Achieving domestic Kyoto targets with building heat pumps in the UK

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ABSTRACT

This paper presents quantitative information about the potential future contribution of heat pumps to the UK commitment to the Kyoto Protocol in targeted application areas. Estimates have been made of the reduction in emissions of greenhouse gases that would result from using heat pumps in the commercial/institutional building sector in the UK between the year 2000 and 2020. The modelling took into account anticipated trends in construction, in the penetration of air conditioning, equipment replacement rates, changing fuel mix for electricity generation and improvements in the energy performance of both heat pumps and fossil fuel boilers. Different refrigerants and Seasonal Performance Factors (SPFs) were used to calculate the direct and indirect components of the Total Equivalent Warming Impact (TEWI).

The total potential CO_2 emissions reduction for the commercial/institutional building sector under a Business-As-Usual scenario (BAU) was estimated at 0.15 Mt $CO_{2equivalent}$ for the year 2000 rising to 0.74 Mt $CO_{2equivalent}$ in 2020. Reductions were shown to be greatest for the office building sub-sector since offices currently account for the greatest proportion of packaged air conditioning systems. The retail outlet sector showed the largest percentage increase in potential reductions. In 2010, approximately 3% of the CO_2 emissions reduction required under the Kyoto Protocol targets established for the UK (based on time frame 2000-2010) could be achieved by heat pumps that replace gas boilers in commercial/institutional building applications.

1. INTRODUCTION

The International Energy Agency (IEA) Heat Pump Programme is the foremost world-wide source of independent information and expertise on heat pump, refrigeration and air conditioning systems for buildings, commerce and industry. The Programme develops factual, balanced information to achieve environmental and energy efficiency benefit through deployment of appropriate high quality heat pumping technologies. One of the main priority strategies of the Programme is to quantify and publicise the environmental and energy efficiency benefits of heat pumps.

To improve the acceptance of heat pump technology and contribute to improved understanding of their potential, the IEA Heat Pump Programme has conducted a number of studies concerning the environmental effects and benefits of heat pumps in the building sector and process industry (IEA 1992, IEA 1999, IEA 1995). These studies have demonstrated that heat pumps can substantially reduce primary energy use and thereby global warming. On average, heat pumps for space heating using electricity produced from the same fuel can save up to 50% of primary energy compared to conventional fuel-fired boilers and furnaces. In process industry they have the potential to reduce total heat energy consumption by an average 2-4%, and for individual processes up to 65%. In 1997, at the time of the Kyoto Global Climate Change summit, the IEA Heat Pump Centre assessed the potential of heat pumps for reducing global CO_2 emissions: the global emissions reduction potential of heat pumps was 6% (of 22 billion tonnes

CO_2 in 1997), and the potential contribution of heat pumps to emissions reduction would increase with time up to 16% due to technology and market developments

To provide government policy makers in IEA countries with independent information on the environmental benefits of heat pumps and show them to what extent they can help to achieve national Kyoto targets, a tool has been developed that assesses the CO_2 emissions reduction potential of heat pumps in buildings. The results of the assessment can be used to formulate (new) heat pump policy programmes. The tool was first applied for an assessment of the UK.

2. HEAT PUMP MARKET UK

The UK has a population of around 60 million and there are about 23 million dwellings in the country. At over 20% of total energy consumption, energy use for space and water heating in the domestic sector is significant. The total energy consumption of the country increased over the period 1990-‘96 at an average annual rate of 1.15%. This compares with an annual increase of 3% in the domestic sector as a whole, and 1.4% for domestic space heating.

In the UK heat pumps have mainly found application in the commercial/institutional sector. The IEA Heat Pump Centre estimated that in 2000, the installed base of heat pumps amounted to 600,000 systems. Current annual heat pump sales in the UK are estimated to be 70,000 units. These are mostly reverse cycle split systems used in commercial/institutional buildings. The UK has been an air conditioning driven market, with less than 1% of heat pumps being used as a prime heat source. Overall penetration of air conditioning in the commercial/institutional sector is estimated to be in the order of 25%. The UK Heat Pump Association reported for 1999 an assumed growth rate of 4% per year and a base market size of 66,000 heat pump units. The heat pump market will continue to grow on the back of a robust air conditioning market. Additional growth is expected to come from utilisation of alternative heat energy sources that are coming into play, recycled prepaid energy, exhaust air heat recovery systems and ground-source heat pump systems. The market is inhibited by low energy cost and perceived high initial costs.

