where possible, new-builds should be designed from the start to take advantage of passive approaches and principles (so-called Passivhaus design), such as high levels of insulation and airtightness, use of internal heat sources and recovery opportunities, and optimised solar gain. In the case of existing buildings, a large-scale national programme of intervention that retrofits appropriate insulation and glazing solutions, minimises draughts and heat leaks, fits SMART heat system controls and encourages active temperature control through behavioural change, is urgently needed.

These actions need to be driven by taking a step forward well beyond the Government's recently announced, and welcome, legislative measures for private rented accommodation, as well as the Liberal Democrats' proposals for a Green Bill in the next Parliament. A radical new approach will be needed, combining a legislative component for mandatory action with a range of financial mechanisms underpinned through general taxation. The Institution has found public support for such a change, with close to 60% of those polled recently in a commissioned ICM survey believing that all publicly owned housing stock should be insulated to a national standard at cost to the taxpayer. In the same poll, about 80% of respondents also indicated that those who can afford to pay for insulation, for example owner-occupiers and commercial companies, should be incentivised to do so to a national standard before they can sell their property. Such an incentive, the Institution suggested, might be to enable sellers to offset the cost of doing so against the stamp duty payable on the sale.

Given that improvement of the insulation levels in the nation's building stock will help to alleviate fuel poverty, improve public health outcomes, enhance energy security and reduce greenhouse gas (GHG) emissions, and that there appears to be public support for radical action, it is difficult to see why the new Government would not put in place a legislatively driven insulation programme for this component of our national infrastructure. This is particularly the case given the fact that the current raft of financial incentives, including the Renewable Heat Incentive, Energy Companies Obligation and Green Deal, are not delivering the step change in scale of action necessary in this area.

PROVIDING HEAT WITHOUT GAS

Beyond demand reduction, the priority is to provide heat using renewable energy resources, energy storage devices and clean, efficient technologies. This report describes a range of engineered options that need to be implemented at the level of the community, town and city, as well as those that can be deployed for individual buildings, be they domestic or commercial units. In the case of the former, solutions include the use of community-wide district heating systems with technologies such as Combined Heat and Power, Energy from Waste and Biomass, Geothermal Energy, Solar Thermal Energy and Industrial-scale Heat Pumps, as is common practice across Europe. At the individual building level, Solar Thermal, Domestic Heat Pumps and Biomass Boilers are all options.

Although the large-scale infrastructure components at national or regional level are likely to be delivered by Government in partnership with the private sector, given the current highly fragmented nature of the UK's heat provision it is critical to ensure the selection of an appropriate installation by the smaller-scale domestic or commercial consumer. This will need to be driven through a mandatory approach that not only makes the purchase of a sustainable system compulsory, and provides an appropriate financial scheme to support those who cannot afford to pay, but additionally recognises and leverages the role of the installer community. Competent, trusted installers, through their unique position as valued advisers to their customers, are the key to a successful sustainable outcome of renewal of the UK's heat infrastructure, and it is therefore important that Government ensures that this technical community of practitioners has the knowledge, expertise and skills to take a holistic view of a building's heat systems. This applies for both energy demand reduction measures and sustainable supply options. In order to achieve such an aim, a compulsory 'free' national training scheme needs to be instigated alongside a mandatory competence registration, similar to the CORGI certification and registration (now 'Gas Safe Register') established as a legal requirement for gas installers in 1991.

RECOMMENDATIONS

The UK's current heat infrastructure evolved in response to the availability of abundant supplies of affordable North Sea gas; it is no longer fit for purpose to meet our future energy security challenges, social needs and decarbonisation aspirations. The Institution of Mechanical Engineers recommends that the UK Government should:

1. **Declare all UK building stock 'national infrastructure' and instigate a legislatively driven insulation programme.** Such an action would need to go far beyond the Government's recently announced legislative measures to force landlords of private rented accommodation to improve the energy performance of their properties. For those who can afford to pay (eg owner-occupiers and commercial companies), key intervention opportunities such as, for example, the sale of a building, should be taken to impose mandatory upgrade points, linked to an incentive such as a reduction in stamp duty. For those who cannot afford to pay, a national scheme to cover the cost of the work should be instigated and paid for out of general taxation. These private and public sector approaches would not only reduce UK heat demand, but also create employment opportunities and allied skills development for installers, as well as tax revenues that would help offset the programme costs.

2. **Recognise the key role of the installer community and instigate a mandatory national installer ‘sustainable heat’ certification scheme.** Competent, trusted installers, through their unique position as valued advisers to their customers, are the key to a successful sustainable outcome for renewal of the UK’s heat infrastructure. It is essential that Government recognises this and ensures that they have the knowledge, expertise and skills to take a holistic view of a building’s heat systems, for both energy demand reduction and sustainable supply, and to recommend installation of equipment that fits harmoniously with that view. In order to achieve such an aim, a compulsory ‘free’ national training scheme should be instigated by Government alongside a mandatory competence registration, similar to the CORGI certification and registration (now ‘Gas Safe Register’) established as a legal requirement for gas installers in 1991.

3. **Tackle the provision of larger pieces of national heat infrastructure, as well as the interconnection and integration of heat systems with other energy networks.** The UK’s heat infrastructure, from individual buildings to larger-scale District Heating networks, should be declared ‘national infrastructure’ and dealt with in a holistic and strategic way. The global exemplar of a truly integrated energy system is in Denmark, where the power generation network, the heat energy network and multiple forms of waste stream are fully integrated to deliver a Sustainable Energy Network (SEN). The aspiration of the UK Government should be to learn from this existing system and adopt the approach within a UK context.

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THE UK GOVERNMENT HAS PLACED AN EMPHASIS IN RECENT YEARS ON THE ATTEMPTING TO ENCOURAGE DECARBONISATION OF THE UK ELECTRICITY SECTOR.

WHY A UK POLICY FOR HEAT?

In the quest to bring modern energy systems to their people, governments around the world focus their attention on electricity provision. With the emergence of aspirations for reducing greenhouse gas (GHG) emissions, this attention has only increased in the past decade. The UK Government has not been unusual in this regard, placing an emphasis in recent years on attempting to design and implement policy initiatives that encourage renewal and decarbonisation of the UK electricity sector.

These efforts reached a milestone in 2014 with completion of the Electricity Market Reform, a combination of policy, legislation and incentive mechanisms intended to make the sector fit for purpose in the coming decades. However, as the Institution's 2013 report on Energy Storage[1] highlighted, electricity is only a small part of the nation's future energy challenge; the level of demand in the UK for heat is far greater than that for power. When the scale and nature of this demand, as well as the characteristics of the nation's current heat delivery infrastructure, are understood, it becomes readily apparent that making the UK's heat system energy-secure, low carbon, affordable and fit for purpose for the 21st century is likely to be the biggest energy challenge facing the country's Government to date.

Figure 1 shows that the approximate split of total energy demand in the UK is: Heat: 600TWh/y (40.5%); Transport: 490TWh/y (33.1%); Electricity: 390TWh/y (26.4%); so electricity clearly represents the smallest portion. In Scotland, there is even less dependence on electricity than for the UK as a whole; recently released data[2] shows a demand split of: Heat: 50%; Transport: 30%; Electricity: 20%. Recent studies by the Scottish Government have indicated that the heating sector energy demand may be as high as 55% of the total[3]. Furthermore, these splits do not account for the amount of heating already achieved through electric-powered devices, which for example may represent about 7% of building heat consumption across the UK, so the heating sector is actually a larger proportion of total demand than this data suggests.

Though challenging in terms of the scale of demand to be met by a new system, these total numbers do not reveal the most significant issue associated with UK heat consumption. Recent work by the University of Sheffield on energy usage data for Great Britain[4] (data for Northern Ireland is not included), **Figure 1**, suggests that while the transport sector energy consumption remains fairly constant over a given year, and electricity displays only a relatively small seasonal variation (ie c 1.2TWh/d in winter to c 0.8TWh/d in summer), heat energy demand shows a substantial seasonal variation. In this regard, given that consumption in buildings accounts for about 40% of the total UK gas usage, and 80% of UK heat demand in buildings is almost wholly met by gas-fired equipment, the nation's annual variation in natural gas consumption can be taken as a rough proxy for variation in heat demand.

