Space Heating and Cooling

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** Heating and cooling technologies have a major influence on global energy consumption, and will continue to do so in the future. In temperate regions, space heating is the single largest energy demand for households. In the commercial sector cooling demand has grown significantly, and with increasing office space being rapidly constructed in developing countries it is projected to rise dramatically over the coming decade. Residential cooling technologies are more important in the US and in warmer world regions. China is already the largest market for residential air conditioners. The market for residential heating technologies is complicated, as different cultural, climatic and physical requirements mean no single style of technology is used globally. In North America, forced air furnaces are common whilst in parts of Europe combination boilers and district heating systems are particularly popular. In terms of fuel input a general theme of heating technologies globally is a shift away from oil and coal towards gas and electricity. This shift is driven by rising fossil fuel prices and legislation driving consumers towards less carbon-intensive technologies. Low-carbon technologies such as heat pumps are becoming increasingly common in domestic and commercial applications and this trend is expected to continue over the coming decade.

■ **PERFORMANCE AND COSTS –** Fossil fuel fired heating systems remain the lowest initial capital cost, however, low carbon alternatives are becoming increasingly competitive when viewed over a five to ten year time frame. Future cost reductions and efficiency improvements in gas boilers and furnaces are not expected as the technology can be regarded as mature. However, the efficiency of technologies currently installed has scope for improvement, particularly utilising technologies such as condensing boilers, which are now mandatory in some countries. Heat pumps and air conditioning systems could see efficiency and cost reduction improvements of at least 20% by 2030 according to the IEA. This guide also highlights a range of developing technologies such as CO_2 refrigerant heat pumps and micro-CHP where there is scope for efficiency and cost reductions that may influence the market in the future.

■ **POTENTIAL AND BARRIERS –** Fossil fuel fired heating systems are expected to remain dominant in the years to come with an increasing proportion of low carbon heating systems which have great potential. CHP, biomass and heat pumps are projected to be some of the key technologies of the future. Legislation is a key factor driving improvements in technology and driving a market shift towards more efficient appliances. The Energy Star label is widely used and the Eco-design requirements being introduced in the EU will become increasingly important in placing minimum performance requirements upon heating and cooling products. A key barrier to the uptake of more efficient technologies is the additional cost, which is being partially overcome through various financial incentives. Additional barriers include consumer awareness, principal-agent barriers, information, transaction cost and regulatory barriers.

PROCESS AND TECHNOLOGY STATUS

In most countries, the building sector accounts for at least 40% of primary energy use in residential and services sectors, and the absolute figure is increasing due to higher construction rates, particularly in China, India and South Mediterranean countries [1]. The residential buildings uses significantly more energy than commercial buildings (around 70% of total building sector energy consumption) Currently, around 39% of CO_2 emissions from the global residential sector are due to space heating and cooling needs. In the service sector's this share is around 35% [2]. In order to keep the average global temperature rise below the 2°C limit agreed at the United Nations climate negotiations, average building energy consumption per person will need to be cut by 60% by 2050 compared to levels in 2005 [3].

Building heating and cooling systems are used to maintain comfortable indoor temperatures through the generation and/or transfer of heat. There are three main technical approaches to reducing the heating or cooling load of a building: first, to reduce the temperature difference between indoors and outdoors by accepting an indoor temperature that is closer to the outdoor temperature (as far as possible); second, to improve the building envelope (see ETSAP R01); and finally to increase the efficiency of heating and cooling products. It is this final approach that is the main focus of this brief. The technologies covered are concerned with primary (main) space heating and cooling technologies. Secondary (localised) heating and cooling systems are not considered in detail as by definition they account for a smaller proportion of demand.

Over the full life cycle (from equipment manufacture to disposal), the main environmental impact from heating and cooling systems occurs during the operation phase, which is directly related to energy consumption [12]. A variety of energy sources are employed, including gas, oil, electricity, biomass and other renewable sources.

■ **Residential Sector -** Residential energy consumption for space heating and cooling varies depending on local climate conditions, season and user behaviour. Domestic energy use is dominated by space heating in colder climates such as in (Northern and Central) Europe, where it accounts for 60-70% of residential primary energy consumption (Figure 1).

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Cooling is important in warmer countries such as India and the Middle East, as well as high-income countries such as the US where standards of living are higher [3]. The market for heating and/or cooling in developing countries is immature and demand is expected to grow significantly [9]. In rural China, energy consumption for domestic space heating is much lower per unit area of floorspace compared to Europe or the US because many homes do not have heating equipment installed, even if heating is required [20].

■ **Commercial Sector -** Energy use for space heating and cooling in the commercial sector also depends on regional factors (Figure 2). The scale of office space means it is by far the greatest overall energy user in most countries [3]. In large commercial buildings, significant savings are often hard to find using upgrades to core heating equipment because a lot of heat is internally emitted through electrical appliances and occupation [5]. In smaller commercial buildings, opportunities for improving the core heating equipment are similar to those in the residential sector [5].