The size of the residential heat pump market in the UK is negligible with around 380 units reportedly being sold annually in 2000 (EHPA 2001). The CO_2 emissions reduction achieved with these units is estimated to be 1,000 tonnes per year. It is anticipated that this market will grow to 8,200 units in 2010. Approximately 5,000 dehumidifier heat pumps were installed as well in 2001. A market for residential ground-source heat pumps is starting to emerge. In 2001, there were probably between 100 and 200 installations, all of which had been installed in the last few years.

Compared to gas-fired central heating, by far the most common residential heating system, ground-source heat pump systems have lower CO_2 emissions, but high capital costs and offer very marginal operating cost advantages. However, a significant minority of houses are outside the natural gas supply area and many of these have electric resistance heating (usually a combination of storage and direct heaters). Ground-source heat pumps are still more expensive in initial cost than these systems, but offer significantly lower operating costs and CO_2 emissions. Target markets for ground-source heat pumps in the UK are:

- New and refurbished housing outside the gas supply area;
- Environmentally conscious purchasers;

- Owners of groups of similar houses.

The annual rate of heat pumps in process industry has been fairly stable at around 100 units over a number of years. The majority of units have been small dehumidifiers/dryers with less than 10% being larger mechanical vapour recompression systems.

3. ASSESSMENT METHOD

The scope of the assessment is restricted to the commercial and institutional building sectors, particularly offices, hotels, retail outlets etc. This is the most prolific area of heat pump application in the UK. The market is being driven by the growth in demand for building air-conditioning, which has a current market growth rate of the order of 5% per year. In general these installations are served by single-package air conditioning equipment that provides air at controlled temperature and humidity conditions to various occupied spaces within the building. Some of these systems are equipped as heat pumps, and recognising that this proportion is increasing, the assessment method considers potential reductions in CO_2 emissions resulting from providing heat to the building by using the system's heat pumping capability rather than using a gas fired boiler. Boilers are by far the most common heating source in UK buildings.

The model considers each of the following ten sub-sectors separately:

- Commercial offices;
- Retail;
- Hotels;
- Education;
- Health;
- Leisure;
- Warehouses;
- Government buildings;
- Communication and transport;
- Other.

The modelling process is summarised in Figure 1. The modelling takes into account anticipated trends in construction, in the penetration of air conditioning, equipment replacement rates, changing fuel mix for electricity generation and improvements in the performance of both heat pumps and fossil fuel boilers. Estimates include the direct and indirect impact on TEWI that would result from expansion of the use of heat pumps in the commercial/institutional building sector up until the year 2020.

The assumptions in the modelling process are as follows:

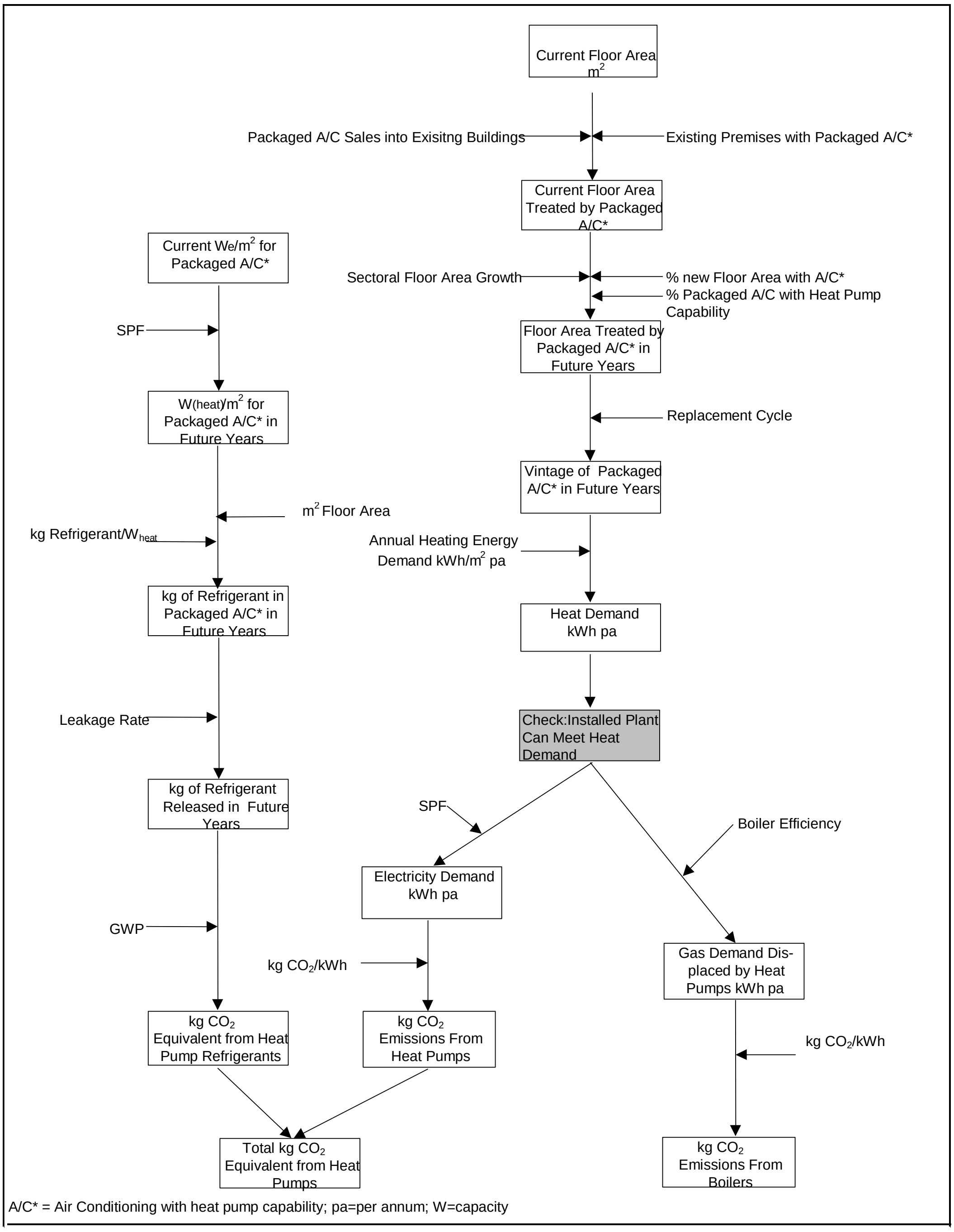

Figure 1. Model Flow Diagram

- The floor area currently serviced with packaged air conditioning systems is determined from knowledge of the current size of the UK building stock and the proportion of space treated with air conditioning.
- The typical installed cooling capacity and energy consumption ($kWh_{electric}$) for each end use sector is determined from an analysis of a sample of existing air conditioned buildings in the UK.

- Market penetration rates for heat pump capabilities in packaged air conditioning (Wolfenden and Giles 1999) indicate that currently 50% of packaged air conditioning systems have heat pump capabilities. This penetration of the market increases by an additional 1% per year (BAU).
- The estimated increase in the amount of building floor area treated by packaged air conditioning systems in future years is based on a knowledge of projected sector growth, the proportion of new buildings with air conditioning (Pout et al. 1998) and current and projected sales of packaged air conditioning equipment.
- It is assumed that the demand for cooling and heating per m^2 of floor area will remain constant in future years and hence, the installed electrical capacity of packaged air conditioning systems will decrease in line with the increase in cooling and heating energy efficiency performance.

With these assumptions, estimates of the floor area with heat pump capacity and the total electrical capacity installed have been calculated for 2005, 2010, 2015 and 2020.

The typical equipment replacement rate introduced in the model is 15 years, based on understanding of the packaged air conditioning market. This provides the vintage of packaged air conditioners in future years.