Figure 1: UK energy consumption by application and 2020 targets for renewable sourcing
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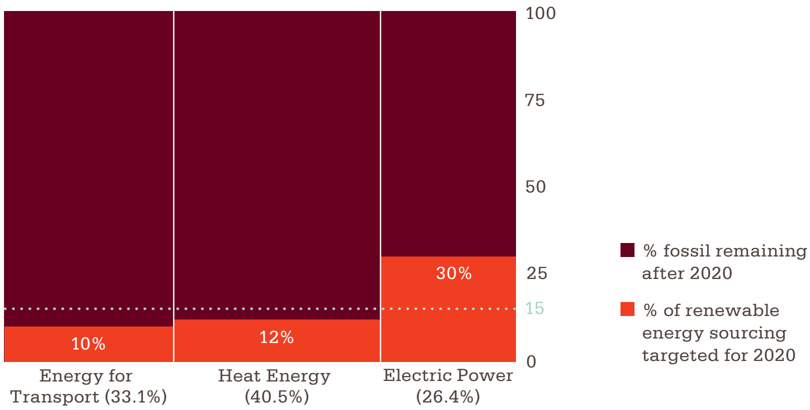
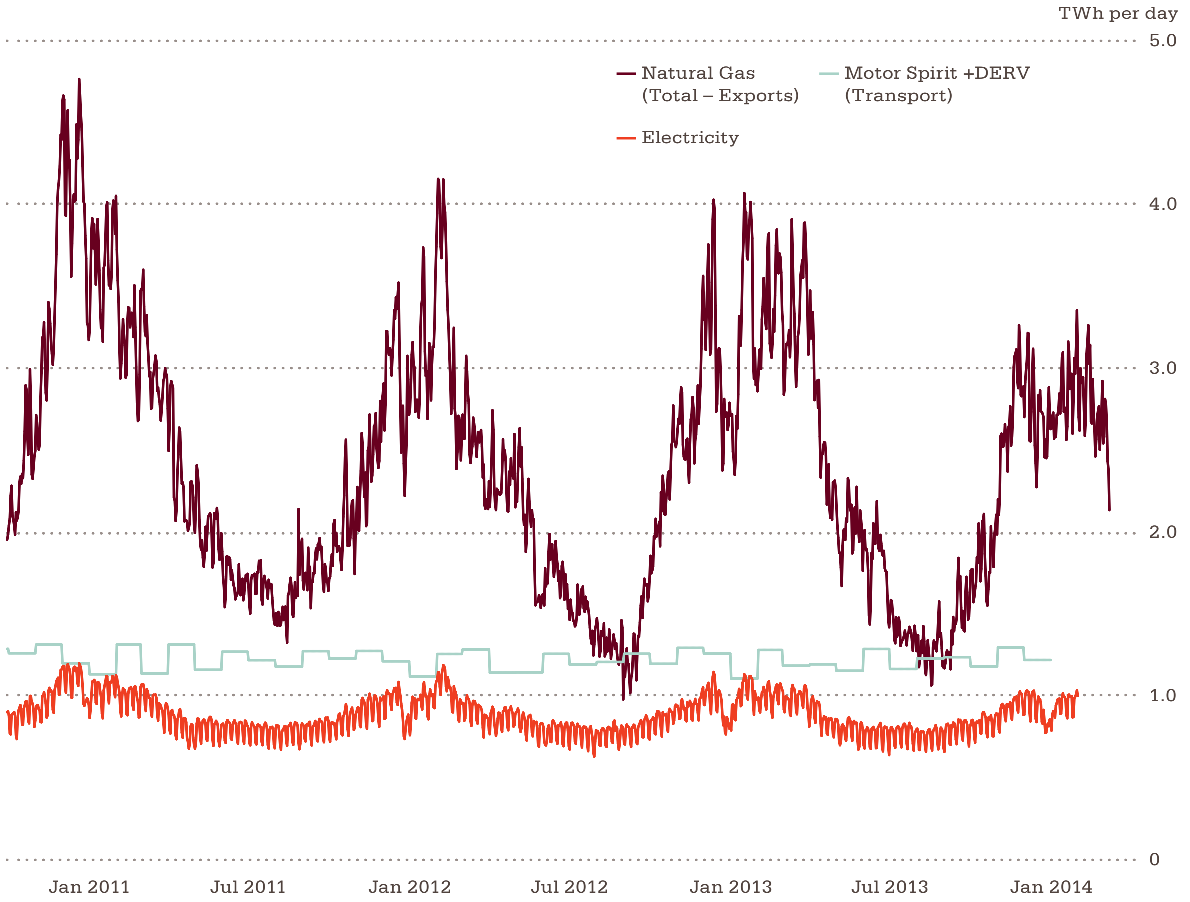


Figure 2 shows a winter peak in gas demand of about 4.0TWh/d compared with a summer demand as low as 1 to 1.5TWh/d. Therefore, the largest potential issue for any new UK system: meeting the seasonal heat energy demand variation between winter and summer. This is not only a technical challenge, in terms of delivering a flexible system that is largely unused for much of the year, but a substantial economic challenge too, as a replacement infrastructure operational for only three to four months annually may well prove unacceptable to investors in terms of the potential returns to be made on their investments.

The UK Government's published strategy for replacing the nation's current heat infrastructure, with one that is both lower in GHG emissions and more energy-secure, is focused on a comprehensive 'electrification' of heat, largely in the late 2020s and 2030s, following full-scale 'decarbonisation' of the nation's power generation system. Given, as shown in **Figure 2**, current total daily UK electricity consumption is on average just under 1.0TWh/d, the UK would potentially need up to five times the current generating capacity to meet the overall heat demand. Setting aside the scale of the engineering involved in delivering such an increase in the asset base – in terms of both resources and time, which should not be underestimated – from a commercial perspective the prolonged periods of equipment downtime that will result raise a question as to the economic viability of such a strategy.

Figure 2: UK energy consumption, Oct 2010–March 2014
(© Grant Wilson, Sheffield University; Permission Granted)



In addition to the seasonal variation, **Figure 2** also serves to illustrate the year-on-year variation in maximum UK heat demand; the most recent peak for heating having occurred in the severe winter of 2010/11, with the three more recent winters having not been as severe. Although the 'peak' consumption is lower in these subsequent winters, the 'heating season', in 2012/13 for example, was considerably longer. Projections from UKCIP for changes in UK climate through the 21st century anticipate that although in general winters will become wetter and warmer, relatively severe cold winters will continue to occur at least through to 2030 and beyond. The UK's heat production and delivery infrastructure will need to be able to cope with this variability, which again leads to economic concerns associated with maintaining what might be perceived as excess or overcapacity.

However, as will be detailed in subsequent sections of this report, simply trying to meet the UK's future heat demand through the provision of different types of energy supply is only a partial solution to the challenge; considerable attention must also be focused on reducing energy demand itself. In this regard the previous Government has, in part, recognised the need and is to be commended for its current efforts through the Renewable Heat Incentive[5] (RHI), Energy Companies Obligation[6] (ECO) and Green Deal[7] initiatives, as well as recently announced legislation aimed at improving the energy performance of privately let dwellings from April 2018[8]. Although this new legal instrument may prove to be effective in the rental sector in due course, it is widely acknowledged that the previously established initiatives are not coming close to achieving what is required to be done in this field[9]. Furthermore, the RHI, while having some success in the case of 'industrial' applications (particularly with regard to biomass boilers), has been much less successful for 'domestic' applications, due to a number of factors including the late start of the programme, unilateral late changes to 'deeming' (requiring the additional cost of retrofitting heat meters) and a late requirement for largely unconnected Energy Performance Certificates[10] (EPCs), all of which have alienated ordinary people who have invested tens of thousands of pounds in 'RHI-compliant' equipment. The new Government needs to learn from this experience and in future avoid making last-minute adjustments to incentives, as this creates an unstable policy environment that risks alienating potential participants, as previously occurred in the case of the Feed-in-Tariff degression for renewable electricity[11].