Various technologies are available and most overlap the domestic and commercial sectors. Centralized systems generate heating/cooling at one point and transfer it to other areas via a distribution system, for example, using a central boiler and distributing heat through radiators. Decentralized systems deliver heat/cooling to the same area in which it is generated, without the need for a distribution system. Examples of decentralized systems include single split heat pumps, and small solid fuel combustion installations such as biomass room heaters. The focus of this brief is on the end-use technologies; however, in the case of centralized systems they form only part of the heating/cooling process and distribution systems are also needed. As highlighted above in Figures 1 and 2, heating and cooling requirements vary significantly with climate, building architecture and cultural influences. All these factors result in a wide range of heating and cooling technologies that are often represented by different dominant technologies depending upon the region or country. The following sections highlight key end use technologies and distribution systems.

■ **Central heating boilers (heaters)** heat water that is circulated through a system of **radiators.** This is the most common heating system used in Europe both for domestic and commercial buildings [8] and in the US for commercial buildings [5]. Boilers often provide both space heating and hot water for sanitary purposes. Cost analysis should take into account this combined production, which does not require a separate hot water systems (ETSAP R03). The vast majority of boilers in Europe are gas-fired, but some use oil [16]. In addition to conventional gas- and oil-fired boilers, biomass boilers and heat pumps can also provide combined space heating and hot water production. Higher efficiencies for both furnaces and boilers can be achieved using **condensing operation**, where some of the water vapour in the exhaust is condensed using a separate heat exchanger. Condensing systems are more popular in cold climates where they offer very significant fuel savings. In China, **coal boilers** used to

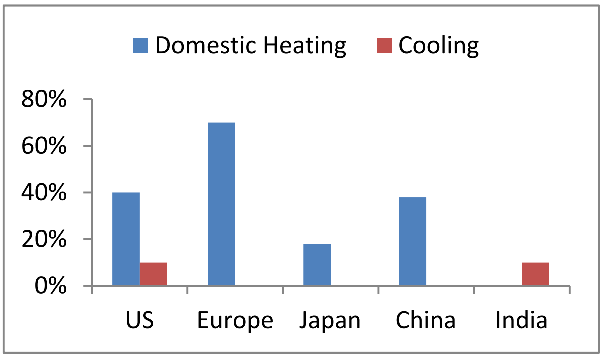

Figure 1 - Heating and cooling demand as a percentage of household energy use [3]

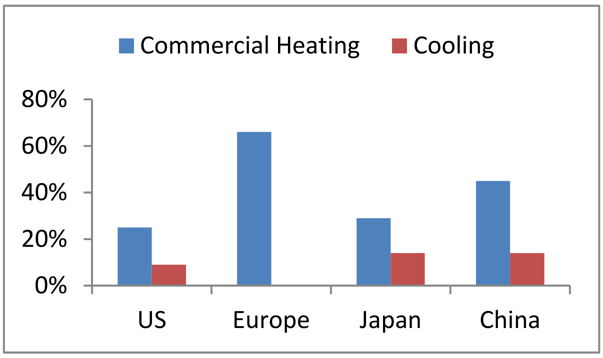

Figure 2 - Heating and cooling demand as a percentage of commercial energy use [3], [7]

be the dominant technology but now environmental regulations no longer permit their use and new boilers run on gas or oil [20]. Another example of legislation influencing technology choice is in Denmark where oil and gas fired boilers are being phased out for new build in 2013 and refurbishments of oil boilers in existing buildings from 2015 [22]. Alternatives to fossil fuel technologies are discussed below.

■ **Forced-air furnaces** heat the air directly and distribute it through a system of air ducts. They are the most commonly used residential heating system in the US, accounting for two-thirds of households and running most often on gas [5]. This type of air distribution system lends itself to the incorporation of air conditioning.

■ **Air conditioning systems** using a halocarbon refrigerant in a vapour-compression cycle and electricity as the main energy input are often used for space cooling in both domestic and commercial properties. At the global level, air conditioners were until recently used only in large office buildings, hotels and high-income homes [7], mostly in developed countries. Air conditioning systems are now becoming more common also in developing countries. Most residential central air conditioners use a **split system** with an outdoor condenser and compressor and an indoor evaporator coil [14]. China is by far the largest market for residential air conditioners with sales of over 25 million units in 2008-2009, while the next largest market is Japan at around 7 million units [25]. **Chillers** are typically used in larger commercial properties; in the US, they represent about 20% of cooling equipment in

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terms of floorspace [5]. They remove heat from a liquid through a vapour-compression or absorption refrigeration cycle. This cooled liquid flows through pipes in a building.

■ **Renewable energy-based heating and cooling** technologies offer low-carbon solutions for buildings and in many cases can also provide financial savings in the long term. Most of the technologies that can deliver savings are commercially available today. Current uptake of renewable energy heating/cooling is relatively low, but is increasing rapidly and projected to make a significant contribution by 2020. For example, many European Member States (particularly Belgium, Denmark, Hungary, Ireland, Italy, the Netherlands and the United Kingdom) have very high ambitions for renewable heating/cooling. The EU's Renewable Energy Directive sets a 20% renewable energy consumption target for the EU in 2020. Many EU countries are setting renewable heat targets as part of the overall strategy for energy consumption. For example the UK has set itself a 12% renewable heat target by 2020, from a baseline of 1.5% in 2011 [21]. The key renewable technologies that can be used for heating and cooling are **biomass boilers**, **solar thermal systems and heat pumps**. In the UK non-domestic sector biomass heating is likely to be the dominant renewable technology of choice.