Next the model determines if the level of heat pump capacity installed per m^2 is sufficient to meet total heating demand over the heating season, for which peak heating load design values have been used. In all cases the installed capacity was found to be in excess of this requirement, and therefore it has been assumed that heat pumps can meet the total heating load. The model uses annual heating demand (kWh_{heat}/m^2) values established for each of the 10 sub-sectors.

The main data inputs are presented in Table 1. Following a future ban on HCFCs and expected use restrictions of HFCs, different refrigerants over the years are applied to the model. It assumes that 1% of the refrigerant charge leaks annually and that, in accordance with proposed legislation in the UK, full refrigerant recovery is achieved at the end of the system lifetime. The equivalent levels of CO_2 emissions corresponding to the 1% refrigerant leakage rates are calculated by multiplying mass of refrigerant that has leaked by the Global Warming Potential (GWP). Propane (R-290) was assumed to require 40% of the charge of a fluorocarbon refrigerant to meet the same heating/cooling demand.

Indirect emissions from heat pump use are calculated from the annual average CO_2 emissions factor for UK electricity generation, the building heating demand, and the assumed average SPF of the future heat pump stock installed. The emission factors for UK electricity generation are based on published projections of the mix of fuels expected to be used in the production of electricity in future years.

The CO_2 emissions that are displaced by using heat pumps are calculated by multiplying the CO_2 emission factor for natural gas by the total annual gas consumption required to meet the heating demand. Here it is assumed that the average seasonal efficiency of the current UK boiler stock is 72%, and for each subsequent 5-year period the average efficiency of the boilers will increase by an additional 4%.

The total equivalent CO_2 emissions reduced by displacing gas boilers with heat pumps in the commercial/institutional sector is thus equal to the CO_2 emissions from the gas combustion used in boilers less total direct equivalent and indirect CO_2 emissions from the heat pumps in delivering the same amount of heat.

Table 1. Model inputs and assumptions

Year	**2000**	**2005**	**2010**	**2015**	**2020**
Growth in packaged AC installed (%)	100	142	183	221	262
AC with heat pump capacity (%) - BAU	50	55	60	65	70
SPF for new heat pump systems	3.0	3.0	4.0	5.0	6.0
Efficiency of new gas boiler - gross base (%)	72	76	80	84	88
Refrigerant	R-22	R-22	R-407C	R-410A	R-290
Refrigerant GWP	1,700	1,700	1,610	1,890	3
Emission electricity generation (kg CO_2/kWh el.)	0.48	0.37	0.35	0.37	0.37
Emission gas boiler (kg CO_2/kWh gas)	0.19	0.19	0.19	0.19	0.19

4. DISCUSSION OF RESULTS

4.1 Commercial/institutional sector

Table 2 summarises the potential equivalent CO_2 emissions reduction by replacing gas boilers with heat pumps in the commercial/institutional sector. The reductions would increase from 0.15 million tonnes in 2000 to 0.74 million tonnes in 2020.

Table 2. CO_2 emissions reduction in thousand tonnes – by application and total

Year		**2000**	**2005**	**2010**	**2015**	**2020**
Hotels		33	62	93	127	169
Offices		32	74	116	151	196
Education		29	49	68	89	118
Health		13	22	31	39	49
Retail		12	33	61	95	140
Warehouses		6	7	8	9	11
Leisure		3	4	6	7	9
Government buildings		3	4	4	5	6
Communication and transport		0.4	0.61	0.78	0.93	1.2
Other		18	25	31	36	45
Total sector	Boiler emissions avoided	395	565	740	918	1,111
	Heat pump emissions (indirect)	239	272	310	345	358
	Heat pump emissions (direct)	7	10	12	14	9
	Emission reduction	149	282	418	558	744

By 2020 the CO_2 emissions from using heat pumps would be one third of those attributable to gas boilers, and whereas the heat pump emissions tend to flatten off over time the boiler emissions continue increasing at about 5% per year. Figure 2 shows the corresponding percentage reductions in CO_2 emissions for those buildings that are expected to be using heat pumps relative to emissions from heating the same buildings with gas boilers. This graph indicates a doubling to almost 70% emissions reduction by the year 2020, relative to 2000.