Despite these relatively recent initiatives to start the process of renewing the UK's heat production and delivery infrastructure, there has been little Government or public recognition to date of the scale of the challenge, or an articulation of tenable, practical and realistic solutions within the context of a holistic sustainable system. A step in the right direction was taken in 2014 in this regard by Carbon Connect, with the publication of the report 'Pathways for Heat: Low Carbon Heat for Buildings'[12]. This report calls for the new UK Government to "set heat as a priority for the coming decade". This recent contribution presents and compares six potential pathways to the renewal of UK heat infrastructure by 2050, as provided by six organisations: UKERC, National Grid, ETI, Delta EE, DECC and the Climate Change Committee. The study found that across all six pathways a large reduction in the use of gas is assumed, through substitution with electric-powered heat pumps and district heating, as well as an increase in the energy efficiency of existing and new buildings. Significantly, it was recognised in the analysis by Carbon Connect that there exists considerable uncertainty regarding how peak heat demand will be met, and a lack of clarity on what will be needed to encourage installers and consumers to transition away from the current deeply entrenched systems.

Although the report and its findings are very welcome, the Institution of Mechanical Engineers recognises that Carbon Connect's objective was to draw out common themes and highlight areas where more work is required. The approach was to compare theoretical 'pathways' focussed on decarbonisation of the UK's heat provision to meet 2050 GHG emissions targets, rather than develop an energy strategy based on what is practical from an engineering perspective. This report aims to build on the existing body of knowledge, by taking an engineering approach within the context of the Energy Hierarchy framework[13] to consider solutions for meeting the challenge. In this regard it begins by considering the route to energy demand reduction in the provision of UK heat, before presenting the Institution's views on the supply-side measures required to deliver a sustainable and secure energy system and what needs to change to help ensure a successful outcome.


Inside
88°
Hold
Cool Setting
88°
1:30 PM
Cool On
Run Schedule
Fan
Auto
System
Cool

THE BIG CHALLENGE: UK HEAT ENERGY DEMAND

In 2009 the Institution of Mechanical Engineers developed and published a new framework to guide energy system decision-making, the 'Energy Hierarchy'[13]. This was specifically designed to encourage a more sustainable approach to energy policy. **Figure 3** shows that in the Hierarchy energy demand reduction is the first priority, followed by energy efficiency (both supply- and demand-side) and then consideration of the sustainable ways by which energy can be supplied for the required applications. This order of merit had been recognised as a useful contribution to energy system thinking and widely adopted in decision-making, particularly outside the UK and in relation to the electricity sector. Its application is equally important and relevant in the area of heat energy policy and heat infrastructure decision-making. In contrast to this hierarchy of prioritisation, UK Government energy policy and regulation to date (as well as EU Directives[14,15]) too often lump 'demand reduction' and 'energy efficiency' together under the single banner of 'energy efficiency'. This leads to an unfocused and ineffective national strategy. The more efficient use/production of energy is to be welcomed, but it is not the same as reducing energy demand.

Heat energy demand reduction can be achieved by various means that largely fall into two categories: technical approaches involving measures to reduce heat loss from the heated space and improve the control of the temperature within through automation; and behavioural approaches involving human decision-making. An example of the latter is an active intervention such as lowering thermostat settings in rooms. The former would include passive interventions such as allowing Smart control systems to optimise energy demand, using *Passivhaus*[16] design or other passive solar principles, eliminating draughts and 'cold bridges', fitting double/triple glazing and increasing the levels of insulation in all parts of the building.

In the case of thermal insulation, there is an urgent need to make improvements across a wide range of the UK's existing building stock, both domestic and commercial, as well as ensure that new construction meets high standards in this area. Building regulations[17] (particularly Parts L1 and L2) are already in place for the latter, and it is important that Government rigorously enforces them, but there is currently little to incentivise the retro-fitting of insulation in existing buildings.

According to the UKGBC's 2008 report[18], "…at least 80 per cent of the homes that will be standing in 2050 have already been built" and given that it is widely known that many existing UK domestic dwellings are poorly insulated, this suggests that to significantly reduce the nation's heat energy demand these buildings will need to be tackled. This will require a substantial amount of investment. In the current political environment, where the focus has been on attempting to put the costs on consumers while simultaneously pursuing policies aimed at forcing energy companies to reduce energy bills, this investment is unlikely to be forthcoming from homeowners, landlords and third-party investors (the general lack of take-up of the Green Deal[9] exemplifies this point). In fact, radical policy and legislative approaches are likely to be required. As a small step in this direction, the Liberal Democrats announced a Green Bill[19] in their pre-election plans for the next Parliament, which they say would incentivise the insulation of up to 10 million homes through a guaranteed discount on Council Tax of at least £100 per year for ten years.

Figure 3: Energy Heirarchy[13] IMechE

SUSTAINABLE

Priority 1: Energy conservation
Changing wasteful behaviour to reduce demand.

Priority 2: Energy efficiency
Using technology to reduce demand and eliminate waste.

Priority 3: Exploitation of renewable, sustainable resources.

Priority 4: Exploitation of non-sustainable resources using low-carbon technologies.

Priority 5: Exploitation of conventional resources as we do now.

UNSUSTAINABLE

A further consideration is the issue of 'fuel poverty', which in the UK has traditionally been said to occur when, in order to heat the home to an adequate standard of warmth (defined as 21°C for the main living area and 18°C for other rooms), a household needs to spend more than 10% of its income on total fuel use costs. By this definition, in 2014 it was estimated there were over 6.5 million UK households living in fuel poverty[20]. However, in August 2013, the UK Government (but not the Scottish Government) changed the definition so households would be fuel-poor only if they have "required fuel costs that are above average and were they to spend that amount they would be left with a residual income below the official poverty line". According to The Environmental Audit Committee (EAC)[21], the new definition will move more than 800,000 households in England out of fuel poverty, as many poor households are smaller than average and cost less than average to heat. Nevertheless, compared against 27 other European nations, the UK ranks 26th, with a higher proportion of people who are struggling to pay their energy bills than every other country in Europe except Estonia[22]. However, it is important to note that focusing on the cost of energy supply is not the only approach available to help move people out of fuel poverty. For example, the populations of Scandinavian countries such as Sweden are subject to much higher energy costs, and substantially colder winters than the UK, but their governments have enforced effective levels of building insulation and largely eliminated fuel poverty.

Given that insulation improvement is not only a route to helping alleviate fuel poverty, but also in the national interest from an energy security and GHG emissions reduction perspective, it would be appropriate for UK building stock to be declared 'national infrastructure' and a legislatively driven insulation programme put in place. Such an action would need to go far beyond the Government's recently announced legislative measures to force landlords of private rented accommodation to improve the energy performance of their properties[8] and the Liberal Democrats' Green Bill initiative[19]. In this broader case the full range of domestic and commercial building stock across the UK should be included in a legal instrument. For those who can afford to pay (eg owner-occupiers and commercial companies), key intervention opportunities such as, for example, the sale of a building or construction of an extension, should be taken to impose mandatory upgrade points, possibly linked to reductions in stamp duty and implementation of favourable planning criteria. A March 2015 poll carried out by ICM for the Institution of Mechanical Engineers found that about 80% of the public believe that all private households should be incentivised to insulate their homes to a national standard before they can sell using such an initiative. For those who cannot afford to pay, a national scheme to cover the cost of the work should be instigated and paid for out of general taxation. The latter would also address the nation's stock of rented social housing. In the same ICM poll, close to 60% believed that all publicly owned housing stock should be insulated to a national standard at cost to the taxpayer. An additional benefit of these private and public sector approaches would be the creation of employment opportunities and allied skills development for installers, as well as the receipt of tax revenues in the Treasury from the new business activity and materials procurement. The latter would help offset the lost stamp duty receipts and additional tax expenditure on the programmes.