Biomass boilers are well established in both the domestic and non-domestic markets and popular in countries such as Germany, Sweden, Austria and Poland [13]. There are many types of fuel with the main sources being wood chips and pellets from forest residues. The European Biomass Association report in their 2011 statistical review, that there are over 70,000 wood chip and pellet boilers in the EU [23]. An important advantage of biomass boilers over other renewables is that they can provide constant high temperatures similar to fossil fuel boilers. This is particularly useful in commercial/industrial situations where process heat is a requirement. In rural areas of developing countries heating from **direct burning of biomass** is common, mainly for cooking and hot water production.

Active solar thermal systems collect radiation from the sun to provide space heating, as well as cooling with thermally driven chillers. However, solar thermal is not typically used for space heating in temperate climates as maximum solar insolation coincides with the minimum in space heating requirement. The predominant application for solar thermal is hot water heating - this is discussed in detail in the ETSAP R03 brief. Solar thermal driven cooling is an application that has great future potential as solar insolation coincides with peak cooling demand. The IEA Solar Heating and Cooling Programme has recently commenced the Task 48 'Quality assurance and support measures for Solar Cooling' (October 2011-March 2015) with the aim of commercialising solar cooling [24].

Heat pumps (see ETSAP E19) are used in both domestic and commercial situations to transfer heat from a cold medium to a warmer medium, or reversed to provide cooling. Electric heat pumps are a relatively mature and versatile technology. Their use has been increasing over the past years since the improvement of thermal efficiency of buildings (see ESTAP R01) has reduced heating demand and facilitated the use of low-temperature heating technologies such as heat pumps. In some cases gas may also be used either for supplying heat to drive absorption heat pumps, or powering a gas engine to drive heat pumps (similar to electric heat pumps). The market for heat pumps in Europe was approximately 200 000 units in 2010 [12]. **Air Source Heat Pumps** (ASHPs) are by far the most common type of heat pump worldwide. They use the temperature difference between indoor and outdoor air. They are typically used in moderate climates [14]. There are two main forms of ASHP, air-to-air and air-to–water, both of which can be reversible. Air-to-air systems tend to be installed more often in warmer climates and commercial offices where the primary energy demand is cooling. Air-to-water systems can provide sanitary hot water and to date have predominantly been used in domestic applications. Air-to-water systems have good potential in the retrofit market as they can be integrated to existing central heating systems. **Geothermal heat pumps (Ground Source Heat Pumps)** use the relatively constant temperature of the earth instead of outside air as the heat source, and transfer the heat from the earth into buildings, typically through a ground loop system. Trench (horizontal) systems are cheaper to install and generally used in rural houses due to the space requirement, whereas borehole (vertical) systems are more common in urban and sub-urban environments as well as for industrial and commercial applications. The loop may be sealed, in which case the heat transfer fluid is contained in a closed piping system. In summer, many non-domestic systems run in reverse, using the earth as a heat sink. An open system uses heat transfer fluid that is part of a larger environment, e.g. ground water. Water-to-air heat pumps provide space heating using a heat exchange coil. Water-to-water systems use refrigerant-to-water heat exchangers. **Direct geoexchange** (DGX) models are less common. They use refrigerant circulated in pipes buried in the ground or submerged in water that exchange heat directly with the ground rather than a secondary heat transfer fluid.

■ **Electric heating** is a mature technology that is popular where low electricity prices prevail, for example in Canada or locations that have no connection to gas networks or district heating. Electric heating is likely to see its market share eroded by heat pumps over the coming years as the latter offers a more efficient use of energy. Both technologies are being considered in conjunction with smart grids particularly by countries increasing their intermittent renewable electricity generation. The use of electric heating via resistant heaters or heat pumps offers a solution to utilise excess renewable generation from technologies such as wind power - particularly at night.

■ **District heating** systems (ETSAP E16) are increasingly favoured by local government in high density areas where buildings have similar loads but limited scope for the application of building integrated renewables. The technology is very common in

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Sweden, Denmark, Finland, the Baltic States and several Eastern European states, where it accounts for around 50% of the heat demand of buildings [13]. A variety of energy sources are used including fossil fuels (e.g. in Poland) as well as renewable energy sources (biomass is important in Nordic countries) [13]. In contrast, the penetration rate is very low in other countries such as the UK and the Netherlands [13]. In China, district heating (often powered by coal) is the dominant source of space heating in cold regions, as the provision of district heat is mandatory in these areas [20]. Cogeneration, i.e. **combined heat and power (CHP)** production (see ETSAP E04) is often used to reduce primary energy consumption and CO_2 emissions in district heating networks. Commercial CHP systems using reciprocating engines, micro-turbines or on-site fuel cells have long term potential but savings are highly dependent on the ability to use waste heat from the power source for other building needs [5]. While large CHP systems are a well-developed technology, the market for **micro-CHP** is immature. Japan is currently the leading marketplace, although global sales in 2009 represented just 38 MW_e of capacity [9].

