A review on house design with energy saving system in the UK

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Abstract

As part of EU incentives, the UK government have set ambitious environmental targets relating to energy consumption including a reduction of carbon emissions of 80% by 2050. The use of various technologies can help meet these targets as well as providing a secure energy source for the UK in the future. This research took the UK as a case study and investigated where reduction measures are most suited to reduce energy consumption. This paper presents a review on the current state-of-the-art on the domestic technology available, in particular solar energy, heat pumps, phase changing materials (PCMs) and micro combined heat and power (micro-CHP) systems, aiming at identifying research and development opportunities for energy saving in these fields. Furthermore, the financial as well as environmental aspects are assessed as these are the two key considerations of typical household. A typical UK house design, including the floor plan, is created through the use of computer aided design (CAD) software. The house design gives a payback period between 8.7 years at best and 11.6 years at worst.

Keywords: Energy consumption; solar energy; heat pump; phase change material; combined heat and power.

1. Introduction

In March 2007, European Union (EU) leaders committed Europe to becoming a, "highly energy-efficient, low carbon economy" [1]. This stems from the realisation that the use of finite resources creates economic, energy security and sustainability concerns as well as the health risks associated with the use of fossil fuels [2]. The targets set include a minimum 20% reduction in EU greenhouse gas emissions (GHG) below 1990 levels, raising the share of EU energy consumption produced from renewable resources to 20%, and a 20% reduction in primary energy use (compared with projected levels) to be achieved by improving energy efficiency [1]. In addition, the EU has offered to increase its emissions reduction target to 30% in 2020, provided that other countries commit to similar ambitious reductions.

In the UK, the Government has taken a number of steps to limit the emissions of greenhouse gases through legally binding targets, both now and in the future. The climate change act commits the UK to reducing GHG emissions by at least 80% in 2050 from 1990 levels [3, 4]. This target was based on advice from the committee on climate change (CCC) report: Building a Low-carbon Economy. The 80% target includes GHG emissions from the devolved administrations, which currently accounts for around 20% of the UK's total emissions. There are sceptics who think the UK will fall short of the targets set for 2020. Data shows that in 2010, the UK produced just 6.5% of electricity from renewable sources, 3.5% short of its target [5]. In 2011 this climbed to 9.6%, still short of the 2010 10% target and well below what is required of the binding legislation, Climate and Energy Package, set by the EU.

Buildings are responsible for 40% of global energy use and contribute towards 30% of the total CO_2 emissions [6]. The Energy Performance of Buildings Directive 2010/31/EU requires efficiency improvements to be implemented in all new EU buildings, with a requirement that from 2020 all new buildings constructed should be "nearly energy zero" [7]. Buildings and other developments can also damage the environment, through poor waste management of inefficient use of resources. Therefore, energy efficiency in buildings is critical in order to reduce the energy use and improve the local environmental sustainability [8, 9]. The UK is facing a significant but exciting infrastructure challenge. This paper provides a comprehensive review of the available methods for analysing and evaluating energy performance in buildings within the UK.

1.1 Energy efficiency in the UK

Within the UK, there is a large push towards micro generation. This is defined as,

"the small-scale generation of electrical power, through means such as solar or wind power."

Households create their own energy through renewable sources such as solar, wind or, in some cases hydro power. The government is pushing individuals to generate their own energy through incentives such as reduced value added tax (VAT) on micro generation products, capital grants for householders and Government policies, such as the Renewable Heat Incentive (RHI) [10] and the Feed-in Tariff (FIT) [11].

Electrical generation in the UK

The trend in UK electrical generation closely follows the demand. Electrical generation has reduced slightly over the past three years but not significantly. Table 1 lists the details of the total generation versus supply [12]. In the last three years, the UK government have had to increase imports on electrical energy from other countries. Table 2 shows how these have changed over the last three years compared to the energy usage within the UK [12]. Of the 2013 generation, approximately 30% was produced from primary sources such as nuclear, wind and hydro while 70% from secondary sources such as coal, gas and oil [13]. Approximately 30% of usable electrical energy generated is used within the domestic market. This is more than any other field, albeit only slightly more than industrial usage at 26% or transport and services at 28%. It demonstrates that the domestic sector has a large impact on the electrical energy usage within the UK and any reduction in usage will have a profound effect on the overall electrical generation. Figure 1 demonstrates the electrical production and usage within the UK. What is striking about this is the vast amount of energy lost in conversion, transmission and distribution within the network. If the properties can produce electricity on site and not require any sort of input from the grid, this would not only reduce these losses but also reduce the reliance on fossil fuel. Micro generation technology such as solar, wind and micro combined heat and power (micro-CHPs) may be the solution required to bring in these changes required to meet such targets as mentioned in the introduction [14-16].

Baxi, a British boiler and micro-CHP company, claims that the use of multiple CHP systems built close to the power consumption point would be much more efficient than having centrally located power plants, due to the energy lost in transmission and transportation. They also claim that the use of six million Baxi Ecogens would generate enough electricity to allow one power station to close [17]. If a move away from finite resources, such as gas, and a transition to cleaner energy is to be realised, a cleaner and cheaper source of electricity needs to be exploited. New technologies in the national grid, such as the smart grid, can allow for larger loads on the network. A recently announced, government-backed proposal for lagoon power plants would also allow for electricity generation to be increased as and when is required by the grid. However, these are in the preliminary stages of planning and would not be operational until at least 2022 [18].

It is generally accepted that for the UK to meet its ambitious carbon targets, as explained in the introduction, then electricity should be generated from renewable sources. The Committee on Climate Change (CCC), an independent advisory board to the government, gave predictions of what could happen to the carbon intensity of electricity generation until 2050. This is demonstrated in Table 3 [19]. If the government's ambitions on renewable energy and low carbon sources are met, these targets could be achieved on schedule. Even if these targets are not met completely, as the carbon intensity of the energy supply reduces, the impact on the emissions of heat pumps will also reduce.

1.2 Energy efficiency programmes and their effect on the UK economy

In order to reduce Carbon emissions, the UK launched the Low Carbon Buildings Programme in April 2006. This scheme gave grants to homeowners and businesses with various on-site micro generation installations such as solar power, heat pumps etc. However, it was not taken advantage of by the public as shown in the Figures from the first two years in operation. Only 444 grants for ground source heat pumps were awarded in the years between 2006 and 2008 [19].

The influences on sales of environmentally friendly energy solutions include the climate, government policy, energy prices, availability of competing energy resources, electricity supply and generation characteristics, housing characteristics, history, geography and geology. For example, a large growth in heat pump sales has been recorded in New Zealand. One reason is that New Zealanders tend to heat one room in the house rather than the whole home as in the UK. The majority are also used for cooling as well, meaning that energy is required all year round. There are also very different economic, technical, energy-related and social contexts in New Zealand to the UK [19]. In Sweden, many elements have contributed to the rise of heat pumps as a popular form of heating. These include high awareness in the public space, environmental concerns and a government support programme [20].

The UK government have a target to achieve 12% of heating in domestic buildings from renewable sources by 2020. In light of this, the government created two schemes designed to attract homeowners and businesses to using micro generation techniques: The Feed in Tariff and the Renewable Heat Incentive. Many open published literatures have commented on how financial incentives can be very effective in attracting customers to using green energy systems [20]. Although the ultimate goal is to have a completely carbon neutral country, it is not necessarily desirable to achieve this in a short timeframe.

As various incentives come to fruition, there is a concern that the skills required to meet the demand of installations are lacking. This could result in the public becoming disillusioned and reacting against energy saving installations. This is of particular concern within the heat pump industry where installation requires a high skill level to achieve suitable results. Evidence in Japan showed a premature uptake of solar installations due to a government-backed grant. The skillset was not available which lead to substandard installations and a backlash against the industry [21]. Further evidence from Singh et al. showed that the loss in consumer confidence is something that the government is concerned with [22]. This could have a long term effect on the popularity of heat pumps within the UK and is something that the government need to take into account. However, if there is little demand for heat pumps, possibly as a result of no government backing, there will be little incentive for companies to acquire the necessary skills. It is a fine line that the government must balance. Over time the government have been flexible with the amount of backing given through various schemes. Initially incentives have been high in order to encourage early adopters. The incentives for the end user tend to track the costs of adoption for the technology. The Department of Energy & Climate Change (DECC) notes that the government originally intended for users to receive a 5% payback through the feed in tariff scheme. The tariff has therefore had to adapt in order to follow this 5% rule.

Feed In Tariff

The feed in tariff (FIT) is a government backed scheme that is designed to promote the use of small scale, renewable energy. Introduced in April 2010, users receive payments for each kilowatt hour produced though renewable sources and for each kilowatt hour sold back to the national grid [5].

The following renewable energy technologies are eligible for the scheme:

- Solar photovoltaic (PV) with a total installed capacity (TIC) of 5 MW or less
- Wind with a TIC of 5 MW or less
- Hydro with a TIC of 5 MW or less
- Anaerobic digestion with a TIC of 5 MW or less
- Micro combined heat and power (Micro-CHP) installations with a TIC of 2 kW or less.

As previously noted, the rate paid for each unit of energy generated and each unit of energy exported back to the grid has been reduced since its introduction in 2010. Consultations were carried out by the government to reduce the FIT rate as it was no longer economically viable. This was mainly due to the prices of the micro generation projects reduces so much. Although the government originally aimed the FIT to provide a return of approximately 5%, the lower initial cost meant that much higher percentages were being realised. An initial reduction was announced on 9th June 2011, with further reductions on 31st October 2011 [23]. The initial reduction announced in June 2011 shows a reduction of between 38% and 72% in the FIT (Table 4) [17]. The number of registrations for the FIT is demonstrated in Figure 2.

The surge in registrations before the new rate is applied is repeated before every new reduction in the tariff thereafter. These peak periods show the time where users can install micro-generation systems for the least amount of money but still get the higher rate from the tariff. This demonstrates that the financial gains are an important factor for users when considering installation of micro-generation systems. Since these reductions, further reductions and variations of the FIT have been created, including different rates to suit different technologies used and different capacities generated. Current FIT rates are displayed in Table 5 [24].

Renewable heat incentive

Another strategy from the UK government, designed to achieve the targets set by the EU, is the Renewable Heat Incentive (RHI). It incentivises users, by means of financial reward, to use renewable energy when powering their home. Initially created for the non-domestic sector, the domestic RHI was launched in April 2014. It provides quarterly payments for seven years for the amount of clean energy used in the households heating systems. Although it is available to all users, both on and off the gas grid, users off the grid may find it easier to reach the savings targets set as they tend to have the most potential for saving.

The incentive is available for the following heating types:

- flat plate and evacuated tube solar thermal panels;
- air source heat pumps;
- ground source heat pumps;
- biomass only boilers and biomass pellet stoves.

As well as using at least one of the four heating systems stated, users must also stay within the regulations of the incentive. If this is the case the users receive payments for the amount of energy produced from that heating system. Table 6 shows the details of the payments households receive per kilowatt hour through the RHI [25].