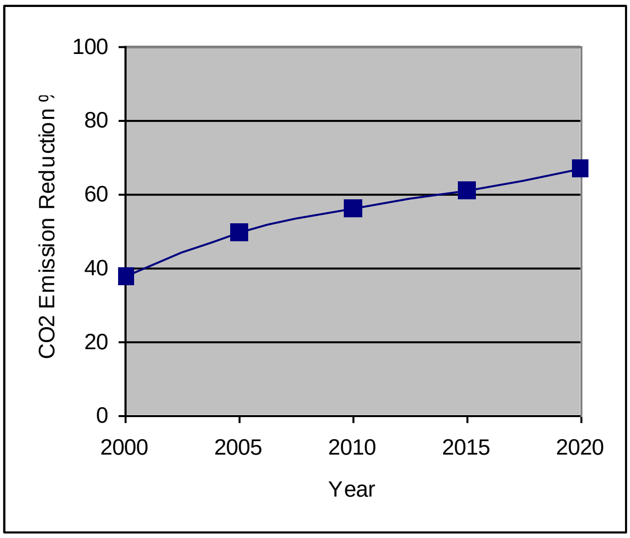

Figure 2. Percentage CO_2 emissions reductions due to heat pump use

In relation to the total CO_2 emissions associated with heating in the UK building service sector, these results indicate that using heat pumps reduces emissions increasingly from 0.5% (of 32.3 Mt CO_{2eq}) in 2000 to 2.5% (of 28.6 Mt CO_{2eq}) in 2020. This is due to a combination of increasing penetration rates of air conditioning with heat pump capacity, improving SPFs and increasing power generation efficiencies. The overall effect is also a CO_2 emissions reduction in absolute terms in the time frame 2000-2020.

Figure 3 depicts that the sub-sector with the potential to reduce the most equivalent CO_2 emissions is office buildings with 0.2 Mt reduced in 2020.

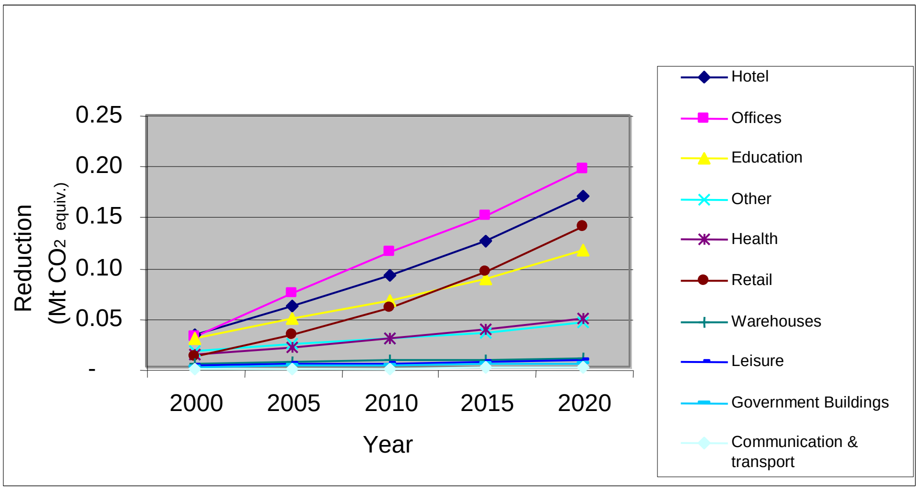

Figure 3. CO_2 emissions reduced by heat pumps for different sub-sectors

However, the greatest rate of growth in emission reductions is in the retail sub-sector, which is predicted to increase in floor area with 50% and a corresponding increase of over 400% in floor space serviced by air conditioning between 2000 and 2020. The potential CO_2 emissions reduction in the retail sub-sector is about 70% (0.14 Mt CO_{2eq}) of that by office buildings, even though the predicted floor spaces are about the same by 2020. That is due to the average heating demand required by the retail sub-sector being 70% of that required in office buildings.

4.2 Sensitivity analysis

The effect of changing two key parameters was analysed:

- A moderate increase in SPF;
- Increased uptake rates of packaged air conditioners with heat pump capacity.