■ **Distribution systems -** End-use technologies used for central heating/cooling differ both in terms of the media used for heat transfer (water, air etc) and the distribution system (ducts, pipes etc). Boilers, micro-CHP and district heating can usually operate at relatively high temperatures and are well-suited to high temperature (55 to 80ºC) delivery systems such as radiators [17]. Domestic properties generally use water circulation in radiators, whereas commercial properties may use steam. Forced-air systems heat air in a central source and distribute it through the building via air ducts. Low temperature (35 to 55ºC) radiant delivery systems, such as **radiant underfloor heating** and **low temperature radiators**, tend to have large surface areas, operate over long hours and result in more gradual temperature changes in the heated space [17]. Heat pumps achieve much higher seasonal performance factors if they are installed with low temperature heat delivery systems especially 35-45 ºC. Heated water can also be circulated through radiant underfloor heating to take full advantage of the high efficiency of condensing boilers. This provides high levels of thermal comfort due to the constant vertical room temperature profile. Low temperature systems will only be effective in thermally efficient properties (see ETSAP R01); therefore thermally efficient buildings are particularly suitable for heat pumps.

Heating, Ventilation and Air Conditioning (HVAC) systems provide temperature control by circulating a certain amount of air at a sufficient temperature. They are often used in larger commercial buildings, particularly where high-rise buildings are not provided with operable windows for ventilation. These are common in the US [5]. More recently, these systems have also been used in energy-efficient housing, which often have airtight construction designs and thus need additional ventilation. Modern systems include heat exchangers to recover energy and improve efficiency.

PERFORMANCE AND COSTS

As mentioned, a range of issues influence the energy demand for space heating and cooling, including local climate, the building fabric and cultural perceptions of acceptable indoor comfort conditions. For instance, space heating consumption in Japan is relatively low because people tend to heat one room instead of the whole house [3]. Urban living, high incomes and greater access to technologies are associated with higher energy use for space heating [3].

Different systems employ different media to receive the heating or cooling. Water-heating systems are capable of achieving higher energy efficiencies than air-heating systems because of the lower energy required to distribute a given amount of heat, lower distribution losses and lack of infiltration of outside air [7]. The efficiency of a boiler or furnace system can be expressed as the Annual Fuel Utilization Efficiency (AFUE) rating in North America which is the same metric as Seasonal Efficiency, used in Europe. These metrics may be more relevant to actual installed performance than rated efficiency as they considers aspects such as standby losses and represent the efficiency of heat generation that ultimately goes to heating the house. However, these metrics vary significantly by region and season, therefore the figures provided in this brief refer to indicative seasonal efficiencies. Typical conventional North American **air-forced furnaces** achieve AFUE ratings of around 78% with a cost around €120/kW for gas-fired models and €145/kW for oil-fired models [17]. Condensing models can earn an Energy Star[1] rating if they achieve AFUE of over 90% for gas furnaces and over 85% for oil furnaces [15]. These more efficient models are slightly more expensive, costing around €130/kW for gas versions and €165/kW for oil versions [17]. Market penetration of these high-efficiency furnaces is growing; in 2009, 50% of residential gas furnaces and 24% of oil furnaces in North America were Energy Star certified, [15]. In Europe, where many residences use **central heating boilers,** AFUE values are around 75% for a typical standard model [17]. Gas boilers cost around €115/kW and oil versions cost around €125/kW [17]. Energy Star-rated boilers have AFUE of 85% for non-condensing models and 95% for **condensing types** [15]. Efficient domestic gas boilers with AFUE of 90% cost around €125/kW and efficient domestic oil boilers with AFUE of 86% cost around €135/kW [17]. For larger buildings (typical size of 40 dwellings or more), the cost per kW reduces significantly [17]. Modern **biomass boilers** have efficiencies of 75% or higher [17] with new models of comparable efficiencies to oil and gas condensing boilers. The main barrier facing biomass boilers is the higher upfront cost at €596/kW versus €125/kW for a new gas boiler. Cost reductions in domestic biomass boilers in particular are expected due to economies of scale and installer familiarity. The lifetimes of different types of heating and cooling equipment are relatively comparable between 15-20

[1] The **Energy Star rating** is an international standard for energy efficient products used in the US, Australia, Canada, Japan, New Zealand, Taiwan and Europe.

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years. At the commercial scale the typical lifetime is typically 5 years longer at 20-25 years, this is based upon maintenance procedures which are usually more thorough at larger scales.

It is important to note that the terminology used to describe the efficiency of heat pumps is different to that used for boilers and furnaces. Heat pumps are examined in terms of their **coefficient of performance (COP**), which is the ratio of heat output to electricity or gas input for a specified source and output temperature. So a heat pump using 1kWh of electricity to provide 3kWth would have a COP of 3.0.

The **Energy Efficiency Ratio (EER)** is the ratio of cold output to electricity or gas input for a specified source and output temperature. The EER for **air conditioners** is measured in terms of cooling power divided by fan and compressor power. The range is typically 3.2 – 3.5, depending on operating conditions [7]. Typical costs for domestic air conditioners are around €440/kW [17]. Energy Star-rated commercial **HVAC** systems represent 37% of the US market for central air conditioners and heat pumps in 2009 [15].