A user should note that regardless of whether the dwelling is attached to the energy network or not, they will still receive payments for the energy produced. If the dwelling is attached to the network, this opens up the possibility of selling energy back to the grid through the use of the governments FIT scheme.

In the first eleven months, 25,000 domestic dwellings were accredited to receive domestic RHI payments, saving nearly 1.4 $MTCO_2$ over their membership lifetime [24]. It is mainly aimed as households that are not attached to the mains gas supply.

1.3 Factors affecting the energy efficiency of a building

In order to reduce the energy usage of a building, it is important to identify what is the main usage of energy and where the most efficiency gains can be made. With data from government sources and studies carried out, the sources of emissions by the end user can be categorised into heating and domestic hot water, lighting and large electrical appliances.

According to the Department of Energy and Climate Change (DECC):

- energy used for heating homes has increased by two-fifths since 1970, although it fell from 2004 to 2009;
- less energy is used now for water heating and cooking in homes than it was 40 years ago;
- more energy is now used for lights and appliances in homes than it was in 1970 [25].

Figure 3 demonstrates the key aspects of creating an energy efficient building. It details the use of both active and passive systems that contribute to a low energy building. Passive design strategies such as the building envelope and orientation allow the building to utilise solar irradiation as well as providing more light. The use of energy efficient technologies to meet the electrical and heating demands of a building is also demonstrated. These will be focused on in the current paper.

Energy usage

Energy usage is strongly dependent on users' behaviour and varies massively between individuals or households. It is extremely important when considering energy usage to take an average of a usage in order to evaluate what is the most suitable to the maximum number of users. It is also important to evaluate this over a relatively small area as climates and therefore usage can change dramatically from region to region. For example, space heating usage in the north of Scotland tends to be higher than that of the south of England, where ambient temperatures are typically slightly higher [26].

Within all housing throughout the UK the median electricity bill is £424 based on annual usage of 3,300 kWh. The median gas bill is £608 based on annual usage of 16,500 kWh according to the Office of Gas and Electricity Markets [27]. The ratio of average energy used between electricity and gas is roughly 1:6. The total energy usage is equal to almost 5.5 tonnes of carbon dioxide per household annually.

Figure 4 shows the average fuel usage per household in the UK. It is obvious that if emissions can be cut from heating, it will have a large impact on the emissions generated. Hot water and appliances are also responsible for a large percentage of emissions so it is important to analyse how these can be reduced remarkably.

The Low Carbon Transition Plan has set a transition budget to reduce the demand for gas to heat UK homes by 27% of the 2008 Figure by 2020 [28]. This must either be done by replacing gas heating with another form or creating better insulated buildings to reduce gas consumption. There are approximately 21.9 million consumers attached to the gas network within the UK [29]. As the UK gas network is divided into various networks, the number calculated is the total from each of the networks consumer base. The networks used are Wales and West Utilities, Northern Gas Networks, The National Grid and SGN. This has a large impact on the type of energy supply chosen for a household as gas is cheap and relatively easy to install.

In the last 40 years, installation of central heating systems has increased rapidly, leading to less than 4% of housing not having it installed (see Figure 5). This has led to an increase in average household temperature from 13.7 °C to 17.3 °C, due in part to the increased aspirations of warmth and expectations of how this can be achieved [26].

According to the UK Housing Energy Fact File 2013, a government-produced document detailing energy usage in UK homes, the percentage of a households energy used on lighting has increased steadily from 1970 to 2002. However, from 2003 till now it has reduced as a faster pace [30]. This aligns with the withdrawal of the sale of incandescent light bulbs and the advent of energy saving bulbs such as compact fluorescent lamps (CFLs), halogens and light emitting diodes (LEDs). Although the usage of light bulbs has increased, especially in kitchens and bathrooms, the use of energy saving bulbs has reduced the energy consumption massively. The UK government have said the banning of incandescent light bulbs will bring an "average annual net benefit" of £108m to the UK between 2010 and 2020 in energy savings. It is also predicted to bring net savings each year of 0.65 $MtCO_2e$ and 0.3 TWh by 2020 [31].

Energy usage per capita peaked in 1990 and has now decreased by 15% since. However, there has been approximately a 10% increase in population since then. Overall this means energy consumption in the UK has reduced slightly since 1990 [2]. For heating and domestic hot water, Scotland has the largest average gas consumption per meter of the whole of the UK. The south east of England has the least [25].This is not surprising due to the difference in climates.

Energy rates in the UK

The largest energy company in the UK is British Gas, serving approximately eleven million homes as well as nearly one million businesses in the UK [32]. The rates of their standard variable tariff are detailed in Table 5 and these are the rates that will be used when calculating the financial viability of various design features.

Table 7 shows the cost varies dramatically from different energy sources for each unit of energy. Electricity is roughly three to four times more expensive than other forms [32]. The price of oil on the international market affects the price of the domestic energy and this is shown in Figure 6 as domestic oil prices roughly follow that of electricity [30]. Although this is generally the case, there seems to be a dip in the oil price between 1998 – 2003. The other energy sources seem to either stay fairly stagnant or rise around this time.

1.4 Domestic dwellings within the UK

In order to affect the most households and therefore decrease the largest amount of overall emissions, it is important to establish which dwelling type is the most common in the UK. According to the Office for National Statistics 2011 census, of the 23.4 million households in England and Wales, 42% are 3 bedroom houses. It also shows that most popular type of dwelling is a semi-detached house which makes up 30.1% of housing with a usable floor area of 91 m². The most common number of people in each household is 2. The average usable floor area is 91 m². This data is all taken from England and Wales due to this being the largest proportion of the UK. The data was not available for the UK as a whole [33].

According to the English housing survey 2010, the average ceiling height is 2.5 m. However, this is gradually reducing due to standard plasterboard being produced in 2.4 m high pieces [34]. Within UK homeowners, the average household moves every 7 to 8 years [35]. If this is taken into consideration, it is reasonable to have eight years as the maximum payback period for investing in new energy saving technology. Although some may argue that it is worth the investment for the environmental impact alone and that it can add value to the property, this must be taken into account as it is a consideration that most people will concern.

In 2014, 137,010 new houses were built in England, an increase of 10% over the previous year although 25% lower than the peak in 2007 [36]. As more new houses are built, bringing the benefits of better insulation and newer technology, the energy usage will reduce and the opportunity for more technology to be implemented is increased.

Figure 9 shows the conditions that are deemed comfortable are between 19 °C and 28 °C according to the ASHRAE-55 Standard. The blue and red zones represent the clothing insulation level typically worn when the outdoor environment is warm and cool, respectively [37]. Anything above or below this will be considered too hot or too cold. The humidity also changes the most comfortable operative temperature, with anything about 90% considered uncomfortable. These standards will be maintained throughout the study when possible.

1.5 Standard assessment procedure

The Standard Assessment Procedure (SAP) has been adopted by the government in order to assess and compare the energy and environmental performance of domestic dwellings. Developed in 1992 as a tool to help deliver energy efficiency policies, it provides an accurate and reliable assessment of energy performance in domestic dwellings. More recently, it has been adapted to the Reduced Data SAP (RDSAP) in order to cut the costs of performing the procedure. This still gives an accurate assessment with the less important data left out. This is used for existing buildings. However, for new buildings the standard SAP is undertaken [38].

SAP works by defining a certain level of comfort and calculating how much energy is required to maintain that comfort level. It is based on assumptions for occupancy and behaviour and, therefore must be taken only as a guide as it could be different for larger or smaller households with varying usage patterns. SAP enables the user to compare the energy efficiency properties for dwellings on a like-for-like basis.

The outcomes of SAP are given in terms of:

- The energy usage per unit floor area;
- A fuel-cost-based energy efficiency rating (SAP rating);
- Emissions of CO_2 (Environmental Impact Rating);

These are all calculated, based on the estimation of the annual energy consumption from heating, domestic hot water (DHW), lighting and ventilation. Every new house has to have a SAP rating which is expressed on a scale of 1 to 100 - the higher the number, the better the rating. The latest version of this document is SAP 2012 version 9.92 [12]. Although use of SAP is widespread throughout the building industry, there have been studies that demonstrate that it is not as accurate as it could be and can lead to perverse incentives being created and therefore, additional CO_2 emission [38].

1.6 Energy efficiency technology and their financial viability

A large factor in reducing energy consumption is the use of technology when generating electricity or heat. There are many technologies that the user must consider in the design of a building that all have various advantages and disadvantages. The use of technology can be affected by many variables including geographical location and the access to local gas and electricity networks. For example, the use of solar panels may be more suited to a hot country with a high solar irradiance whereas the use of wind turbines will be more suited to locations where wind speed is high, constant and steady.

1.7 Heat pumps

As part of EU directives to increase the energy efficiency within buildings, heat pumps have become a very popular as a source of heating [39, 40]. They come in two forms: a ground source heat pump (GSHP) [41, 42] or an air source heat pump (ASHP) [43, 44]. These both work by extracting low temperature heat from the surrounding land (typically a garden) or air and increasing the temperature through an electric pump and compression system [19]. The GSHP has a pipe that is buried usually about two metres below ground. At this depth the temperature of the ground can be very different to that of the top layer and stays at a constant temperature. This allows the heat pump to work effectively all year round as the temperature remains fairly constant. The more common type is an ASHP which draws air in through a fan. They can usually operate at temperatures as low as -15 °C when, even at this low temperature, heat can still be extracted.

For some reasons, heat pumps have not had the popularity in the UK that has been demonstrated in other parts of Europe [45]. Figure 10 demonstrates the number of heat pumps in the UK compared to other countries within Europe. This lack of uptake may be due to lack of awareness of the technology or simply due to economic reasons.

There are a few countries in the EU that contain a large market for heat pumps, including Germany, France and Sweden. However, in many other countries the market remains small. Data from sales show that 102,400 GSHP's were sold in the major EU markets in 2007 (14 countries). Popularity of ASHP was 4.5 times more than that of GSHP in eight European markets in 2008 despite lower energy efficiency credentials. The global financial crisis in 2008 led to a drop in sales of heat pumps throughout Europe. Since 2008 demand for heat pumps of both formats has been very changeable with a decrease of 7.9% in the heat pump market between 2011 and 2012 [46].

Efficiency

The major benefit of using heat pumps is widely considered to be the energy efficient credentials that they achieve. This can not only reduce energy bills but also reduce the carbon footprint of the building [47]. According to the energy saving trust, users changing from a non-condensing gas system to a ground source heat pump can save between £410 and £595 per year. This is not including the government funded Renewable Heat Incentive which provides a payment of 19.10 p/kWh generated from the GSHP or 7.42 p/kWh for ASHP [48].

When calculating how effective the use of a heat pump is with various heating systems and insulation levels, the coefficient of performance must be calculated. This will indicate how many units of heats can be generated from one unit of energy input. The maximum theoretical coefficient of performance (COP) of a heat pump in terms of the Kelvin temperatures of the warm condenser (T_1) and the cool evaporator (T_2) is:

$$COP_{max} = \frac{T_1}{T_1 - T_2}$$

where T_1 is the temperature of the warm condenser and T_2 is the temperature of the cool evaporator.