The key importance of installers must not be underestimated in developing policy to meet the challenges of renewing the UK's heat energy infrastructure. Installers are in many cases in a unique position to determine the success or otherwise of initiatives for demand-side reduction, as well as supply technology changes, often occupying a place of trust and influence with customers. In this regard, domestic and commercial building owners tend to maintain lengthy relationships with their chosen heating contractor, and turn to them for guidance and advice on the options available to them for renewal and upgrade (in the UK about 5,000 heating boilers are replaced each day). Ensuring that existing installers, and those who are entering the marketplace for the first time, have the technical knowledge, skills and competence to support demand reduction and supply-side initiatives, as well as act as advocates for more holistic sustainable solutions, will likely increase the potential for a successful outcome to Government initiatives in this area.

RENEWING THE SUPPLY SIDE

Before detailing potential solutions to the challenges of future UK heat supply, it is important to understand why the nation has its current system in place; a system largely composed of infrastructure established following the discovery during the 1960s of substantial natural gas reserves in the North Sea. Since that time, both domestic and commercial heating have been increasingly achieved through the use of individual gas boilers, each dedicated to a single property with its own natural gas supply line, effectively creating independent systems for each consumer. This is in contrast to the rest of Northern Europe, where District Heating (DH) schemes based on shared community and industrial sources of heat are much more prevalent. According to Pöyry Energy[23], less than 2% of UK heat is provided through DH schemes, compared with 49% in Finland and 60% in Denmark, both of which have a long history of DH. In Austria, the figure is lower, at 18%, but in Vienna alone, DH supplies 36% of buildings.

An example of the divergence of UK and European heating preferences can be found in the case of Peterborough, which in 1968 was designated as an 'expansion town' to alleviate growing population pressures in nearby London. One of the new townships, Bretton, was equipped from the outset with a DH scheme, supplied from a centrally located gas boilerhouse. The scheme opened in 1972 and operated reasonably well for the next decade, but closed in 1983 due to failure to secure a long-term gas supply contract. A report[24] published in 2000 noted that in relation to the system, "It had proved exceedingly difficult to operate it with maximum economy, not least because the 4,000 houses served were not metered but charged on a scale related to dwelling size. Residents therefore had no incentive to economise as the system provided domestic hot water as well as heating the homes." Within a very short period, most of the houses had the DH pipes removed and their own individual natural gas supplies and boilers installed.

A further development during the past two decades, which has reinforced the predominance of the independent consumer rather than community shared model, has been the emergence of the 'combi' type boiler as the technology of choice for provision of both hot water and space heating. This type of boiler operates rapidly on demand and, since it removes the need for any hot water storage provision to be made within the property, has had broader implications for UK energy storage infrastructure. According to the Centre for Low Carbon Futures (CLCF), as recently as 2009 about 14 million households in the UK had a traditional hot water storage cylinder that functioned as part of a dedicated hot water system separate from space heating provision (giving a maximum combined storage capacity for the UK of about 80GWh), but now that c 80% of sales of new boilers in the UK are of the 'combi' type, this infrastructure is being removed[25]. This development has led to a significant reduction in the heat energy storage capacity of the UK at a time when the nation should be moving in the opposite direction and installing more[1].

Given that the UK's heat energy infrastructure has been developed on the basis of an abundant, easily accessible, affordable and secure supply of natural gas from the nation's sector of the North Sea, the principal immediate challenge facing the supply side is the rapid depletion of this resource. The UK became a net importer rather than exporter of gas in 2004, currently imports about 40%, and is projected to be importing 80% by 2030[26]. Although these imports are currently from parts of the world that are friendly to the UK and politically stable, for example Norway and Qatar, in a future where competition for primary energy resources will increase substantially (the International Energy Agency, IEA, anticipates a 40% increase in demand by 2035, with 90% of that growth being from non-OECD countries[26]), gaining access to a secure, affordable supply may become challenging. Furthermore, since the UK is an island nation on the western fringe of Europe, apart from the limited volumes that can be transported through subsea pipelines from near Continental neighbours[27], importing gas from overseas requires the use of liquefied natural gas (LNG). This involves the gas being liquefied at the point of origin, for example Qatar, then shipped in large LNG carriers to stores at LNG terminals such as those at the Isle of Grain and Milford Haven. Upon demand the LNG is then regasified for use in the UK's transmission pipelines. This activity uses a considerable amount of energy in the process (typically equivalent to 15% of the energy in the natural gas prior to liquefaction) and also wastes substantial amounts of that energy in the form of cold 'dumped' during the regasification step[28], all of which leads to additional GHG emissions.

In the search for an alternative to a future locked into importing an increasing volume of natural gas from overseas, the UK Government and a number of energy companies are exploring the possibility of using the nation's untapped shale gas resources[26]. Although the latter are known to be substantial[29], there is currently significant uncertainty regarding the economic viability of exploitation, and therefore the actual size and potential of the nation's shale gas reserves, as well as the degree to which the UK public will be prepared to accept development of this new onshore industry[30]. In order to resolve these uncertainties, a programme of exploration is required and though the companies involved are working towards undertaking the necessary investigations, public resistance to the use of the hydraulic fracturing technique means that progress has been slow in recent years. Despite the finding in a March ICM public survey for the Institution of Mechanical Engineers, that just over 60% of those polled would be in favour of a North Sea replacement based on obtaining gas from shale rocks, if importing gas were more costly and less predictable, 66% believed that the companies have lost the public opinion battle and 61% that Government had not handled the issue well.

However, regardless of whether the nation's future gas supplies come from a new indigenous resource or overseas, it is important to consider the long-term use of this energy source with regard to its contribution to global warming. Although natural gas has a lower level of CO_2 emissions per unit of energy delivered when compared with coal and oil, it is a fossil fuel, and many analysts suggest that it will need to be phased out in the long term if the UK's GHG emissions reduction targets are to be achieved[31,32]. Successive reports from the UN Intergovernmental Panel on Climate Change (IPCC) have recommended the global phasing out of fossil fuel use, the most recent of which states: "To limit warming to below 2°C relative to preindustrial levels… would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived GHGs by the end of the century"[33]. The UK Climate Change Committee (a statutory adviser to Government on emissions reduction), among others, proposes a phase-out of gas within the nation's energy mix in the period to 2050[32]. In such a scenario it is clearly important to find alternative forms of primary energy and sustainable ways of applying these to provide heat in the UK.

DOMESTIC (HOUSEHOLD) SYSTEMS

Energy demand reduction and energy efficiency (the first two tiers of the Energy Hierarchy) are as important in domestic dwellings as in any other building type, and the various ways by which demand for heat can be reduced in this sector have been detailed in the previous chapter. In this regard the primary emphasis should be on better insulation, improved levels of glazing, eliminating draughts and the use of more efficient appliances, as well as effective control systems. Beyond these measures, attention should be focused on the provision of a sustainable energy supply, and for properties located in urban areas, DH systems are the most effective way of providing heat to domestic dwellings (in terms of both cost and performance), which is why they are prevalent in many EU countries[12,23]. While recognising that there are few DH systems available in the UK at present[23], to simply replace gas boilers in urban housing with individual alternative devices that use more sustainable sources of supply, would miss the opportunity to gain from the economies of scale and flexibility of 'fuel' source that DH systems offer. It is therefore important that the UK Government develops an aspiration for the provision of DH infrastructure, as part of both new-build projects and urban renewal activity, and seeks to create a policy framework that incentivises its deployment. The Scottish Government's district heat loan fund[34] is a small step in the right direction in this regard, but a much more ambitious nationwide scheme is required.

For rural properties and off-grid systems, which are unlikely to ever benefit from DH schemes, or interim solutions in urban settings where DH provision is not plausible in the near term, there are several standalone solutions for more sustainable supply available. These include:

Solar thermal systems; these are now readily available at domestic scale[35] and have become more cost-effective in recent times; solar thermal panels are typically installed on south-facing roofs of buildings and are very effective at producing domestic hot water, particularly during the summer months. In addition, there are promising hybrid domestic systems in development that will provide both electricity and heat from the same solar panel[36].