For both COP and EER it is becoming common practice to refer to the efficiency over a heating season so Seasonal COP (SCOP) or Seasonal EER (SEER). Energy Star-rated models are about 14% more efficient than standard models [14]. **Chillers** have an EER of up to 7.9 under full load operation and even higher under part loading [7].

The heat pump market is continuing to show innovative technology developments that will influence not only the types of products but also continued improvements to the costs and performance. The projected improvements are expected to result in cost reductions of 20-30% and efficiency improvements of 30-50% by 2030 [25]. Variants of existing products are being introduced to the market. The use of **natural refrigerants**, particularly CO_2 refrigerant, is such an example; this technology - whilst more expensive - offers the ability to heat to higher temperatures, thus enabling efficient sanitary hot water production and offering a new market in domestic retrofit or commercial sector in particular. The efficiency of gas fired heat pumps is referred to as the **Primary Energy Ratio (PER)**, the energy supplied is then the higher heating value (HHV) of the fuel supplied. The aforementioned COP for electrically driven heat pumps can also be reported in PER by multiplying the COP with the power station efficiency. Unless power generation has a low carbon intensity, comparing the PER of electric and gas driven heat pumps can result in a similar overall efficiency[2]. As electricity grids decarbonise in the future, the PER of electric driven heat pumps will continue to improve. Gas engine heat pump technology is already used for heating and cooling worldwide, and currently has an efficiency (PER) of around 1.5 (under this example 1kWh of gas would provide 1.5 kWh of heat) [17]. The technology is predominantly geared towards commercial applications; their use in the residential sector is usually limited to multi-unit dwellings. Liquid-based **absorption heat units** have also recently entered the market [17]. Solid-based adsorption systems, which use the exhaust from a gas condensing boiler to drive the pump, are currently under development, and expected to be introduced within 2 years. Efficiencies of at least 1.2 (PER) could be achieved in these units [17].

Air-source heat pumps (ASHPs) are widespread in warm climates as they can be operated in reverse to provide cooling, whereas **ground-source heat pumps (GSHPs)** are more suitable for colder countries and typically offer greater efficiency. Air-source heat pumps have lower installed cost at €1,275/kW compared to €1,625/kW for ground source heat pumps because there is no need to install a ground loop [17]. The costs of ground loops themselves vary significantly with geology; typically horizontal trench based systems cost almost half of an equivalent size borehole. There also is a wide range in product performance; Energy Star-rated geothermal heat pumps are at least 45% more efficient than standard models. The wide range in product performance and site specific factors means that variation in installed heat pump costs for domestic properties can be large demonstrated by the range in installed costs published by the IEA [25]. Indeed this report illustrates the much higher installed costs in Europe are compared to other regions such as North America where the installed costs for ASHPs range from €385-530/kW and GSHPs from €405-690/kW. Energy-star rated geothermal heat pumps reached 59% of the US heat pump market in 2009 [15]. Heat pumps can also be categorised depending on how the extracted heat is used. In the United States and Japan both of which have mature heat pump markets air is the most common heat distribution medium [28]. Air-to-air heat pumps pass air directly into the room or distributed through a forced-air duct system. Air-to-water (hydronic) systems are used to heat water to around 40°C to 45°C [18]. Air-to-air heat pumps usually have a higher performance because the temperature of the heat sink is lower (30-50°C) than hydronic systems (45-55°C) [28], but typical efficiencies are expected to be in the range of 3.2-3.5 (heating) and 2.6-2.6 (cooling) for both types [17].

Hybrid heat pumps combine a heat pump with a second heating system to match specific heat loads which can lead to an overall improvement in performance. Since the efficiency of air source heat pumps drops when the outside air temperature is low, it can be more efficient to use a boiler during these periods. Combining ground source heat pumps with secondary heating source can reduce the size of the ground loop required, reducing installation costs, and allowing the heat pump to run more efficiently as it is not overworked in peak season [17]. However, there is currently some debate amongst installers in some

[2] Applying the PER approach to electrically driven heat pumps. As an example, with gas fired electricity generation of 40% and a heat pump performing at a COP of 3.0 then to consider this on a primary energy basis it would be: primary energy input (natural gas)*electricity generation efficiency*heat pump efficiency=PER
For example: 1*0.4 (power station efficiency)*3 (heap pump COP) = PER of 1.2

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countries such as the UK over the approach to sizing heat pumps. New guidance recently released by a UK Government scheme recommends sizing heat pumps for domestic dwellings to be the only heat source, as opposed to designing systems to be used with a secondary source [27].

The amount of thermal energy provided by **active solar thermal** systems is typically between 300 and 900 kWh/m^{2}·year [9]. Installed cost ranges from 1,100 to 2,140 US$/kW for new build and 1,300 to 2,200 US$/kW for retrofit [9]. As mentioned previously these devices typically provide sanitary hot water, and the use of a backup system is typically needed in temperate countries. There is potential for increased use of solar thermal to feed into part of the heat load of a district heat network. Recent examples of such an approach are available in Denmark and Germany where large commercial scale solar thermal plants have been installed.