Fawcett et al. suggest that the maximum COP for a heat pump providing a temperature of 35 °C when the outside temperature is 2 °C is 9.3. However, this is reduced if the heat pump is connected to a high temperature heating source such as radiators or used for DHW. In reality this high level of efficiency is difficult to be achieved. One company suggests that the use of an ASHP barely improves the efficiency over a condensing boiler which is not only cheaper, but also easier to install (An ASHP has a COP of 1.75 with this setup compared to an efficient condensing boiler of between 1.7 and 1.9) [49]. However, the ASHP would only be more suitable if there was no mains gas supply to the building.

This is a theoretical efficiency and it does not take into account any discrepancies such as temperature fluctuations and heat loss in the system. An obvious but important observation is that, as the difference in the temperatures reduces, the efficiency of the heat pump increases. Table 8 demonstrates the relationship between the input and output temperature and the coefficient of performance of two air-source heat pumps. The efficiency of the heat pump is dependent on the difference in the temperature of the warm condenser and the cool evaporator. When a large difference is present, the efficiency of the pump drops dramatically. For this reason, heat pumps work most effectively when used in conjunction with a low temperature heating solution such as under floor heating (typically operates at 30-35 °C) and oversized radiators (typically operates at 40-55 °C) [19]. With the temperature of traditional heating systems of about 60-75 °C, the COP of a heat pump reduces dramatically. Again this means that for a lot of UK households, having a heat pump will not be as efficient as first thought unless a new heating system and insulation is installed.

Despite being part of the RHI, there is evidence that the installation of a heat pump is not as environmentally friendly as first thought. In terms of CO_2 emissions, the average heat pump actually produces more CO_2 than a gas condensing boiler due to electricity production within the UK. According to a report on the role of heat pumps in the UK, the energy generated in the UK is carbon intensive [50]. As heat pumps require electricity to operate, the carbon emissions generated rely on having a clean source of electricity supplied to the pump. This means that heat pumps can only be effective in reducing the carbon emissions of a household if the supply of electricity is a clean, low-carbon source.

Figure 11 details how the carbon emissions of a heat pump are currently higher than that of a gas boiler [19]. As electricity is generated from cleaner sources, this will change in favour of heat pumps. There is much literature suggesting that in order for this to change, three transitions unrelated to heat pumps must occur:

i) A transition to low carbon electricity supply;
ii) A transition to well-insulated housing stock via retrofit;
iii) A transition to low temperature household heating systems [19].

Unfortunately all three of these conditions require long term investment, especially within the UK where the housing stock is relatively old [51]. If all three conditions are met, the use of a heat pump could be an efficient and environmentally sound option for generating heat within a domestic dwelling.

Other issues

Heat pumps are quite complex machines that require a specialised installation. This means there are few people with the skillset to install them, which increases costs. As they become more popular, it is reasonable to presume that more installers will be trained, resulting in a lower cost and higher quality installation [22]. Heat pumps also have a predicted longer working life than that of conventional gas boilers (25 years compared to 15 years) meaning they could provide a more suitable long term investment. As heat pumps use electricity to generate heat, often at peak periods, it may be challenging for the government to meet these demands. As previously mentioned, the introduction of a smart grid and cleaner technology should reduce this issue.

Fawcett et al. are very positive about heat pumps at the start, saying that they are widely believed to be a major contributor to reducing carbon emissions in UK heating supply [19]. However, it goes on to say this view of the future is a long way off as the current use of heat pumps is very low. The main reason could be the installation cost and that installation only seems to take place in housing unconnected to the main natural gas supply. The paper also says that an efficient gas condensing boiler will produce lower carbon emissions than a heat pump due to the high carbon electrical supply that the UK has. However, there is no reference for this or much information backing it up so should not be taken as solid information. As more modern houses are being constructed (160,000 every year according to the UK housing fact file 2013), the use of heat pumps will become a more viable option, due to better insulation values and a more realistic option to install low temperature heating systems.

Financial viability in house design

As mentioned previously, the financial aspects are very important to most people when considering energy use in the home. The weak uptake in the UK is partly due to the upfront costs being far too high and the reduction in bills seems too small to justify it. A survey of GSHP adopters shows that most were happy with the installation but only 40% got the financial savings that they expected [52]. This either means that they had unrealistic expectations or that it the heat pumps were not saving as much money as they could do. The survey found that most of the adopters found the system not easy to use and a quarter of users complained about the slow response time and inability to heat rooms to the required temperature. The energy saving trust suggests that, in general, the simpler the heat pump setup, the more efficient the system is which explain that complications in using the system may result in a lower efficiency.

According to the energy saving trust, if an old electric heating system is used, the user could save approximately £420 per year for a GSHP or £300 per year for an ASHP. However, compared to a gas boiler costing around £2,500 to install, the annual cost seems to be very similar due to gas being significantly cheaper than electricity [53]. The cost of installation of an ASHP is between £7,000 - £11,000 and while for a GSHP is £11,000 - £15,000. The Office of Gas and Electricity Markets predicts that electricity costs will rise relative to gas [24]. The report compared four different scenarios with all four showing a rise in electricity prices compared to gas in the UK. This means that the cost of using a heat pump may increase compared to that of a gas boiler. Obviously price is a large factor when purchasing a new heating system and these results do not favour heat pumps. With financial backing from the government, this could be offset to become slightly more reasonable. However, most of the evidence suggests that running costs will not be reduced significantly over the lifetime of the product [53]. This also continues to suggest that the quality of installation of the heat pump plays an important role in the efficiency. As installers gain more experience as sales increase, the efficiency of heat pumps should also increase.

The FIT is not available to users of heat pumps. However, the RHI provides a favourable rate of 7.42 p/kWh for ASHP and 19.10 p/kWh for GSHP. When calculating the payments of the RHI, the estimated annual heat load is required for the building. This is provided from the Energy Performance Certificate (EPC) for the building. A Seasonal Performance Factor (SPF) that measures the efficiency of the heat pump is also required. The heat pump changes efficiency depending on the difference in temperatures, as was previously detailed. This means that a high degree of insulation will be required in order for the heat pump to be effective and maintain a high SPF. If the SPF is below 2.5 then the heat pump will not be legible for the RHI scheme. This ties in with the difference in efficiency of gas boilers and heat pumps demonstrated in Figure 11. In order to calculate the annual energy suitable for the RHI the estimated annual heat load is multiplied by (1-1/SPF) [27].

Without a reliable set of information, it is difficult to predict exactly how much energy and money would be saved as a result of installing a heat pump. However, in a new build house with a low temperature heating system, such as under floor heating, it can be assumed that the use of a heat pump would be economically viable. As electricity sources become cleaner, the use of a heat pump will also gradually improve the environmental aspects. Also with the use of solar PV panels, electricity generated on site may also allow the energy used to be clean.

The average annual UK heat demand is 14,256 kWh (space heating and DHW from Figure 4). A heat pump with an SPF rating of 2.6 is used as a demonstration to show how the lowest suitable efficiency will provide a payback. The annual suitable energy is calculated using the following formula:

$$Annual\ suitable\ energy = 14{,}256\ \times \left(1 - \frac{1}{2.6}\right)$$

This gives an annual suitable energy of 8773 kWh which is multiplied by the rate for a GSHP (19.10 p/kWh) giving an annual payment of £1675.62. As the RHI is only available for 7 years, the total from the RHI is £11729.40. This is the worst possible outcome as the SPF rating could be larger due to great insulation and a low temperature heating system being implemented. If the SPF rating of the heat pump was higher, for example 3.6, the annual suitable energy for the RHI would be 10,296 kWh, providing an annual payment of £1966.54 or £13,766.75 over the RHI duration. Due to heat pumps using less energy per unit of heat energy provided, the cost of heating is decreased. The energy savings trust predicts a reduction in fuel bills by about £410 - £595. However, this is when compared to an old non-condensing boiler, not a new efficient boiler. Although there does not seem to be much research into how much energy is saved, it could be expected that the savings will be minimal, if anything at all.

In a new build with a high level of insulation and low temperature heating system, the SPF achieved by the heat pump will be high, meaning the financial viability is suitable. However, this does not take into account interest rates and is relying on a highly efficient house design anyway. In terms of environmental savings, heat pumps can perform well and will increase in performance as electricity generation becomes cleaner. However, Fawcett et al. compared to a modern gas boiler the average heat pump installation and concluded that the average ASHP installation generates 38% more emissions than a modern boiler. The average GSHP generates 14% more emissions. As has been discussed, the complex installation of a heat pump, lack of skills in the UK and high reliance on fossil fuels could contribute to this as will the lack of low temperature heating systems and insulation. As these change over time, the use of heat pumps will become more and more efficient.

1.8 Solar

One renewable energy source that is largely untapped is that of the sun. Energy can be harnessed from the sun to generate electricity and also heat. In a similar way to heat pumps, the influence of government incentives, reduced costs and environmental credentials have boosted the popularity of solar energy generation. Use of photovoltaic (PV) panels for electricity generation has increased massively in the UK over the past few years due to a reduction in costs, government incentives and greater public awareness of climate change [54].

Due to human activities, the climate has been changing massively in the last few decades. One aspect of this is the change in cloud formations, which has an important influence on electricity generation within solar panels. By 2080, summer cloud cover is expected to decrease in southern England by up to 18% but increase in parts of northern Scotland by up to 5% [55]. During the winter period the cloud cover is predicted to be fairly small but still occur. This will have a profound effect on how much energy is produced through solar techniques in the future.

Definition of Solar Irradiance - *The rate at which radiant energy is incident on a surface per unit area of surface measured in W/m^2 (watts/meter squared)* [56].

Figure 12 demonstrates how the most suitable location in terms of solar irradiance in clearly in the south of England [54]. Although Scotland would still allow some solar generation, there are areas, particularly in the highlands, where the solar irradiance is almost half of what is available on the south coast of England (about 74.5 Wm^{-2} compared to 123.4 Wm^{-2}).

Photovoltaic

Photovoltaic (PV) panels can provide electricity using energy harnessed from the sun. Recently the popularity of solar panels has increased dramatically, prompting the government to revise up the estimated energy generated through PV systems [57, 58]. This surge in popularity has been the result of plummeting installation prices, helped by numerous Chinese manufacturers entering the market and various government backed incentives throughout Europe [59]. A 2 kW solar PV system on a roof in the UK should save 1 tonne of carbon a year. However, as will be discussed later, the location within the UK can have a significant effect on the output of the system.

Solar thermal

In a similar way to PV systems, solar thermal technology allows heat energy to be generated from the sun, primarily for hot water purposes [60]. According to the energy saving trust, it can reduce hot water bills by approximately £65-£125 per year depending on the system that it is compared to (a gas system costs less to heat water than an electric system and therefore saves less money comparatively). The use of solar thermal technology also qualifies for the RHI making a predicted saving of £195 annually for a two person household. This rises to £470 when a household contain six people.