A less rapid increase in SPF for heat pump systems in the commercial/institutional sector is perhaps pessimistic, but it sets a lower limit. Increased uptake rates could be a realistic possibility. It could be the result of support measures, incentives or other policy instruments. Table 3 shows the assumed moderate SPFs, as well as the increased annual uptake rates following a 2% incremental and a 2% compounded time path. Each set of scenarios uses the same 15-year replacement cycle.

Table 3. Variation of SPF and heat pump uptake (%)

Year	**2000**	**2005**	**2010**	**2015**	**2020**
Moderate SPF	2.5	2.5	3.0	3.5	4.0
2% incremental annual uptake	50	55	65	75	85
2% compounded annual uptake	50	55	66	78	92

Table 4 shows the CO_2 emission reduction results for these scenarios. With a moderate SPF assumed over the time frame 2000-2020 and increased uptake rates for heat pumps, the total equivalent emissions reduction in 2020 never reaches the level (0.744 Mt) that is achieved with higher SPFs and normal uptake (BAU); see also Table 2.

Table 4. Total sector CO_2 emissions reduction in thousand tonnes

Year	**2000**	**2005**	**2010**	**2015**	**2020**
Moderate SPF/Uptake BAU	101	228	338	438	587
Moderate SPF/2% incremental annual uptake	101	228	353	485	687
Moderate SPF/2% compounded annual uptake	101	228	356	499	729
Higher SPF/2% incremental annual uptake	149	282	437	618	871
Higher SPF/2% compounded annual uptake	149	282	441	636	924

In each scenario considered, the office sub-sector would provide the highest emissions reduction in 2020 followed by the hotel and retail sub-sectors.

Figures 4 and 5 show the total equivalent CO_2 emissions reduction over the period 2000-2020 for the moderate and higher SPF values respectively for the three different uptake rates considered.