CHP is a mature technology and developments in gas engines, gas turbines and steam turbines are still expected to deliver small, incremental improvements in efficiency [17]. **Micro-CHP** for domestic properties can range in size from 0.8kW$_{e}$ for a small dwelling to 5kW$_{e}$ for large multi-family dwellings [17]. Some units are noisy or require mounting on a concrete pad, which can limit suitable installation sites in dwellings. A major barrier preventing the uptake of Micro CHP is the high installed costs which range from €5,300/kW upwards, with fuel cell-based units currently significantly more expensive [17]. **CHP district heating** systems can range from small gas engines (from 200kW upward) supplying multi-dwelling buildings to large steam turbines or combined cycle gas turbine (CCGT) plant supplying a district heating network [17]. Integrating a carbon capture and storage (CCS) unit into district CHP plants could contribute to decarbonisation goals while reducing energy penalty and operating cost of CCS [17]. For a large (500 MW$_{e}$) gas-based CHP district heating scheme, the installation of a CCS system would lead to an energy penalty of about 10% and increase capital cost by around €570/kWe, which add an extra €6/MWh to non-fuel operating costs [17].

POTENTIAL AND BARRIERS

■ **Potential -** Conventional boilers and furnaces are likely to remain an important technology for several years to come [17]. Many countries have recently progressed from standard models to more efficient condensing versions [4].

Low-carbon, zero-carbon and energy-efficient heating and cooling technologies for buildings could reduce CO_2 emissions by up to 2Gt and save 710 million tonnes oil equivalent (Mtoe) of energy by 2050 if deployed globally [9]. According to the International Energy Agency, the key technologies to achieve this aim are active solar thermal, CHP and heat pumps [9].

Heat pumps have a relatively high capital cost and this, together with requirements for space to install them may limit their uptake [17]. This also applies to varying degrees to solar thermal and biomass technologies. Commercial scale heat pump systems are on the other hand more cost effective typically in the region of €500-€700/kW depending upon whether the heating medium is air or water. Uptake of more sustainable heating and cooling systems is being driven by legislation, financial incentives and increased consumer awareness. Despite these barriers significant effort is being made to address these issues which are discussed below.

The energy saving potential that is realised in practice may be significantly lower in part due to the slow stock turnover. In developed countries, many properties built before energy efficiency regulations were introduced will still be in use in 2050; for example, 50% of European housing stock was built before 1975 [3]. This slow building stock turnover therefore requires an integrated approach to improving building thermal efficiency to enable a market shift in heating appliances.

Cooling demands in modern buildings (particularly commercial building) have grown due to the need to offset higher internal heat gains from computers, servers and other appliances. There has also been a rapid rise in the demand for air conditioning in developing countries as their economic growth requires new offices and their higher incomes can meet demand for greater thermal comfort. For example, offices are expected to increase energy consumption for cooling in China by 12% per annum [3]. Efficiency improvements are expected to help reduce the overall demand increase with the IEA projecting a 20-40% cooling efficiency improvement by 2030 [25]. One aspect that is likely to facilitate improvements is that the majority of air conditioning/heat pump expertise is located in South-East Asia, predominantly Japan and South Korea.

Uptake of more efficient heating and cooling plants and devices is increasingly required by legislation and building codes. For example, solar thermal obligations form part of the building codes in Italy, Portugal and Spain [13]. In Europe the Renewable Directive (2009/28/EC) includes renewable heating/cooling in the overall target and in the National Renewable Energy Action Plans. The Directive also requires building regulations to specify a minimum level of energy from renewable sources in new and refurbished buildings [13]. Legislation will also be important in influencing technology choices, for example Denmark is prohibiting the installation of oil boilers in new buildings from 2013 and retrofitting new oil boilers from 2017.

The new Eco-design requirements being introduced in the EU will introduce minimum performance criteria that are progressively increased through to 2020. The associated new eco-labelling requirements also offer consumers better information on the energy performance of products that has previously not been transparent due to different reporting methodologies. As an illustration of the Eco-design requirements forcing the market, it is proposed to set the minimum fuel boiler efficiency ($\leq$70kW) at 86% [26]. Eco-design requirements are currently in draft for space heating boilers and heat pumps.

■ **Financial incentives –** Financial incentives such as investment subsidies, low interest loans and tax reductions have been widely applied to stimulate the market uptake of renewable installations, which often have relatively high capital costs and long pay back periods. In the UK, a novel financial instrument has been adopted – the Renewable Heat Incentive pays a fixed sum for each unit (kWh) of heat generated by various installations on a technology-specific basis. In the German Market Incentive Program, soft loans and investment subsidies are available for biomass plants[13]. The financial incentives aim to help achieve renewable energy targets but also more importantly drive down costs and increase technology familiarity through economies of scale. An example of economies of scale can be taken from the solar photovoltaic sector where dramatic cost reductions over the last five years have seen governments reduce fiscal incentives accordingly.