Hybrid (PVT)

A hybrid of PV and thermal panels (PVT) allows the user to generate heat as well as electricity [61-63]. A PV system can reach high temperatures which affect the efficiency of the system. By using a cooling fluid, not only can the PV system become more efficient, the heat extracted can be useful for DHW or space heating. However, larger costs and a conflict between efficiency in the electrical and heating production associated with hybrid systems have restricted uptake in the mainstream [2].

One study has found that 51% of the total electricity demand and 36% of the total hot water demand over a year for an average house can be covered by a photovoltaic thermal hybrid system [2]. In this assessment, the flow rate of the PVT system and the covering factor of the collector with PV were changed in order to assess the more effective combination. Other conclusions are also drawn that can maximise the efficiency.

Figure 13 shows a schematic diagram of the hybrid photovoltaic thermal system, detailing the energy flow within the system. With the bypass deactivated, the normal operation consists of water being pumped to the solar collector where it is heated. This then flows through the water tank, heating the tank contents as it flows and then returns to the solar collector, via the pump to be re heated. There is a bypass valve that allows the water to be passed through the collector without losing heat in the tank. This is to ensure that the water increases the temperature within the tank rather than decreasing it. When hot water is required, it is pumped through an auxiliary heater in order to heat the water to a suitable temperature. When this temperature is below that of the water contained in the tank, the water is mixed with the cold water supply in a mixer. The study using this design is solely focusing on the efficiency of the heating system so the use of a mixer is not being considered.

In order to achieve these results, it was concluded that the system must adapt to the following conditions:

- The pump ceases operation between 6 pm and 6 am the next day. This is due to very low solar irradiance and the temperature of the PVT unit being lower than that of the water entering the collector.
- Water bypasses the storage tank and is re-circulated through the PVT unit when the water temperature is between the inlet flow temperature and the hot water storage tank temperature. In the test this occurred between 6:30 am and 9:00 am.
- Bypass is deactivated, sending water through the tank heat exchanger when the temperature is higher than both the exit of the collector and the temperature exiting the heat exchanger.
- Even though between 17:30 and 18:00 the temperature difference in the input and output of the collector is smaller than the temperature difference in the input and output of the exchanger, the bypass is still deactivated and the pump is still run. This was found to be beneficial as less heat would be lost from the collector.

This could change depending on the type of PV and thermal panels used as well as the location of the building. This test was carried out on a house in London where the solar irradiance is vastly different to other parts of the UK (see Figure 12 map). The timing of the test is also important. As this was undertaken on a day in July when the days are long and the solar irradiance is high, the results could be vastly different to those in the middle of winter. The system could be developed to automatically adjust the pump activation with regards to solar irradiance and various temperatures within the system in order to achieve maximum results.

Solar angle

The angle and orientation of the panels are extremely important with the face of the panel perpendicular to the sun for the longest time possible [64]. It has long been accepted that panels should point towards the equator as this receives the most solar irradiance. However, the optimum angle can change between location depending on monthly, seasonal and yearly variations in solar radiation [65], mainly due to the angle of the sun varying as the seasons change. In the middle of winter, the sun is lowest meaning the angle of the solar panel needs to be much larger to the horizontal surface. Similarly, the angle should be lower to the horizontal as the sun rises in the peak of the summer. The change can be so large that even within one city the optimum angle can be between 20° and 30° with a small change in the efficiency of the panel [66]. As the sun also moves throughout the day, the most appropriate angle should be selected to capture the maximum solar irradiance.

Many studies have been undertaken to find the most suitable average angle for solar PV and thermal panels over the years. According to Siraki et al, the most suitable angle can be calculated with the following steps. For the average household this is a complex procedure to undertake and requires a vast amount of knowledge and many calculations. To simplify it, the angle of the sun can be calculated and the suitable angle of the panels (perpendicular to the sun) predicted. This may also be constrained by the angle of the roof that the panels will be mounted upon.

Glasgow has a latitude of 55.86° North and longitude of 4.25° West with an average annual solar irradiance of approximately 96.3 W/m^2 [67]. During the winter solstice, the angle of the sun in Glasgow is approximately 11° to the horizontal, while the summer solstice it rises to 58°. The spring and autumn equinox have an angle of 33° (see Figure 15). Both the winter and summer solstice angle is only available for a short period of time during the day so it would not be suitable to place a fixed panel at this angle. The angle of 33° at both spring and autumn equinox will be repeated in the year so it logical to have the angle of the solar panels fixed at this angle to supply the maximum output throughout the year. Unfortunately this means that the angle of the panels is not as efficient as it could be for much of the year, reducing their effectiveness.

Solar tracker

As previously discussed, there are many studies that use complex equations when determining the optimal angle of the panels. Although these are accurate and take into account many atmospheric variations of the location, it is over complicated for a simple design and requires adjustment every few weeks in order to track the sun's positioning. For domestic use, this is not feasible or convenient which leaves the designer with two options: to install angled panels that will generally give the best performance or to install a solar tracker.

Solar tracking devices [68,69] can be used for monitoring the sun's position and optimise the panel angle and direction. Manufacturers' estimates vary between 20% - 60% better efficiency over fixed position panels [70,71]. If the end user is focused on the economic impact of the solar panels, the use of a solar tracker may also be beneficial. Although expensive, analysis shows that they should have a reasonable payback period and increase the efficiency of the panels (see next section for details). This is again dependant on the location of the panels and the angle at which they are placed. Trackers are generally more effective nearer to the equator as the solar irradiance increases. They are also more effective on buildings where a suitable roof angle is not present, for example, a flat roof. Figure 16 demonstrates the difference in using a fixed panel, two single axis tracking systems and a multi axis tracker system. It is clear that as both angles are tracked, the energy generated is greater throughout the period. If only a single axis tracker was installed then it is more effective if it tracks the sun in a north-south direction.

The gains from a tracker vary between locations. However, the increase in energy generation in one study is roughly between 20-35% for a two-axis tracking system [72]. Huang et al. suggest that the cost of installing a one-axis three position sun tracking PV is similar to the cost of a regular rooftop mounting. However, the cost of the tracking unit is much more expensive. The study concludes that the energy generation increases between 25-37%. A study of the power generation was conducted in Taipei which has a low solar energy resource. Over nine months, the increase in energy generated with the use of a tracker was 25.4%. This will be used as the percentage increase for the tracker system in the house design. It is expected that a location with higher solar irradiation would achieve an increased energy generation of more than 37.5%. A flat roof design or garden area may be required for this to be possible. An issue that could occur is the reliability of the technology. Units can be prone to breakdown which will increase costs associated with the maintenance [73].

From an environmental perspective, the use of a tracker can only be positive as it will increase the time the panel is perpendicular to the sun, maximizing the energy generated. However, it may not be financially viable due to the cost of installation and maintenance required. With moving parts, a solar tracker introduces more risk that maintenance will be required. However, one manufacturer claims that the expected lifetime of the solar tracking system is to be approximately 25 – 30 years [74]. Although it may be just as effective in the North of Scotland as in the South of England, the financial gains will not be as significant simply because of the disparity in solar irradiance available. One manufacturer offers trackers suitable for panels up to 20 m^2 for up to £3,226.75 excluding VAT. Trackers are also available for up to 6 m^2 and 16.5 m^2 for £1,102.49 and £2,590.89 respectively [71]. Companies seem reluctant to provide pricing for domestic solar trackers, making it difficult to achieve realistic pricing for installation. The prices noted above will be used in order to calculate the payback period.

Another consideration should be the maintenance required for PV or PVT panels. Although generally reliable and expected to last approximately 25 years, panels may require the inverter to be replaced prior to this date. The energy savings trust estimates this to be about £800. Although they should last longer than this, many companies give a guarantee of 5-10 years on the inverter [75]. When taking this into consideration, the financial benefits of using solar decrease dramatically. The area of the panel used in the experiment is 15 m^2 resulting in the cost of the tracker installation being £2,590.89.

Financial viability in house design

With the conclusions that a hybrid system not only provides hot water but also increases the efficiency of the PV panel, the PVT system would be the most suitable system to implement if it was deemed economically viable. Herrando et al. concluded that the use of a hybrid PVT system will meet up to 52% of the annual electrical demand and 48% of the annual hot water demand of a household [2]. This was on a study in London where the annual solar irradiance is approximately 109.8 W/m^2. As the location of the design is in Glasgow with a solar irradiance of approximately 99 W/m^2, this would be reduced by just over 10%. Therefore it is logical to conclude that the use of a PVT system could account for approximately 45% of electrical demand and 43% of hot water demand. If the average annual electricity usage is 3,300 kWh and annual hot water demand is 3,762 kWh per household, it can be concluded that the use of a solar PVT hybrid system could save 1,485 kWh in electricity and 1,618 kWh in hot water demand annually.

With the use of a tracking system, this could rise to 1,856 kWh for electricity and 2,022 kWh for hot water as this increases efficiency by approximately 25.4%. In order to calculate the financial viability of a PVT system and tracker, the energy savings were multiplied by the unit rate of the standard variable tariff from British Gas. The electricity supplied is also multiplied by the rate of the feed in tariff and the hot water supplied by the RHI rate. As the system used in the test was 2.25 kW, the FIT rate used is 13.39 p per kWh. In order to simplify the process, it is assumed that all this electricity is used on site and not resold to the grid. This resulted in an annual saving of £479.59 (£383.72 without tracker) for electricity and £480.00 (£384.11 without tracker) for gas, assuming that the system is replacing a highly efficient gas boiler. The tracker is contributing an annual saving of £191.76 (£95.89 in hot water saving and £95.87 in electricity). If the tracker is bought for £2,590.89, the payback period is just over eleven years. This is without any maintenance that may be required. The payback period of the hybrid PVT system is just over eleven years without any maintenance. This is calculated from the money saved through lower energy usage and both the feed in tariff and renewable heat incentive. It also does not include the savings made with the tracker system and uses a cost of the system of £8500, according to Herrando et al. It is clear that the financial incentives are only viable as a result of large funding through government incentives. There are some research works that question how economically viable this is on a larger scale [3]. However, on a domestic scale it seems to be economically viable as well as providing significant environmental benefits.

1.9 Micro combined heat and power

Micro Combined Heat and Power (micro-CHP) offers an alternative to a gas boiler [76]. Although mainly used as a DHW and space heating supply, it also generates a small amount of electricity, usually at a ratio of 6:1. This ratio is in line with the average domestic usage of gas and electricity as discussed previously. The ratio is different for various types of micro-CHP systems and can be used to generate more electricity than heat. One advantage of installing a micro-CHP system is that it is designed to replace a boiler unit, meaning that installation is relatively easy and the user does not need to change habits or operation of the heating.