Domestic heat pumps; these can be of the ground-source, water-source or air-source type[37]; air-source heat pumps are the cheapest and easiest to install but the coefficient of performance (CoP) is significantly lower; furthermore, heat pumps, by themselves, are not 'renewable' energy devices, so care has to be taken to ensure that the electrical supply to the heat pump has been generated from renewable resources.

Biomass boilers; these are typically designed for fuels such as wood logs, woodchip or wood pellets[38]; when designed to gasify, rather than simply combust the fuel, such systems can be highly efficient. However, it is good engineering practice to retain a 'back-up' system (which will necessitate a heat meter) and increasing pressures on sustainable wood-fuel supplies are likely to lead in the future to escalating fuel prices and hence operating costs.

It should be noted that to obtain maximum value from the three domestic-level technologies listed above, it is necessary to have an adequate level of thermal storage available within the property; as noted earlier, the widespread use of combi-type boilers in the UK has resulted, and continues to result, in the removal of much of the hot water storage capacity in UK domestic dwellings and this trend needs to be reversed. New innovations such as 'heat banks' (which enable mains-pressure hot water to supply pump-free showers, for example), and phase-changing material (PCM) thermal stores, offer many advantages over traditional hot water cylinders and should be considered for development and future deployment[1].

COMBINED HEAT & POWER (CHP)

The classic definition of CHP (known in the USA as 'Co-generation') is of the "simultaneous production of heat and power" and since the emergence of the first 'heat engine' in the Industrial Revolution of the 18th century, such devices have been 'CHP plants'. For example, the steam turbine (operating in a Rankine Cycle, or similar) upon which most of the world's electricity production is based, is inherently a CHP plant, as it simultaneously produces both heat and power. However, in a conventional coal, gas or nuclear power station, up to two thirds of the primary energy consumed is wasted with much of the heat exhausted to the environment.

To transform a conventional power station into a useful CHP plant providing both heat and power to consumers, requires little change to the technology, but a substantial change in public attitude along with the deployment of heat distribution infrastructure. The steam used in the turbines of a power plant is traditionally converted back to water in a steam condenser, which operates under a vacuum, after the power generation step. The water from the condenser, which is at a temperature where it is technically termed 'low-grade' heat, is itself then cooled using a cooling tower or other form of heat exchanger, with the result that the energy available in the heat is simply transferred into the environment. By replacing the conventional steam condenser with a 'district heating' condenser, which operates at a slightly higher pressure, the water output from the condenser (with a temperature typically about 90°C) is suitable for use in a DH scheme. Waste Heat Recovery (WHR) is largely the counterpart of CHP, and is often effected by retrofitting CHP to conventional thermal power generation and industrial processes using technologies such as industrial heat pumps and Organic Rankine Cycle (ORC) devices, some of which are capable of recovering the energy from relatively 'low-grade' heat sources.

As a result of applying CHP/WHR technology to a power plant, there is a reduction in turbine power output, but the heat is no longer wasted and there is thus an overall increase in the efficiency of the plant. If there is a requirement for higher pressure, or higher temperature, steam, for use in an industrial process, this can be provided by extracting the steam from a higher pressure section of the turbine, or by using the exhaust steam from a 'back-pressure' steam turbine. Although the efficiency gain depends on the actual requirements of the CHP plant application, in all cases there is an overall improvement and clearly the fossil fuels that would normally be consumed to supply the heating requirement, and associated GHG emissions, are avoided.

Other commonly available heat engines that can be used as the basis for a CHP plant include gas turbines and internal combustion engines. In the latter case where the engine is driving a generator, the otherwise waste heat can be recovered from the cooling system and exhaust gases, though this requires additional heat exchangers and auxiliary components to be added. For a gas turbine application of CHP, the high-temperature exhaust heat is commonly recovered in a Heat Recovery Steam Generator (HRSG) to produce steam for a steam turbine. This is usually referred to as a Combined Cycle Gas Turbine (CCGT) plant.

A new opportunity for CHP systems using nuclear power may potentially emerge in the UK, with the possible development of Small Modular Reactors (SMRs), which are defined by the industry as units producing less than 300MW of output, for deployment on smaller-scale nuclear licensed sites distributed across the country[39]. Since all nuclear reactors produce large quantities of heat, their use not only for electricity generation but also for heat sourcing could open up DH applications local to the sites. The inherent safety features of the SMR design mean that they could be considered for locations close to industrial and domestic consumers of heat. In this regard it would be practical for all the SMR designs to be used for process heat in the form of steam, but the gas-cooled variants are better suited to those industrial applications requiring higher temperatures. Gas-cooled reactors often use helium as the primary coolant and operate at temperatures up to 850°C, whereas SMR variants using water/steam as coolants operate at about 350°C. Several research institutes, particularly in North America[40] and Russia[41], have considered this potential application of SMRs, concluding it to be economically viable and more environmentally friendly than alternatives such as natural gas.

To conclude, CHP is more frequently used with electricity generating plant in other countries than it is in the UK; in Denmark, for example, most power stations are designed as CHP and these form the basis of the nation's extensive DH infrastructure, in addition to providing the supply for the national electricity grid. If the UK Government is serious about meeting its highly ambitious GHG emissions reduction targets, it must ensure that no new thermal generating plant is commissioned unless it is designed as a CHP system.

ENERGY FROM WASTE (EFW) PLANTS

Previous work by the Institution of Mechanical Engineers has considered in detail the use of heat produced through the combustion of waste material in EfW plants for the supply of DH systems[42]. In particular, the report recommended that the UK Government promote and encourage investment in district and community heating projects, with 'local' waste being used as the system's fuel source. However, despite subsequent progress in this area, EfW plants continue to be built in the UK as 'electricity-only' plants, which is not only a waste of valuable heat that must be supplied to potential consumers through the unnecessary consumption of other energy resources, but also in stark contrast to the practice in most European and neighbouring Scandinavian nations.

In Denmark, consistent Government policy over decades has resulted in numerous localised EfW plants forming an integral part of the nation's heating network. In addition to providing a method for dealing with a local community's residual solid waste (that remaining after recycling and re-use) and generating electricity for the local grid, these EfW plants provide much of the heat energy to the country's nationwide heating network. As a result of the Danish Government's enthusiasm for and commitment to EfW CHP plants, the Danish people are equally committed to them, with a number of Denmark's EfW plants being owned by local communities rather than large utility companies. Illustrative of the positive, innovative attitude to EfW in Denmark is the new plant being built at Amager Bakke, in a suburb of Copenhagen, which is scheduled to open in 2016[43]. This CHP plant, which will be fuelled by 400Mt/y of municipal solid waste (MSW) and provide electricity for a minimum of 50,000 homes, as well as heating about 150,000 homes, has been designed to double up as a local ski slope facility, while the exhaust gases (cleaned to the requirements of the EC's Waste Incineration Directive[44]) will create laser-illuminated smoke rings to promote the CO_2 savings compared to a similarly rated coal-fired power station.

By contrast, successive UK Governments have failed to fully grasp the opportunities offered by investment in new EfW plants. There are some good working examples, for instance, at Sheffield in South Yorkshire (up to 225,000 tonnes/yr waste processing with 45km heat network [2006]) and Lerwick in Shetland (22,000 tonnes/yr waste processing with 26km heat network [1998]), but deployment of the method for waste management, electricity generation and heat sourcing is still far from being normal practice.

ENERGY FROM BIOMASS (EFB) PLANTS

There are many similarities between combustion plants that make use of different waste streams (which are often biomass-rich) and those that use virgin biomass as a fuel, such as wood pellets, though they are less complex in design as there is no regulatory requirement for them to meet the very low Emissions Limitation Values (ELVs) of the EU Waste Incineration Directive[44] (WID). However, in the case of these EfB plants, the biomass fuel has to be purchased in competitive markets, and there can be issues raised regarding the sustainability of the source. In this regard, though there is certainly a limit to the amount of biomass that can be sustainably grown in the UK, importing biomass need not necessarily be unsustainable in all cases[45]. Given that biomass is one of the few renewable resources that is not intermittent and can therefore generate electricity on demand for meeting baseload needs, it is regarded as a useful potential contributor to help deliver the UK's energy needs while simultaneously reducing GHG emissions.