■ **Consumer Awareness** - A number of consumer information programmes have been set up to increase consumer awareness. The Energy Star label is used both in the US and in Europe In addition there has been a rapid growth in green building certification, and forecasts predict that a cumulative 53 billion net square feet of floorspace will be certified by 2020 [10]. The aforementioned eco-design directive will introduce energy labelling in a consistent format applied to other products such as white goods throughout the EU. The use of labelling will improve customer understanding of performance.

■ **Barriers –** The energy efficiency improvement potential is not fully realised because of principal-agent market barriers, information and transaction costs [1].

Principal-agent barriers occur when the benefits of energy efficiency do not accrue to the person who incurs the cost. This is common in commercial and domestic lease properties, where the landlord chooses the equipment but the tenant typically pays the utility bill. A split incentive also exists if owners do not expect to hold a property over the full payback period of a technology, as this is usually realised through energy savings over several years. No single policy instrument is capable of overcoming principal-agent barriers in all contexts. Mitigation can be achieved through use of policy instruments such as providing transparent information about energy performance (e.g. through green building certification programmes), addressing contract design and setting minimum standards for the energy efficiency of equipment.

Information barriers arise when the consumer lacks sufficient information to optimize their energy consumption. This is a major problem in developing countries, but consumers in developed countries tend to be well-informed [3]. In addition, there is relatively little understanding of "as-constructed" performance of newer technologies [4].

Transaction cost barriers include the costs of gathering information, time and costs for installation of new equipment. The fragmented nature of the building industry means it can be difficult to identify appropriate contractors [3].

Finally, **regulatory barriers exist** in developing countries such as China and Brazil, because of the lack of regulation or enforcement [3].

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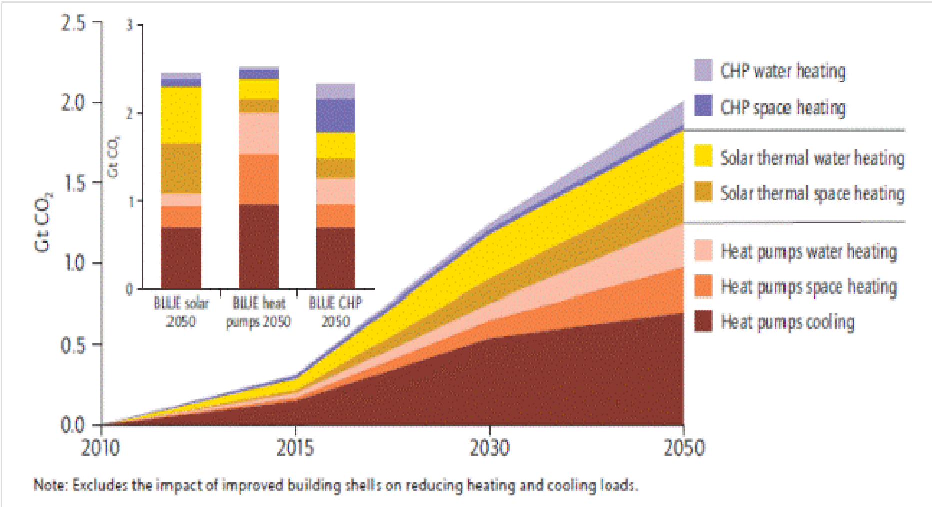
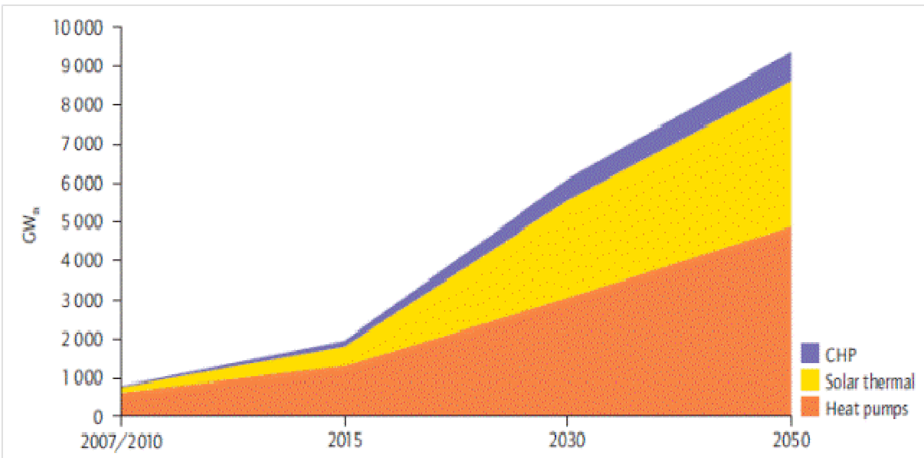
CO_2 Emissions Reductions from Heating and Cooling Technologies- IEA BLUE Map and Alternative Scenario



Global Installed Capacity of Efficient and Low/zero Carbon Heating Technologies (GWth) - IEA BLUE Map Scenario



Notes: The IEA BLUE Map scenario assumes that heating and cooling technologies reduce building related emissions by 2 Gt by 2050. This is based on an acceleration in the rate of low carbon and energy efficient technology uptake worldwide. The Blue map scenarios assume significant improvements in efficiency and cost reductions including low-cost thermal storage and deployment of solar thermal. Further details of the scenarios is provided in the IEA report [25].