Despite excellent efficiency qualities, the technology is relatively immature and has the potential to become even more efficient as the technology advances. Initially the installation of a CHP unit is more expensive than a standard boiler as one might expect. However, one paper suggests that this will offer a payback period of between 3-5 years depending on the usage [77]. It also shows that people seem happy to spend capital on longer-term investment projects such as PV, which can be up to or over a decade long. Although financially this is not always a suitable investment, users seem to see it as a "money for nothing" investment where very little work is required. The satisfaction of helping the environment and having a large proportion of energy effectively paid for are two possible explanations for this reasoning. Many studies seem not to take into account the maintenance required for various technologies. This could be especially expensive with immature technology such as micro-CHPs as the spare parts may not be as readily available and expensive.

One issue with micro-CHP systems is that they need to be on long enough to produce a decent amount of electricity. If this is a medium to large house without much insulation, this will not be a problem. However, if the system is implemented in a modern, well-insulated house with low heating demands, it may not provide too much electricity meaning reduced savings from the investment. As the technology develops, the use of higher efficiency products may reduce this need for extended periods of use. Harrison suggests that that the development of fuel cells will allow households with smaller thermal demands to benefit as a result of a low heat-to-power ratio [35].

As it is a source of micro-generation, it is important the household is connected to the grid in order to make sure excess electricity can be exported back to the grid under the feed-in tariff scheme (See section feed in tariff for details). Some other countries do not have this procedure available which will have an effect on the attractiveness of this option. This connection to the grid is especially important in micro-CHPs due to the fluctuation in electricity and heating demands on a single property. Having the backup of the national grid means that fluctuations are evened out. In standard CHPs which cover larger loads, the demand on it tends to be more constant, predictable and active for a longer period of time - 6000 hours per annum rather than 2500 for an average household [35]. This means that the electricity generated should adequately cover what is required. Similar to a commercial building, the use of a communal CHP would generate better results through the use of larger heating and electrical loads. However, even though this may reduce bills and improve the energy efficiency of every household within the scheme, it is generally accepted that people prefer to have individually owned units and independence in regards to energy supply. This means that a micro-CHP system may be preferable.

Three different types of engine are installed within a micro-CHP system. Stirling Engines offer a low pollutant emissions and high combustion efficiency solution for a micro-CHP system [78]. They also have a low running cost and long maintenance intervals due to operating without valves [35]. One issue that may arise is that they do not provide instant feedback when adjusted due to the substantial heat stored in one end of the engine. This results in the engine still producing electricity despite not being required or used. As it is more than likely that the household will be connected to the grid, this may not such a problem as unused energy can be sold back to the grid. The internal combustion engine (ICE) [79] as detailed below gives an instant change in power, one of the main reasons is that it is used in automobiles and why external engines are not suitable. The benefits of using this over an ICE is extended time between service intervals, high efficiency and low noise and vibrations (although these are still not quite low enough to have within an occupied space in a home.

ICE offers a tried and tested technology that has been used in motor vehicles for decades. It has the same basic principles as a diesel engine but runs on gas or liquefied petroleum gas (LPG) rather than diesel and is then connected to an electrical generator. Although efficient, the large body and slightly noisy operation restricts the combustion engine CHP units to commercial or communal projects [35]. Other micro-CHP units tend to be the size of a conventional boiler, allowing it to be replaced without too much work being undertaken.

Fuel cells offer a new alternative in CHP technology [80]. The two main types of fuel cell presently used are Proton Exchange Membrane (PEM) [81] and Solid Oxide Fuel Cells (SOFC) [82]. The development is still in the early stages and, as a result, there are not many commercially available. However, the system companies seem to be offering more are SOFCs. This could be due to the reduced cost and complexities, as well as a higher conversion efficiency that the system offers [83]. SOFC systems allow for a ratio for heating against electricity produced of roughly 1:3 [84]. This could therefore be suitable for a well-insulated home with lower heating demands.

The majority of the 1.5 million gas boilers sold in the UK are as a replacement for an old system. As mentioned previously, a micro-CHP system with a smaller ratio of heating to electricity will be more suitable if included in a house with low heating requirements. A SOFC unit gives a heat-to-power ratio of 1:2, very different to that of other systems which give a 6:1 ratio. According to Harrison [35], this allows for it to produce a suitable electrical demand for homes that have a thermal demand of over 2600 kWh per annum, which includes almost every gas connected household in the UK, as shown in Figure 17. However, due to the low capacity, this would only realistically cover the provision of hot water meaning another system would need to be used for heating.

Some critics argue that current micro-CHP methods are not efficient enough to justify an upgrade to a current boiler and that the technology needs to be mature in order to extract the most out of it. Harrison [35] argues this is not the case and that people should make the most of the finite gas that is still available no matter how small the savings, both financial and environmental. From a wider and longer term point of view, it is suggested that the use of micro-CHPs will reduce the expected overload on electricity demand in the UK. It shows that two energy companies expect a shortfall in electricity supply if certain power plants are to close. A newer report from the UK government demonstrates that electricity generation has indeed decreased, and that the country is importing more electrical energy from other countries as a result [85]. Another issue with the micro-CHP system is that all new build homes must be carbon neutral from 2016 [86]. This restricts the use of micro-CHP systems in newly built housing using fossil fuels. However, it can still be used in traditional housing as a replacement for a boiler and as a means to save energy.

Figure 18 shows the difference in terms of CO_2 emissions for a standard gas boiler, a boiler combined with solar photovoltaic and various micro CHP systems (internal combustion engine, Stirling engine and fuel cell). Clearly the fuel cell powered micro-CHP produces the lowest emissions over a year, about 3400 kg of CO_2 less than that of a conventional boiler. However, as was discussed earlier, with a ratio of heat to power being 1:2, the unit may need to be supplemented by another technology in order to provide adequate heating or DHW to the building. Within a traditional house where there may be a high heat demand, a user may consider a micro-CHP unit powered by a Stirling engine as this will reduce the emissions by approximately 2150 kg of CO_2 annually. However, the slightly noisy operation may require the user to consider the placement of the unit within an occupied space. It should also provide enough heat to supply a large home with all the heating requirements as well as much of the electricity requirements. The use of an internal combustion engine can only really be suitable for community projects or commercial buildings, meaning it cannot really be considered for use in a single home.

Financial viability in house design

Micro CHPs qualify for use with the feed-in-tariff, despite energy being generated from fossil fuels. This is due to the process being considered “low-carbon” compared to traditional electrical generation processes [84]. If the micro-CHP system covers the household for DHW and space heating, this will cover 14,256 kWh for the average household. With a Stirling engine micro-CHP providing a ratio of 6:1 hot water to electricity ratio, the electricity produced would be approximately 2,376 kWh, which is lower than the required 3,300 kWh per household. If the household required the electricity supply to be covered, the ratio would need to be nearer to 4:1. However, this would decrease the heat output, resulting in a possible need for another heat source. Any unused electricity will be exported back to the grid and a payment made through the feed-in tariff scheme of 4.85 p/kWh. Although this is an unrealistic scenario, when calculating the payback period, the writer will assume that all the electricity generated is used on site. If 2,376 kWh is generated, this will result in an annual payment of £319.57 with the rate set at 13.45 p/kWh. It will also reduce electricity bills for the household by approximately £295.81 when using the standard variable tariff from British Gas. The annual saving is £615.38. There are only a few micro CHPs available on the British market, especially domestic, Stirling engine ones. A typical example is a Baxi Ecogen. This is designed to be a direct replacement for a standard boiler, with similar dimensions and ratios. The cost without installation is £7,400. With installation this would not rise above £8000. At this cost, the payback period is calculated to be just over 11 years. However, the feed-in tariff expires after ten years, extending the payback period to closer to 13 years. Also there may be electricity that is sold back to the grid when not used, allowing for the system to generate slightly more savings.

1.10 Phase changing materials

Phase changing materials (PCMs) contain properties that increase thermal mass without adding too much weight to the building system [87]. By reorganising their microstructure, PCMs can store or release heat at certain temperatures which can be altered by reorganising the PCM structure. To make this a viable solution in a building, PCMs must go through the phase change at typical building temperatures. The temperature at which the latent heat energy is released or stored and the quantity of the PCM used allows the user to reach a form of programmable inertia [88]. As the temperature of the UK is expected to increase over the next century, as shown in Figure 19, these materials could become very important in reaching comfortable living environments within buildings. This is especially the case in warmer climates where the summers are expected to reach very high temperatures. The use of PCMs could keep buildings at a constant temperature rather than fluctuating throughout the day.

When integrating PCM into the building envelope, it is important to match the expected demand of the building to the thermal performance of the material [89]. Design considerations that should be made include the amount of heat to be absorbed by the material, the peak time of the day for heat flows and the discharge time for the material to be effective. An effective ventilation system may also need to be installed in order to increase the efficiency of the PCM [88]. Studies have concluded that the application of PCM in a building envelope needs careful consideration of the material properties. One study investigated this when comparing two PCMs of differing melting points (21 °C and 27 °C). At 27 °C, the PCM resulted in overheating. At 21 °C, the material required a large surface area that may not be suitable for all building types. It was discovered that PCM is most effective when the indoor thermal comfort average temperature is just below that of the phase changing temperature. This is most effective in climates with low solar radiation and mild winters. Although the study is from 1981, the information is still relevant to PCM installation today [90].

Figure 20 demonstrates how the PCM is charged by an under floor heating system. At 6 am this is turned off and the temperature of the PCM reduces rapidly due to it being higher than the melting temperature of 28 °C. However, when it reaches this point, heat is released slowly over a period of just less than three hours. It is then recharged again and discharged over a longer period, resulting in a fairly even room temperature. More recent studies have shown that the effects of PCM in various constructions. This includes a study that demonstrated PCM installation reducing the energy usage by up to 50%. It compared three structures with different properties; one with PCM, one with PCM and a ventilated air gap and another with just a ventilated air gap and came to this conclusion [91]. These are demonstrated in Figures 22, 22 and 23.

The results demonstrated that the use of PCM with a melting point of 32 °C reduces the flux of the internal temperature by up to 50%. It has also been concluded that the installation of PCM boards in a room was found to reduce the fluctuations in room temperature between summer and winter [92]. Studies on PCM have concluded that:

- A box structure with PCM installed can consume up to 50% less energy than that with just a ventilated air gap;
- Having PCM installed in a room reduced the fluctuations in temperature in summer and winter;
- PCM with temperature ranges of 25 °C and 28 °C could reduce indoor peak temperature by about 4°C;
- After a few consecutive hot days and without proper ventilation, the PCM will lose its heat storage capacity and become much less efficient;
- In temperatures greater than 18 °C, it is important that some sort of ventilation system is present in order to obtain optimal performance from the PCM.