Despite the opportunities that EfB plants offer, as in the case of EfW, the take-up in the UK has been very slow compared with most other EU countries and there has been little enthusiasm for CHP, as opposed to 'electricity-only' plants. One UK example of a modern EfB plant is Steven's Croft in Lockerbie, Scotland, which is fuelled by 475Mt/y of wood products[46]. This plant is the largest EfB plant in the UK and though it claims to save 140Mt/y of GHGs, it is an 'electricity-only' plant; from the 126MWth produced in the process, just 44MWe is supplied to the national grid. The main lessons which should be learned from Steven's Croft are:

1. Such plants should be built closer to the people/processes that can be served by a sustainable heat supply.
2. Due to water abstraction restrictions, an air-cooled condenser had to be used – this sacrificed a substantial amount of the available enthalpy drop and increased the parasitic electricity losses.
3. A 'district heating' condenser should have been used instead, which would have allowed the plant to produce a similar amount of electricity and large amounts of heat energy.

GEOTHERMAL ENERGY

Conceptually, a DH network supplied with heat from a deep geothermal energy source is a relatively simple system. Hot water is pumped from a hot aquifer deep below the ground surface, passed to consumers through a pipe network, and the cooled return water is then disposed of at the surface or (more commonly) re-injected to another portion of the deep aquifer, where it will reheat. The latter approach is one of the methods by which DH is delivered in Reykjavik, Iceland, where the hot water pumped from the aquifers is of sufficiently high quality that direct use of the water for both space heating and domestic hot water is feasible. About 490MW_{th} is supplied in this manner, from aquifers located directly beneath the urban area. However, more commonly, water pumped from deep geothermal sources is saline and heat exchangers are therefore used to transfer the thermal energy to fresh water circulating as the working fluid in the heat network. This is the approach taken in 29 such systems currently operating in eastern Paris (220MW_{th}) and in the UK's sole such system in Southampton (1.7MW_{th}).

A further approach is possible where high-enthalpy reservoirs are exploited for electricity production; after the water has been processed in steam flash or binary (typically Organic Rankine Cycle) plants, the effluent typically still has a temperature of about 80°C. This effluent comprises a mix of primary separated water and (where flash power production is used) turbine exhaust condensate. For instance, in addition to direct use of deep aquifer sources, Reykjavik also benefits from a further 21MW^{th} of water piped some 40km to the city from the Hellisheiði and Nesjavellir power plants, located west and north respectively of the active Hengill volcano.

Although deep geothermal DH systems are characterised by extremely low CO_2 emissions (typically about 6–7kgCO_2/MWhth) and very low operating costs (they are already cost-competitive with gas-fired heating on a levelised cost basis), the principal barrier to their wide uptake is the cost and uncertainty associated with the drilling of the first few wells in any new reservoir. Well success is typically less than 60% until three or four wells have been drilled and their data contributed to a more sophisticated understanding of the reservoir; thereafter success rates tend to increase to over 80%, which is far more 'bankable' from a commercial perspective. Governments determined to promote deep geothermal DH often operate a form of dry well insurance scheme, where a loan can be written off as a grant if a drilled well is unsuccessful, but the funding is recovered from operating revenues if it is successful.

Although the UK has been slow to take up geothermal DH (with only a system in Southampton in operation to date), several companies and local authorities are actively developing deep geothermal projects (targeting faulted radio-thermal granites or deep sandstone and limestone aquifers) in Cornwall, Staffordshire, Cheshire, Manchester, County Durham, Newcastle upon Tyne, and central and north-eastern Scotland[47]. A 2012 study[48] undertaken for the UK Government estimated the total deep geothermal DH resource at about 140GWth – a substantial proportion of total national heat demand. Given the good operating experience in other European countries, this source of renewable heat energy needs to be more widely utilised in the UK than it is at present[47].

SOLAR THERMAL ENERGY

In recent years the opportunities for solar thermal installations for the provision of hot water to individual domestic properties in the UK has grown significantly[49], but to date the Northern Europe trend for the deployment of much larger solar thermal systems to supply heat energy to DH networks has not emerged.

In Germany, for example, large solar thermal plants with at least 40m² surface area are being actively promoted for DH network supply and operators are incentivised by the government through the offer of a (up to) 40% subsidy to amortise investment costs. Historically DH operators in Germany have tended to consider solar-based thermal energy as competing with CHP installation, because its introduction for heat provision leads to a reduction in the operation hours of a CHP plant. This has however changed, with a new strategic direction being taken as part of Germany's '*Energiewende*' initiative[50]. The use of CHP is now focused primarily on tackling the intermittency challenges for power supply that arose as a result of the large-scale deployment of electricity generation based on wind and photovoltaic sources. As a result, solar heat will continue to become more attractive in German DH networks, but it should be noted that for optimal integration of collectors and other energy sources, large heat storage capacities are required.

To increase storage capacity, thermal stores are currently subsidised at 250€/m³ capacity in Germany and the state-owned KfW bank also proposes a repayment grant of 250€/m³ storage volume (up to 30% of the investment costs) for CHP plants with 20% and more solar heat, or 50% and more renewable heat. The amended CHP Law and the '*Marktanreizprogramm*' also both offer subsidies for district heating pipelines: 100€/m in the former case, 60€/m in the latter. It is noteworthy that the government also promotes the integration of small private solar thermal plants into district heating networks, unless locally prohibited; connecting a small solar thermal plant to a district heating network receives a bonus of €500, in addition to the normal incentives for solar thermal installations.

There is much that the UK Government can learn from the incentivisation framework and investment environment established to encourage the deployment of large-scale solar thermal plants in Denmark and Germany.

INDUSTRIAL HEAT PUMPS

Industrial heat pumps are an established technology in Scandinavia, where they are deployed for the utilisation of the excess power from wind farms operating at times of low demand. In this role they utilise the excess electricity to produce hot water, which is held for long-term energy storage on a seasonal timescale, thereby transferring energy collected in the summer for later use in the winter months.

Heat pumps work by cooling a heat source (such as a body of fluid or the ground) and taking the acquired energy through a vapour compression circuit, broadly similar to that found in a mechanical refrigeration system. The heat input from the source causes a working fluid in the circuit to boil to vapour, which in turn is compressed to higher pressure and temperature in a compressor. This action requires work to be imparted, usually by an electric motor that drives the compression equipment. The (now high-pressure) vapour is subsequently delivered to a heat exchanger, commonly known as the condenser, where energy is transferred from the vapour to a process fluid (either air or water), thereby heating it. As energy is released from the working fluid vapour, it cools and condenses. This high-pressure liquid is then passed through an expansion device located in proximity to the original heat source, where it is allowed to vaporise again, which in turn draws more heat from the source. The heated process fluid is delivered as heat energy to a thermal storage network, as is the case for example in Denmark, and then used to heat buildings rather than being converted back to electricity, as in conventional storage systems. Typical heat sources for a heat pump are boreholes in the ground and bodies of water, which result high coefficients of performance for heat (CoP^h – ratio of heat delivered from the system divided by the driving energy input to the system; usually electricity consumed), as well as ambient air, though the CoP^h for the latter is significantly lower.

A significant benefit of developing and deploying heat pump technology is its ability to harness sources of low-grade heat that can otherwise be difficult to utilise, such as rivers, sewage treatment plants, underground aquifers and flooded mine workings, and where the ambient temperature can be close to 0°C. In these applications the CoP^h is typically about 3, whereas reclaiming the waste heat from 30–50°C heat sources, such as data centres, power station cooling systems and electricity sub-stations, can give a CoP^h of over 5. In a UK context, a recent report by BuroHappold suggests that there is sufficient low-grade waste heat in London for the support of heat pumps capable of delivering the capital city's total heat demand[51].