Figure 3 - Projections for Global low-carbon Heating and Cooling [25] (incl. a proportion of hot water heating).

Table 1 – Summary Table: Key Figures for Heating and Cooling Technologies [14], [17]

Technology Class	Technology Name	Capacity kW	Capital Cost €/kW	FixO&M Cost €/kW-y	Lifetime yrs	Heating Efficiency HHV,	Cold Effic. HHV	Electric Effic. HHV
Dwelling scale Boilers	Existing Gas Boilers	20	115	5	15	0.75	-	-
	New Gas Boilers	20	125	5	15	0.90	-	-
	Existing Oil Boilers	20	125	5	15	0.75	-	-
	New Oil Boilers	20	135	5	15	0.86	-	-
	Current Biom.Boilers	20	596	13	15	0.70	-	-
	New Biomass Boilers	20	596	13	15	0.85	-	-
	Existing Coal Boilers	20	115	5	15	0.75	-	-
Furnaces (dwelling scale)	Existing gas furnaces	20	120	5	18	0.78	-	-
	New gas condensing	20	130	5	18	>0.90	-	-
	Existing oil furnaces	20	145	5	17	0.78	-	-
	New oil condensing	20	165	5	17	>0.85	-	-
Building-scale Boilers (typical 40 dwellings / building for moderate climate)	Existing Gas Boilers	120	70	2	25	0.75	-	-
	New Condensing Gas Boilers	120	80	2	25	0.90	-	-
	Existing Oil Boilers	120	75	2	25	0.75	-	-
	New Oil Boilers	120	90	2	25	0.86	-	-
	Existing Biom Boilers	120	375	10	25	0.70	-	-
	New Biomass Boilers	120	375	10	25	0.85	-	-
	Existing Coal Boilers	120	100	2	25	0.75	-	-
Heat Pumps domestic scale	Existing Heat Pumps	12	1,500	15	15	2.50	2.50	-
	New Ground-to-Water H. Pumps	12	1,625[3]	15	15	3.3-3.6	2,3-2,6	-
	New Air-to-Water Heat Pumps	12	1,275	15	15	3.2-3.5	2,3-2,5	-
	New Air-to-Air Heat Pumps	12	600	15	15	3.2-3.5	2,3-2,5	-
	Gas Absorption Heat Pumps	12	700	15	15	1.25-1.35	0.63	-
Heat Pumps comm./industrial scale	New Air to air	300	535	2-3	20	3.2-3.5	2.3-2.5	-
	New Air to Water	300	670	4	20	3.2	2.3-2.5	-
Large Scale CHP	500kWe Gas engines	500	1,000	32	15	1.3*	-	0.38
	5MWe Gas engines	5,000	900	30	20	1.3*	-	0.44
	5MWe Steam Turbine (biom.)	5,000	4,500	100	25	3.5*	-	0.16
	60 MWe CCGT	60,000	800	20	20	1.0*	-	0.45
	60MWe Steam Turbine (biom.)	60,000	4,200	100	25	3.5*	-	0.21
	500MWe CCGT	500,000	700	18	20	0.5*	-	0.52
Micro-CHP	Stirling Eng..Micro-CHP	1	6,300	10	15	0.77	-	0.13
	ICE-based Micro-CHP	1	5,300	10	15	0.63	-	0.23
Mini-CHP	ICE-based Mini-CHP	5	2,382	5	15	0.60	-	0.25
CCS-enabled CHP	Gas 50MW CHP CCS	50,000	1,237	33	25	0.5*	-	0.39
	Gas 500MW CHP CCS	500,000	1,270	33	25	0.5*	-	0.47
Hybrid Technologies	Boiler-Solar Hybrid	20	275	10	15	1.00	-	-
	Heat Pump - Boiler Hybrid	12 or 20	1,402	15	20	-	-	-
Air conditioners	Existing air conditioner	12	440	15	14	-	3.2-3.5	-
	New air conditioner	12	440	15	14	-	3.2-3.5	-
Radiators	High temperature radiators	20	120		20	-	-	-
	Low temperature radiators	12	250		20	-	-	-

* heat to power ratio

Notes: costs given in 2010 Euros. Prices in US$ have been converted to Euros using an exchange rate of 0.755. HHV = higher heating value. Heat pumps: district heating network costs not included; Stirling engine-based Micro CHP based on Whispergen Mark 4; Ice-based Micro CHP based on Honda ECOWILL; PEMFC-based Micro CHP based on Japanese PEMs; SOFC-based Micro-CHP based on Japanese SOFCs; Mini-CHP based on Baxi-Dachs system (80% overall efficiency). Additional cost due to CCS is EUR570/kW. High temperature radiators based on assumption of EUR2,400 to fit a 100m2 house. Low temperature radiators based on EUR3,000 to fit a 100m2 house. Capital costs include installation costs. Figures are based on European climate – performance in other climates may vary. Fixed O&M costs cover maintenance such as a boiler check or F-gas check for heat pumps.

[3] Ground and air source heat pumps to a wet heating system include the cost of low temperature radiators as part of the installation.

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