One interesting idea is the use of PCMs in furniture. Although this is not part of the house design, it is interesting to note that this could be a possible relatively cheap way of helping stabilise the room temperature. One house design in the Solar Decathlon Europe competition incorporated this in the design in order to regulate the temperature of the room more effectively. The melting point of the PCM should be just above the comfort range, between 19 °C and 28 °C, as mentioned in section 1.4. (Domestic Dwellings within the UK). In some instances, PCM materials have been used with electric under floor heating. The heating is turned on during the night, when electricity is cheaper and the PCM changed from a solid to a liquid as it absorbs heat. During the day the heating is turned off and heat released from the PCM as it solidifies [93]. Butyl stearate could be a good material for PCM in building envelope. It has a transition point between 18-23 °C which falls in the suitable range for a comfortable living temperature. On the occasion that the building requires cooling, Butyl stearate should act as a coolant, unless the temperature reaches very high levels.

Financial viability in house design

The financial viability for the use of PCM is uncertain. Nowadays, it is not financially viable with an installation costing £1143 [88]. After an internet search, there does not seem to be many suppliers of PCM. One supplier, "DuPont" offers a PCM product called Energain which has a melting point of around 22 °C. Although many factors must be taken into account, the company gives a general rule that for every 1 m^3, 0.5-1 m^2 of PCM should be used [94]. With a ceiling height of 2.4 m and a floor area of 91 m^2, the volume of the average house is approximately 218.4 m^3. Therefore the area of Energain required would be between 109 m^2 to 218 m^2.

There is not much information of the cost of PCM materials. One study concluded that a 44.4% cost saving and 35% consumption saving could be made by installing PCM in flooring and in walls of a building [95]. However, the average energy saving over a week was 18.8%. According to the DuPont website, an energy saving of 15% is made. If this saving is used for space heating, this would result in an annual saving of 1,574 kWh for an average dwelling. This would result in an annual cost saving of £66.58 assuming heating from a gas boiler. One paper suggested that the cost of £50/m^2 resulting in a material cost of £5,450 to £10,900 not including installation [96]. With the lower rate giving a payback period of just under 82 years, this is obviously not a financially logical investment. However, it will reduce energy consumption and maintain a more comfortable living environment.

1.11 Passive design strategies

The majority of the energy used in a building is to protect the users from external elements and maintain internal comfort. This energy consumption can be reduced significantly through the use of passive design strategies [97,98] that help increase the interior comfort and decrease the reliance on active heating or cooling systems.

Passive systems include the building envelope, orientation, geometry/ratios and hybrid solutions. From a Europe-wide test of the thermal comfort of various building designs, multiple design variables involving passive design strategies were tested. Although many aspects were tested, it is clear that use of a high performance envelope was a key design element of energy efficient houses [99]. The Solar Decathlon Europe competition happens every two years and compares various house designs. Comparisons are made in various categories including architecture, innovation and house functioning as well as others [99]. One category is the energy efficiency of the house. One paper looks at the different design features of all 18 houses and compares the results of the energy efficiency of them. From this there seems to be a few categories that stand out as things to include or exclude in the design.

The test mentions no financial analysis, meaning that not all of the design strategies will be possible but it seems to present some interesting ideas and results. Figures 25 and 26 show the variations and the thermal performance of each house design.

Notable results from the test are:

- An external insulation layer seems to be an effective way to minimise thermal bridges. In the SDE 2012 event, 14 out of the 18 designs contained them and tended result in a better thermal performance. Out of the bottom 3 houses, 2 of them did not have an external insulating layer. The only exception seems to be house 18 which came in fourth position. However, the top twelve houses are separated by so little that it would make near as no difference to the final outcome of the efficiency.
- Houses 5, 14 and 16 are the only ones to have a foyer or entrance vestibule. Obviously the designers did not think this was a worthwhile addition, contradicting another paper which said a foyer added to the thermal qualities. Interestingly, house 16 was the best performing house in terms of thermal performance whereas 5 and 14 were considered two of the worst.
- 7 out of the top 10 did not have a ventilated façade.
- In terms of ventilation, all houses included a mechanical ventilation system. However, only two designs had a ventilation system using a phase changing material heat exchange. These houses were rated the top 2 houses in thermal performance. With the exception of one, all houses implemented a ventilation system with heat recovery. The house that did not implement this scored lowest in terms of thermal performance. Although this could be a coincidence and there may be other factors, this seems an important strategy in creating a high thermal performance in a building.
- All but one design (house 14) contained high performance glazing. This design came 16th out of 18 houses in terms of thermal performance.
- All houses had a passive solar gain. However, house 16 was the only design to incorporate a double skin house façade. This was also the highest performing house in the thermal performance test.

The SDE competition works to find what has the most efficient house design overall and gives a general idea of what works and what does not. However, it can be hard to tell which technologies are making the most difference as many of them are being changed at the same time. In order to really analyse what works well, two similar buildings should be created with only one difference separating them. In this instance, features such as a radiant floor and/or ceiling are implemented in half of the houses. In the results these houses are spread fairly evenly throughout the thermal performance results, making it difficult to gauge the effectiveness individual components.

1.12 Building envelope

Creating a suitable building envelope is one of the most effective passive design strategies when creating an energy efficient building. It is the barrier that protects the internal environment from the external conditions and so careful consideration must be taken. The most relevant characteristic is its u-value, which measures the heat loss in a building element such as windows, doors, walls etc. The higher the u-value of the building envelope, the better it will be at keeping the heat in during winter and the heat out during summer [100].

Insulation

Some research works argue that a well-insulated building envelope can lead to higher loads in the summer due to the extended use of cooling technologies [101]. However, it is suggested that this would only really be necessary if the exterior temperature was lower than that of the internal temperature during the summer period, which is an unusual situation, even in hotter climates [99]. It is also not an issue due to the location of the proposed design.

Other factors that must be taken into account when considering the building envelope are its absorbing qualities, thermal lag and thermal energy storage capacity. For translucent materials, such as windows, it is not only suitable to take into account the u-value, but also the solar heat gain. The results from the SDE concluded that of the top eight performing houses in the thermal comfort sub-contest, six of them had the lowest thermal transmittance and five of them were among the eight lowest thermal transmittance in the ceilings. It is fairly conclusive that having decent thermal properties such as a low u-value in the walls and ceilings contributes a large part to the efficiency of a building.

The importance of air tightness and u-value for the building envelope obviously increase as the exterior climate increases in intensity. If the climate is constantly at a comfortable temperature all year round then having a low u-value will not add a great deal of comfort to the building. However, if the climate has a large range between hot summers and cold winters, the u-value and air tightness are extremely important factors to be considered. Figure 27 shows the energy saved as the thickness of the thermal insulation (mineral wool) is increased. As the thickness increases, the energy saved per unit of thickness reduces. The user must consider what the most appropriate thickness is while still providing adequate insulation to the building. Table 9 shows the results from a study on optimum wall insulation thicknesses for various materials [102]. Through comparing the cost of insulation and thermal conductivity, the life cycle costs were established for each material. The study concludes that the use of fibreglass-urethane at a thickness of 0.048 m is the most suitable wall insulating material. Figure 28 demonstrates the variations in optimum thickness of the various wall insulation materials. Again it shows that fiberglass-urethane provides the largest saving over its lifetime. However, Ucar and Balo suggests that the use of foamboard 1200 gives a greater saving than fibreglass [103] while Bojic et al suggest that mineral wool provides the greatest insulation [104].

1.13 Efficiency evaluation of a building

Five technologies have been analysed for the financial and environmental effects on a house design. Table 10 demonstrates the annual saving and payback period for each technology and Table 11 demonstrates the annual energy saving for each technology. From the authors' point of view the technologies that should be incorporated in a modern house design should be a ground source heat pump, PVT panels and a solar tracker. If a solar tracker is not used, the angle of the solar panels should be approximately 33° to the vertical. The use of a micro-CHP system would be suitable. However, it cannot be used in parallel with a heat pump and, due to the extended payback period, would not be suitable. Although PCM materials will save energy and provide a more comfortable living environment, the cost significantly outweighs the energy gains so this is not considered. However, as the technology advances and prices reduce, this could become a very exciting and useful material when reducing energy consumption in the future. The initial costing of the GSHP, PVT panels and tracker costs approximately £22,090.89 – £26,090.89. The annual economic savings of these are £2,240.74 – £2,531.66 giving a payback period of 8.7 years at best and 11.6 years at worst.

2 Design of building

The final design of the semi-detached house is shown in Figure 29. The house is designed as a large, three bedroom semi-detached house to coincide with the average house type in the UK. The design was generated in the design software, SketchUp by Trimble. This allows a large amount of flexibility when creating designs and gives a quick and simple representation of the appearance of buildings, products or even landscapes. It can also provide some level of detail but not to the same standard as expensive architectural software such as AutoCAD, Inventor or Revit. The software also allows users to import assemblies or parts that other users have generated and uploaded to a public library. This enables users to generate and share designs quickly and easily. In this design the public library has been used to import the solar PVT panels excluding the fixings, the ground source heat pump and the main door. The windows have also been imported and then edited to create the suitable frames.

The windows on the south facing walls are larger than those on other sides of the building to maximize the solar thermal gains. However, due to the colder climate, the windows are not as large as demonstrated in the SDE competition. There are solar PVT panels attached to the roof of the building with a fixed position at 33° to the vertical. However, if the user felt these were too imposing and ruined the look of the building, there is the option of garden PVT panels with a tracker system as demonstrated in Figure 30. There is a ground source heat pump at the rear of the building that will have the pipes placed in the garden about two metres below ground. This would need to be used in conjunction with a low temperature heating system such as under floor heating to really gain significant benefits. The floor plan shows how the main living space is on the south side of the building to ensure the most effective use of natural light and heat. The ground and first floor plans are detailed in Figure 31. A large, open plan living area is created with larger windows in the south facing wall to ensure the most effective use of natural light.

Concepts of the roof and wall details are shown in Figures 32 and 33. These illustrations are generated using a combination of extrusions, offsets and sketches in AutoCAD software. Although not to scale, they are based on standard wall systems used in house building and show how the use of insulation and PCM could be implemented if PCM was being used. This system should give an air-tight and well insulated construction for the building but must be researched in greater detail. The PCM material, if being used, is shown in pink and a layer of insulation is incorporated. A detail of a wall section is shown in Figure 34. This demonstrates the PCM's position within the wall construction.

3 Discussions

There are many factors that affect energy consumption on a building, occupants' behaviour, local climate and financial aspects to name a few. When designing a house, there are many aspects that must be analysed in order to reach the most efficient design. Often these can only be seriously analysed through the use of real-life experiments over a long period of time. If it can access to energy analysis software, this could have also been utilised to get some new data as opposed to data from other research works. It was predicted that the house design presented could give annual economic savings of between £2,240.74 and £2,531.66, resulting in a payback period of between 8.7

years and 11.6 years. The energy savings could be as high as 3,878 kWh in gas and electricity, a saving of approximately 19.5% compared to a standard three-bedroom house in the UK. Some of the data gathered could be quite vague and was not always applicable to the design of a house in Scotland. For example, a research work on the solar gains from a PVT system in London, where energy generation would be greater, was analysed. Although the difference was taken into account, it may not have been too accurate.