LARGE-SCALE HOT WATER ENERGY STORAGE

Large thermal storage facilities (or heat accumulators) vary in size, storage temperature and pressure from 95°C (atmospheric) to 125°C (pressurised). The largest currently in use is in Denmark and has a capacity of 75,000m^3 (height 40m, diameter 50m). They are often located adjacent to a power plant, where they provide three to five hours of maximum heat demand for the purpose of enabling CHP units to generate electricity, while simultaneously providing heat in the most cost-effective manner.

More recently, thermal storage pits have been developed for use on a seasonal timeframe in conjunction with large-scale solar thermal arrays. These store water at about 80°C, which has been heated in the summer so that it can be fed into a DH system in the winter. The water temperature is usually upgraded by heat pumps to elevate it to the required distribution temperature. Stores of this type with volumes as large as 400,000m^3 are proposed.

Denmark aspires to be completely 'carbon-neutral' by 2050 and plans to achieve this in part through the development of large-scale wind-based electricity production. At present, excess power generated during periods of low demand is exported to neighbouring countries, but increasingly it will instead be used to produce heat, either directly via electrical resistive heating or through the utilisation of large-scale (>5MW) industrial heat pumps deployed with sea and sewage farm sources. This heat will then be stored to resolve seasonal variation in demand.

WHAT NEEDS TO CHANGE?

The UK's extensive heat supply infrastructure is a product of 1980s' thinking, based on an assumption of the availability of an abundant unrestricted supply of cheap gas and therefore is not fit for purpose in the coming decades. Gas-based technology, processes and customer expectations are deeply embedded in the nation, for both domestic and commercial space and water heating, as well as cooking, and the UK faces a significant technical, social and political challenge in shifting to a secure, sustainable alternative to meet current and future heat demand. The first step on this difficult journey is to recognise the scale of heat demand in the UK, which is almost double that for electricity and transport applications combined, as well as recognise its significant seasonal variation, with winter consumption roghly of the order of three times that associated with the summer months.

For heat, as with all forms of energy supply, energy demand reduction must be the priority. To help achieve this, all new and existing domestic, commercial and industrial buildings should be insulated to meet current Building Regulation standards and have leakage paths and draughts eliminated. Additionally, these buildings should be equipped with genuinely SMART energy management systems that include optimised control of heat usage to meet the consumer's needs and preferences. These actions need to take a next step beyond the previous Government's legislative measures for private rented accommodation, by additionally embracing the full range of domestic and commercial building stock across the UK. This will need a similarly radical approach combining a legislative requirement for those who can afford to pay, for example owner-occupiers and commercial companies, to pay (possibly using key intervention opportunities such as building sale or extension construction as mandatory upgrade points), and a national scheme to cover the cost of the work out of general taxation for those who cannot afford to pay.

Beyond demand reduction, the technologies presented in this report for use at the individual building or property development level need to be considered as options for the sustainable supply of heat on a case-by-case basis. However, additionally the Government must, in all cases, ensure the selection of an appropriate installation by the domestic or commercial consumer through a mandatory approach. In this regard, not only will it be necessary to combine a legislative mechanism that makes the purchase of a sustainable system compulsory, with an appropriate financial scheme to support those who cannot afford to pay, but additionally the role of the installer community must be fully recognised and leveraged. Competent, trusted installers, through their unique position as valued advisers to their customers, are the key to a successful sustainable outcome for renewal of the UK's heat infrastructure. It is therefore important that Government ensures that this technical community of practitioners has the knowledge, expertise and skills to take a holistic view of a building's heat systems, for both energy demand reduction and sustainable supply, and to recommend installation of equipment that fits harmoniously with that view. In order to achieve such an aim, a compulsory 'free' national training scheme needs to be instigated alongside a mandatory competence registration, similar to the CORGI certification and registration (now 'Gas Safe Register'[52]) established as a legal requirement for gas installers in 1991.

Further to what can be achieved at the individual building or property development level, the Government needs to tackle the provision of larger pieces of national heat infrastructure, as well as the interconnection and integration of heat systems and networks with those for electricity generation and distribution. In this regard the UK heat infrastructure, from individual building to large-scale DH networks, should be declared 'national infrastructure' and dealt with in a holistic and strategic way. The global exemplar of a truly integrated energy system is in Denmark, where the power generation network, the heat energy network and multiple forms of waste stream are fully integrated to deliver a Sustainable Energy Network (SEN). The aspiration of the UK Government should be to learn from this existing system and adopt the approach within a UK context.

Figure 4 illustrates Denmark's exemplar SEN. The power network, depicted in green, is based upon a national grid supplied through electricity generated from different renewable sources (onshore and offshore wind, solar PV, hydro and others) in combination with the electrical output of large CHP plants (fuelled by waste, biomass and some fossil fuel). The heat network, shown in red, combines the heat output from EfW and EfB plants with that of large-scale solar thermal arrays, and incorporates upgraded heat from industrial heat pumps, all of which is supplied to consumers through a DH network that is almost nationwide. Finally, the waste streams are depicted on the diagram in grey and are shown supplying fuel/feedstock to EfW plants, including Anaerobic Digesters (where the biogas is either used directly as a source for heating, or is upgraded to bio-methane for use in transport or other applications).

It is important for Government and the UK public to understand how the nation's current unintegrated heat infrastructure evolved in response to the availability of abundant supplies of North Sea gas, and that it is no longer fit for purpose in the context of future energy security challenges and decarbonisation aspirations. The existing fragmented system needs to be urgently replaced, but the scale of the engineering task involved in undertaking the replacement and integration work, as well as the financial cost, should not be underestimated. In order to have energy-secure sustainable heating in the future, a nationwide heat network needs to be retroactively provided and, as in Denmark, this should be fully integrated with the power network as well as waste management infrastructure. For the UK, deployment of such an integrated system will require a significant change of mind-set at all levels of society and it is not simply a case of blindly deploying ideas and solutions from overseas; a clearly-defined, tailor-made and, above all, competently engineered approach must be taken at a national level. The cost of this is almost certainly beyond the means of the private sector and will, at least in part, have to be underwritten by Government through general taxation.

Figure 4: Denmark's Sustainable Energy Network (SEN)
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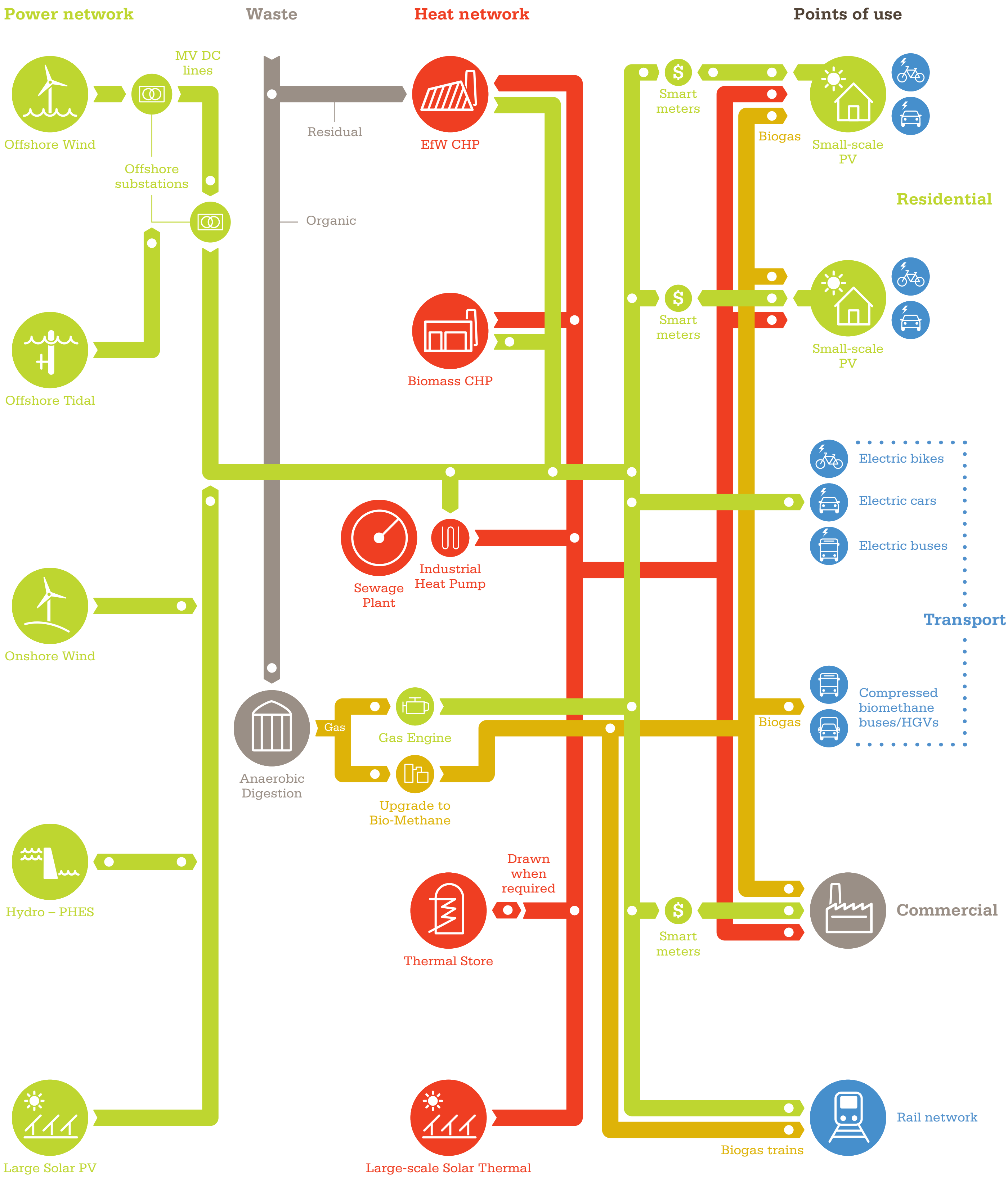

RECOMMENDATIONS

Renewal of the UK's heat infrastructure is urgently required to ensure that it is fit for purpose in the 21st century. In this regard the Institution of Mechanical Engineers recommends that the UK Government should:

1. **Declare all UK building stock 'national infrastructure' and instigate a legislatively driven insulation programme.** Such an action would need to go far beyond the Government's recently announced legislative measures to force landlords of private rented accommodation to improve the energy performance of their properties. For those who can afford to pay (eg owner-occupiers and commercial companies), key intervention opportunities such as, for example, the sale of a building, should be taken to impose mandatory upgrade points, linked to an incentive such as a reduction in stamp duty. For those who cannot afford to pay, a national scheme to cover the cost of the work should be instigated and paid for out of general taxation. These private and public sector approaches would not only reduce UK heat demand, but also create employment opportunities and allied skills development for installers, as well as tax revenues that would help offset the programme costs.
2. **Recognise the key role of the installer community and instigate a mandatory national installer 'sustainable heat' certification scheme.** Competent, trusted installers, through their unique position as valued advisers to their customers, are the key to a successful sustainable outcome for renewal of the UK's heat infrastructure. It is essential that Government recognises this and ensures that they have the knowledge, expertise and skills to take a holistic view of a building's heat systems, for both energy demand reduction and sustainable supply, and to recommend installation of equipment that fits harmoniously with that view. In order to achieve such an aim, a compulsory 'free' national training scheme should be instigated by Government alongside a mandatory competence registration, similar to the CORGI certification and registration (now 'Gas Safe Register') established as a legal requirement for gas installers in 1991.
3. **Tackle the provision of larger pieces of national heat infrastructure, as well as the interconnection and integration of heat systems with other energy networks.** The UK's heat infrastructure, from individual building to larger-scale District Heating networks, should be declared 'national infrastructure' and dealt with in a holistic and strategic way. The global exemplar of a truly integrated energy system is in Denmark, where the power generation network, the heat energy network and multiple forms of waste stream are fully integrated to deliver a Sustainable Energy Network (SEN). The aspiration of the UK Government should be to learn from this existing system and adopt the approach within a UK context.

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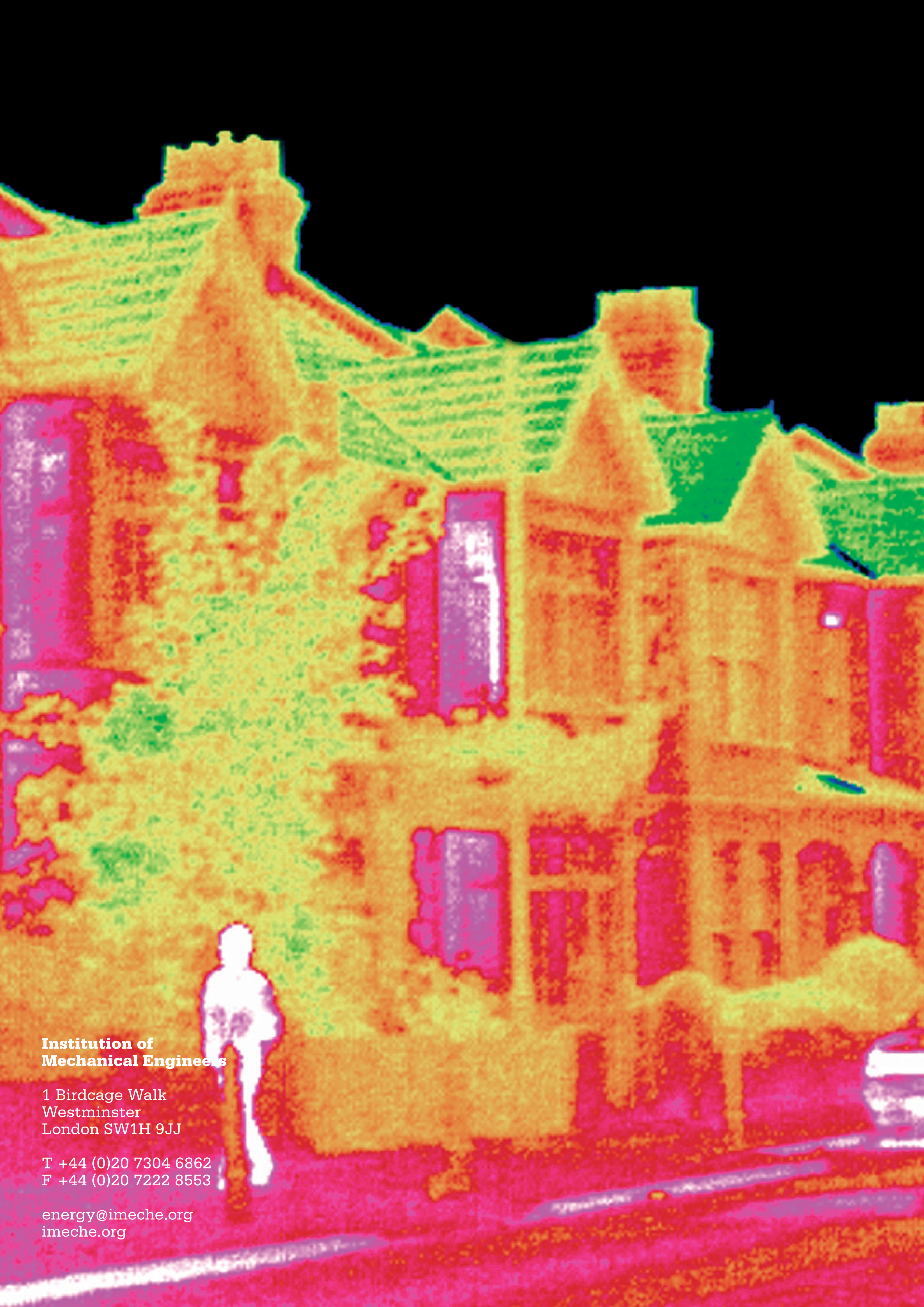

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