4 Conclusions

Gas consumption needs to be reduced but there are few viable options for use in heating systems. The only realistic alternatives would be an air or ground source heat pump combined with a low temperature heating system. This is incredibly expensive to install in current building stocks and will not offer give the user a decent payback period. The only realistic option when reducing gas consumption is to increase the insulation of the property, through the use of new technologies such as PCM. As new houses are built and old houses demolished, the insulation of housing will increase and the opportunity to install low temperature heating solution will be available. This will allow for heat pumps to be installed, reducing the reliance on the gas network. The design presented gives a solution that would decrease the energy consumption in the average home and give a reasonable payback period.

5 Recommendations and further work

Anaerobic digestion, or biomass, generates clean, green energy from living or recently living plant matter such as trees or crops. It is carbon neutral due to the crops taking the same amount of carbon out of the atmosphere as it releases under burning [105]. As long as it is managed carefully and the plant life replenished in suitable time, the cycle is maintained, giving biomass its green credentials. It can also meet all the hot water and heating demand, making it a viable alternative to gas. If there is no connection to the gas network, the use of biomass has a huge potential to provide an alternative to gas.

Further research on micro CHP units could be undertaken as this technology is in its infancy. It has the potential to reduce emissions through creation of DHW, heating as well as electricity. This should include the study of fuel cells which have the potential to have a low heat-to-power ratio and therefore be suitable for homes with lower thermal demands. Micro-CHP units that use other energy sources such as oil or bio-liquids could also be investigated more. This is due to restrictions coming in 2016 that states that new homes should be zero carbon that may limit the installation of mains gas powered micro-CHPs.

More research on solar trackers may be advantageous. There does not appear to be much information on exactly what savings can be made, both in financial and environmental terms. Various manufacturers have suggested that up to 60% more energy can be generated but this is not from a neutral source and the details of the analyses are not published. The location of one analysis is in Spain where solar irradiance will clearly be much higher than in northern Europe. The building envelope and insulation levels within a house must be analysed. There are also many technologies that can be investigated when insulating exterior walls and the roof of a building.

“Hard to treat” buildings usually have two options with regard to insulation; internal or external wall insulation. From tests within the SDE 2012 event, it is obvious that the inclusion of an exterior insulation layer is effective as a means to reduce thermal bridges [99]. This may be included in the final design if the financial aspect of it is suitable. Internal and external wall insulation in the UK does not seem to have too much work written on it, giving potential for improved systems and processes to be developed.

Green roofing provides insulation as well as acts as a green space, helping the environment by reducing CO_2 emissions. It has a layer waterproof membrane with a growing medium and layer of vegetation placed upon it [106]. However, there are more effective processes when insulating a building and it is also only really appropriate on a flat or shallow pitched roof.

The orientation of the building can have a small but significant impact on the energy usage within that building. Three factors which influence the efficiency of a building's thermal properties are orientation, geometric parameters and ratios [99]. In order to get a truly efficient building design, these should be researched further and applied to the housing design if applicable and suitable. It is more than like that having a large equator-facing wall will result in a greater energy saving. However, this may cause issues with land availability and public perceptions of such a building.

Future technology:

High altitude wind generation offers some exciting possibilities in the future of electricity generation. The main reason for this is that stronger and more consistent winds can be found at higher altitudes than that of a regular wind turbine. An American company, Altaeros, has created a prototype, known as "The Bat" which can be positioned up to 600 m above the ground. The main benefit is that the wind speed at such altitudes can generate far more electricity as the power output does not follow speed linearly but at a cubic factor. This means that if the wind speed is doubled, the electricity generated is eight times the original value. Although this sort of technology would not be suitable for individual houses, it would be ideal as a communal power source, especially remote places that are off the grid or even in disaster zones.

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REFERENCES

[1] European Commission, "The 2020 climate and energy package," 2014, Available: http://ec.europa.eu/clima/policies/package/index_en.htm.

[2] M. Herrando, C. N. Markides and K. Hellgardt, "A UK-based assessment of hybrid PV and solar-thermal systems for domestic heating and power: System performance," London, 2014.

[3] Committee on Climate Change. The Fourth Carbon Budget: Reducing Emissions through the 2020s (2010).

[4] J. Giesekam, J. Barrett, P. Taylor, A. Owen, The greenhouse gas emissions and mitigation options for materials used in UK Construction. Energy and Buildings, 78:202-214, 2014.

[5] R. Cherrington, V. Goodship, A. Longfield and K. Kirwan, "The feed-in tariff in the UK: A case study focus on domestic photovoltaic systems," Coventry, 2012.

[6] M.W. Ahmad, M. Mourshed, D. Mundow, M. Sisinni, Y. Rezgui, Building energy metering and environmental monitoring – A state-of-the-art review and directions for future research. Energy and Buildings, 120:85-102, 2016.

[7] S. Mandley, R. Harmsen, E. Worrell, Identifying the potential for resource and embodied energy savings within the UK building sector. Energy and Buildings, 86:841-851, 2015.

[8] P.H. Shaikh, N.B.M. Nor, A.A. Sahito, P. Nallagownden, I. Elamvazuthi, M.S. Shaikh, Building energy for sustainable development in Malaysia: A review. Renewable and Sustainable Energy Reviews, 2016 (in Press).

[9] D.A. Chwieduk, Towards modern options of energy conservation in buildings. Renewable Energy, 101:1194-1202, 2017.

[10] J.R. Snape, P.J. Boait, R.M. Rylatt, Will domestic consumer take up the renewable heat incentive?

An analysis of the barriers to heat pump adoption using agent-based modeling. Energy Policy, 85:32-38, 2015.
[11] R. Cherrington, V. Goodship, A. Longfield, K. Kirwan, The feed-in tariff in the UK: A case study focus on domestic photovoltaic systems. Renewable Energy, 50:421-426, 2013.
[12] DECC, "The Government's Standard Assessment Procedure for Energy Rating of Dwellings,"BRE, Watford, 2014.
[13] M. Raugei, E. Leccisi, A comprehensive assessment of the energy performance of the full range of electricity generation technologies deployed in the United Kingdom. Energy Policy, 90:46-59, 2016.
[14] S. Murugan, B. Horak, A review of micro combined heat and power systems for residential applications. Renewable and sustainable Energy Reviews, 64:144-162, 2016.
[15] M. Caliano, N. Bianco, G. Graditi, L. Mongibello, Economic optimization of a residential micro-CHP system considering different operation strategies. Applied Thermal Engineering, 101:592-600, 2016.
[16] J.E.P. Navalho, J.M.C. Pereira, J.C.F. Pereira, A methodology for thermal analysis of complex integrated systems: Application to a micro-CHP plant. Applied Thermal Engineering, 112:1510-1522, 2017.
[17] Baxi, "Benefits of Micro-CHP,". Available:http://www.baxi.co.uk/renewables/combined-heat-and-power/benefits-of-micro-chp.htm.
[18] Tidal Lagoon Swansea Bay Plc., Aailable: http://www.tidallagoonswanseabay.com.
[19] T. Fawcett, "The future role of heat pumps in the domestic sector," Oxford, 2011.
[20] L. Lind, "Swedish Ground Source Heat Pump Case Study (2010)," 2010.
[21] J. Constable and L. Moroney, "The Renewable Heat Incentive: Risks and Remedies," Renewable Energy Forum Ltd., 2010.
[22] H. Singh, A. Muetze and P. Eames, "Factors influencing the uptake of heat pump technology by the UK domestic sector," London, 2010.
[23 DECC, "Feed-in tariffs scheme: consultation on Comprehensive Review Phase 1 - tariffs for solar PV," Crown, 2011.
[24] OfGem, "Feed-in Tariff Generation & Export Payment Rate Table for Non-Photovolatic Installations - FIT Year 6 (1 April 2015 - 31 March 2016)," 2015.

[25] OfGem, "Domestic Renewable Heat Incentive: Case Studies," OfGem, 2015.
[26] DECC, "United Kingdom - Housing Energy Fact File," Cambridge, 2012.
[27] DECC, "Sub-National Gas Consumption Statistics," 2012.
[28] HM Government, "The UK Low Carbon Transition Plan: National strategy for climate and energy," London, 2009.
[29] National Grid, "The Gas Distribution Network," Aailable: http://www2.nationalgrid.com/UK/Our-company/Gas/Gas-Distribution-Network/.
[30 DECC, "UK Housing Fact File 2013," Cambridge, 2013.
[31] Parliament UK, "Incandescent Light Bulbs Section 22 May 2012 : Column 46WH," 2012. Available: http://www.publications.parliament.uk/pa/cm201213/cm hansrd/cm120522/halltext/120522h0002.htm.
[32] Centrica, "British Gas," Available: http://www.centrica.com/index.asp?pageid=279.
[33] ONS, "Population and Household. Estimates for the United Kingdom. March 2011," Office for National Statistics, 2013.
[34] Office of National Statistics, "English Housing Survey: Homes 2010," 2010.
[35] J. Harrison, "Micro combined heat and power (CHP) systems for residential and small commercial buildings," 2011.
[36] Department for Communities and Local Government, "House Building: December Quarter 2014, England," London, 2015.
[37] ASHRAE, "Thermal Environmental Conditions for Human Occupancy," Atlanta, 2004.
[38 S. Kelly, D. Crawford-Brown and M. G. Pollitt, "Building performance evaluation and certification in the UK: Is SAP fit for purpose?," Cambridge, 2012.
[39] V. Bianco, F. Scarpa, L.A. Tagliafico, Estimation of primary energy savings by using heat pumps for heating purposes in the residential sector. Applied Thermal Engineering, 114:938-947, 2017.
[40] G. Leonzio, Solar systems integrated with absorption heat pumps and thermal energy storages: state

of art. Renewable and Sustainable Energy Reviews, 70:492-505, 2017.
[41] U. Lucia, M. Simonetti, G. Chiesa, G. Grisolia, Ground-source pump system for heating and cooling: Review and thermodynamic approach. Renewable and Sustainable Energy Reviews, (in press), 2016.
[42] A. Zarrella, G. Emmi, M.D. Carli, A simulation-based analysis of variable flow pumping in ground source heat pump systems with different types of borehole heat exchangers: A case study. Energy Conversion and Management, 131:135-150, 2017.
[43] Z. Wang, F. Wang, X. Wang, Z. Ma, X. Wu, M. Song, Dynamic character investigation and optimization of a novel air-source heat pump system. Applied Thermal Engineering, 111:122-133, 2017.
[44] M. Dongellini, C. Naldi, G.L. Morini, Sizing effects on the energy performance of reversible air-source heat pumps for office buildings. Applied Thermal Engineering, (in Press), 2016.
[45] M. Szreder, "A field study of the performance of a heat pump installed in a low energy house," Warsaw, 2014.
[46] Eurobserver, "Heat Pumps Barometer," 2013.
[47] T.H. Lim, R. D. Kleine, G. A. Keoleian, Energy use and carbon reduction potentials from residential ground source heat pumps considering spatial and economic barriers. Energy and Buildings, 128:287-304, 2016.
[48] DECC, "Domestic Renewable Heat Incentive," Crown, London, 2013.
[49] Kensa Heat Pumps, "Factsheet - GSHP vs. ASHP V4".
[50] E. A. Byers, J. W. Hall and J. M. Amezaga, "Electricity generation and cooling water use: UK pathways to 2050," Newcastle-Upon-Tyne, 2014.
[51 M. R. Hall, S. P. Casey, D. L. Loveday and M. Gillott, "Analysis of UK domestic building retrofit scenarios based on the E.ON Retrofit Research House using energetic hygrothermics simulation - Energy efficiency, indoor air quality, occupant comfort, and mould growth potential," Nottingham, 2013.
[52] R. Roy, S. Caird and A. Jennie, "YIMBY Generation – yes in my back yard! UK house-holders pioneering microgeneration heat," 2008.
[53] The Energy Saving Trust, "Getting warmer: A Field Trial of Heat Pumps," Energy Saving Trust, London, 2010.
[54] D. Burnett, E. Barbour and G. P. Harrison, "The UK solar energy resource and the impact of climate change," Edinburgh, 2014.
[55] J. Murphy, D. Sexton, G. Jenkins, P. Boorman, B. Booth, K. Brown, R. Clark, M. Collins, G. Harris and L. Kendon, "UK Climate Projections science report: Climate change projections," 2009.
[56] J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Process, Hoboken, New Jersey: John Wiley & Sons, Inc, 2013.
[57] S.L. Piano, K. Mayumi, Toward an integrated assessment of the performance of photovoltaic power stations for electricity generation. Applied Energy, 186:167-174, 2017.
[58] A.S. Mundada, K.K. Shah, J.M. Pearce, Levelized cost of electricity for solar photovoltaic, battery and cogen hybrid systems. Renewable and Sustainable Energy Reviews, 57:692-703, 2016.
[59] R. Harrabin, "Solar energy 'could provide 4% of UK electricity by 2020'," BBC, 24 March 2015. Available: http://www.bbc.co.uk/news/science-environment-32028809.
[60] N. Zhou, Y. Yu, J. Yi, R. Liu, A study on thermal calculation method for a plastic greenhouse with solar energy storage and heating. Solar Energy, 142:39-48, 2017.
[61] C. Good, Environmental impact assessments of hybrid photovoltaic-thermal (PV/T) systems – A review. Renewable and Sustainable Energy Reviews, 55:234-239, 2016.
[62] A. Khelifa, K. Touafek, H.B. Moussa, I. Tabet, Modeling and detailed study of hybrid photovoltaic thermal (PV/T) solar collector. Solar Energy, 135:169-176, 2016.
[63] J. Guo, S. Lin, J.I. Bilbao, S.D. White, A.B. Sproul, Areview of photovoltaic thermal (PV/T) heat utilization with low temperature desiccant cooling and dehumidification. Renewable and Sustainable Energy Reviews, 67:1-14, 2017.
[64] S. Seme, B. Stumberger, M. Hadziselimovic, A novel prediction algorithm for solar angles using second derivative of the energy for photovoltaic sun tracking purposes. Solar Energy, 137:201-211, 2016.
[65] A. G. Siraki and P. Pillay, "Study of optimum tilt angles for solar panels in different latitudes for urban applications," Quebec, 2012.

[66] H. Hussein, G. Ahmad and H. El-Ghetany, “Performance evaluation of photovoltaic modules at different tilt angles and orientations,” Cairo, 2004.
[67] softUsVista Inc, “Glasgow Longitudes and Lattitudes,” Available: http://www.distancesfrom.com/gb/Glasgow-Scotland-latitude-longitude-Glasgow-Scotland-latitude-Glasgow-Scotland-longitude/LatLongHistory/440127.aspx.
[68] H. Fathabadi, Comparative study between two novel sensorless and sensor based dual-axis solar trackers. Solar Energy, 138:67-76, 2016.
[69] J. Wu, B. Zhang, L. Wang, Optimum design and performance comparison of a redundantly actuated solar tracker and its nonredundant counterpart. Solar Energy, 127:36-47, 2016.
[70] Degar Energie, “Solar Tracking,” Available: http://www.degerenergie.de/en/solar-tracking.html.
[71] Wind & Sun, “Lorentz Trackers,” Available: http://www.windandsun.co.uk/products/PV-Mounting-Structures/Lorentz-Trackers#.VSqc3Y6KvgI.
[72] B. Khadidja, K. Dris, A. Boubeker and S. Noureddine, “Optimisation of a Solar Tracker System for Photovoltaic Power Plants in Saharian region, Example of Ouargla,” Ouargla city, 2014.
[73] B.-J. Huang, Y.-C. Huang, G.-Y. Chen, P.-C. Hsu and K. Li, “Improving Solar PV System Efficiency Using One-Axis 3-Position Sun Tracking,” Taiwan, 2012.
[74] Linak, “Linak,” Available: http://www.solar-tracking.com/.
[75] SMA Solar Technology AG, “Sunny Boy 1200 / 1700 / 2500 / 3000,” Available: http://www.evoenergy.co.uk/wp-content/uploads/2012/05/SB1200_3000-DEN110712W.pdf.
[76] H. Ito, Economic and environmental assessment of residential micro combined heat and power system application in Japan. International Journal of Hydrogen Energy, 41:15111-15123, 2016.
[77] R. Heith and J. Harrison, Small and micro combined heat and power (CHP) systems: Advanced design, performance, materials and applications, Woodhead Publishing, 2011.
[78] H. Damirchi, G. Najafi, S. Alizadehnia, R. Mamat, C.S.N. Azwadi, W.H. Azmi, M.M. Noor, Micro combined heat and power to provide heat and electrical power using biomass and Gamma-type Stirling engine. Applied Thermal Engineering, 103:1460-1469, 2016.
[79] P. Arbabi, A. Abbassi, Z. Mansoori, M. Seyfi, Joint numerical-technical analysis and economical evaluation of applying small internal combustion engines in combined heat and power (CHP). Applied Thermal Engineering, 113:694-704, 2017.
[80] A. Adam, E.S. Fraga, D.J.L. Brett, Options for residential building services design using fuel cell based micro-CHP and the potential for heat integration. Applied Energy, 138:685-694, 2015.
[81] Y. Li, J. Yang, J. Song, Structure models and nano energy system design for proton exchange membrane fuel cells in electric energy vehicles. Renewable and Sustainable Energy Reviews, 67:160-172, 2017.
[82] A. Adam, E.S. Fraga, D.J.L. Brett, Modelling and optimization in terms of CO_2 emissions of a solid oxide fuel cell based micro-CHP system in a four bedroom house in London. Energy Procedia, 42: 201-209, 2013.
[83] microchap, “fuel cells,” 23rd September 2013. Available: http://www.microchap.info/fuel_cells.htm.
[84] J. Harrison, “The Value of Microgeneration,” 2012.
[85] DECC, “Digest of United Kingdom Energy Statistics (DUKES),” Crown, London, 2014.
[86] E. Heffernan, W. Pan, X. Liang and P. de Wilde, “Zero carbon homes: Perceptions from the UK construction industry,” Edinburgh, 2014.
[87] S.S. Chandel, T. Agarwal, Review of current state of research on energy storage, toxicity, health hazards and commercialization of phase changing materials. Renewable and Sustainable Energy Reviews, 67:581-596, 2017.
[88] S. M. Sajjadian, J. Lewis and S. Sharples, “The Potential of Phase Change Materials to Reduce Domestic Cooling Energy Loads for Current and Future UK Climates,” 2015.
[89] H. Akeiber, P. Nejat, M.Z. Abd. Majid, M.A. Wahid, F. Jomehzaden, I.Z. famileh, J.K. Calautit, B.R. Hughes, S.A. Zaki, Areview on phase change material (PCM) for sustainable passive cooling building envelopes. Renewable and Sustainable Energy Reviews, 60:1470-1497, 2016.
[90 C. Carter, “Phase Change Sotrage in Passive Solar Home Heating,” Oxford, 1981.
[91] P. Principi, G. Di Pema, A. Borreli and A. Carbonari, “Experimental energetic evaluation of changeable inertia PCM containing walls.,” Santorini, 2005.
[92] L. Shilei, Z. Neng and F. Guohui, “Impact of phase change wall room on indoor thermal environment in winter,” Tianjin, 2005.

[93] H. Ge, H. Li, S. Mei and J. Liu, "Low melting point liquid metal as a new class of phase change material: An emerging frontier in energy area," Beijing, 2012.
[94] DuPont, "Phase Change Materials," Available: http://energain.co.uk/Energain/en_GB/sales_support/faq.html.
[95] R. Barzin, J. J. Chen, B. Young and M. M. Farid, "Application of PCM underfloor heating in combination with PCM wallboards for space heating using price based control system," Auckland, 2015.
[96] M. Fraser, "Increasing thermal mass in lightweight dwellings using phase change materials – a literature review," Newcastle upon Tyne, 2009.
[97] Q. Roslan, S.H. Ibrahim, R. Affandi, M.N. Mohad Nawi, A. Baharun, A literature review on the improvement strategies of passive design for the roofing system of the modern house in a hot and humid climate region. Frontiers of Architectural Research, 5:126-133, 2016.
[98] X. Chen, H. yang, Y. Wang, Parametric study of passive design strategies for high-rise residential building in hot and humid climates: miscellaneous impact factor. Renewable and Sustainable Energy Reviews, 69:442-460, 2017.
[99] E. Rodriguez-Ubinas, C. Montero, M. Porteros, S. Vega, I. Navarro, M. Castillo-Cagigal, E. Matallanas and A. Gutiérrez, "Passive design strategies and performance of Net Energy Plus Houses," 2014.
[100] D. I. Kolaitis, E. Malliotakis, D. A. Kontogeorgos, I. Mandilaras, D. I. Katsourinis and M. A. Founti, "Comparative assessment of internal and external thermal insulation systems for energy efficient retrofitting of residential buildings," Zografos, 2012.
[101] U. Eicker, "Cooling strategies, summer comfort and energy performance of a rehabilitated passive standard office building," Stuttgart, 2009.
[102] T. M. Mahlia, B. Taufiq, Ismail and H. Masjukia, "Correlation between thermal conductivity and the thickness of selected insulation materials for building wall," Kuala Lumpur, 2007.
[103] A. Ucar and F. Balo, "Effect of fuel type on the optimum thickness of selected insulation materials for the four different climatic regions of Turkey," Elazıg, 2008.
[104] M. Bojic, M. Miletic and L. Bojic, "Optimization of thermal insulation to achieve energy savings in low energy house (refurbishment)," Kragujevac, 2014.
[105] W. Lan, G. Chen, X. Zhu, X. Wang and B. Xu, "Progress in techniques of biomass conversion into syngas," Luoyang, 2013.
[106] H. F. Castleton, V. Stovin, S. B. Beck and J. B. Davison, "Green roofs; building energy savings and the potential for retrofit," Sheffield, 2010.