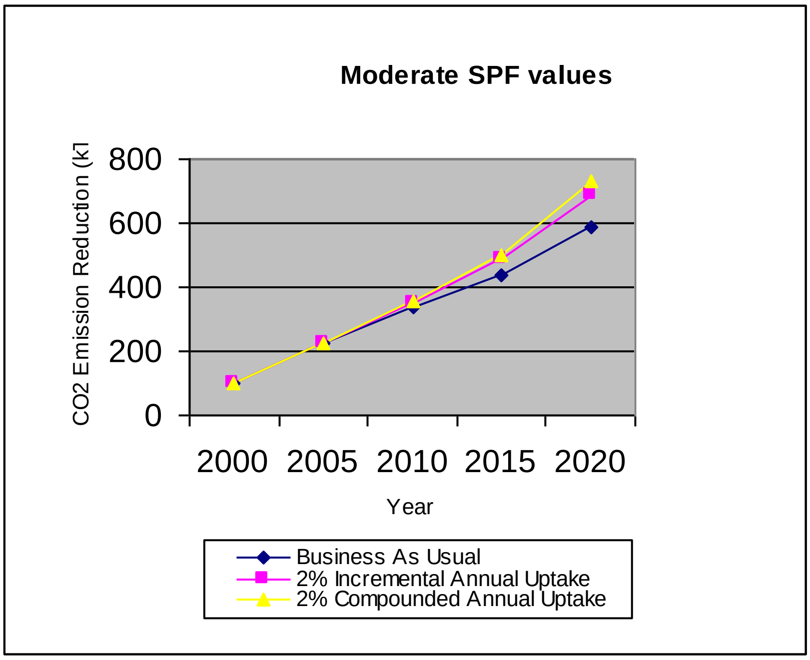

Figure 4. Equivalent CO_2 emissions reduction – Moderate SPF

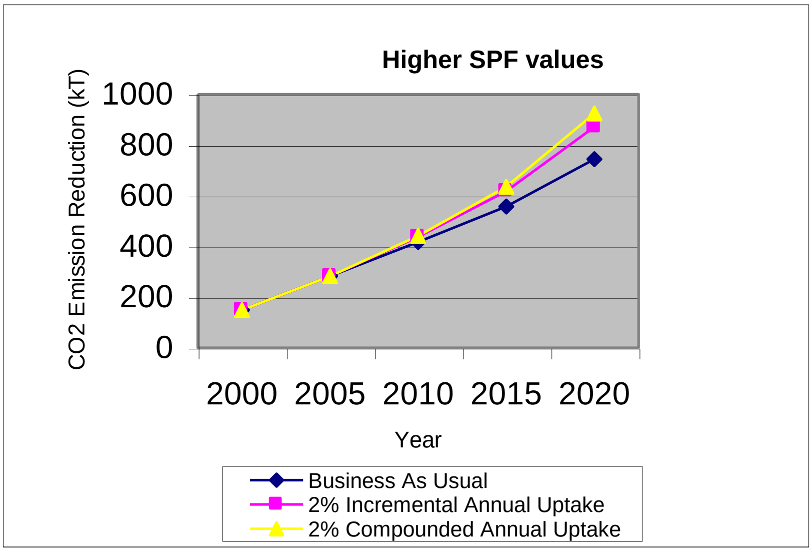

Figure 5. Equivalent CO_2 emissions reduction – Higher SPF

In terms of cumulative CO_2 emissions reduction between 2000 and 2020, assuming a linear relationship, it can be calculated from the results in Table 2 that the total equivalent emissions reduction due to the use of heat pumps in buildings would amount to 8.5 Mt CO_2. This can be compared to the greenhouse gas emission target set by the Kyoto Protocol for the UK, which requires a 12.5% reduction (92.6 Mt CO_2 equivalent) from 1990 levels (741 Mt CO_2 equivalent) by the year 2010. According to United Nations Framework Convention on Climate Change official data (IEA 2000) considering all greenhouse gases, this level had already been reduced by 8.3% (61.5 Mt) by 1998. By 2010 the annual emissions would be 15.7 Mt less than what they were in 2000 (approximately 664.1 Mt). It can be estimated that under the scenario of the enhanced market penetration rate assumptions, it is potentially possible that by 2010 the use of heat pumps to replace gas boilers in commercial building applications could contribute up to 3% (0.441 Mt CO_2 in 2010) of the CO_2 emissions reduction required under the Kyoto Protocol target established for the UK. In 2005 the contribution could be 3.6% (0.282 Mt CO_2).

4.3 Residential sector

There are around 4.5 million households outside the gas supply area and 1.3 million of these households heat their house with electricity. It has been estimated in the UK that an achievable sales target would be about 15,000 heat pump systems per year. A potential market size of the order of 100,000 (ground-source) heat pumps per year in replacing electrical systems in existing dwellings (more than 60,000) and electric central heating in new construction (40,000) has been suggested. The estimated sales target would therefore represent a share of the potential market of 15%. To reach a sales level of 15,000 systems per year in 25 years time would require a compound growth rate of the order of 25% per year.

The resulting CO_2 emissions reduction, assuming that all ground-source heat pump systems are to replace or displace direct, or storage electric heating are an order of magnitude smaller than those projected for heat pumps in commercial buildings.

5. CONCLUSIONS

By 2020, up to 70% CO_2 emissions reduction could be achieved if heat pumps would be used in the UK commercial/institutional building sector replacing gas boilers. Whereas the heat pump emissions tend to flatten off over time the boiler emissions continue increasing at about 5% per year.

The greatest rate of growth in CO_2 emissions reduction is in the retail sub-sector, while the office building sub-sector has the potential to save the most CO_2 emissions, followed by the hotel sub-sector.

CO_2 emissions reduction attributable to heat pumps could range anywhere from 0.418 Mt by 2010 to 0.744 Mt by 2020 in a Business-As-Usual scenario. Stimulating market penetration of heat pumps in the commercial/institutional buildings sector by implementing policy and other support measures could lead to increased emissions reduction relative to gas boilers ranging from 5.5% by 2010 to 24% by 2020. The potential growth of packaged heat pumps to replace gas boilers in commercial/institutional building applications in the UK could reduce CO_2 emissions from 0.282 Mt in the year 2005 to as much as 0.924 Mt by 2020, a more than 200% increase. In 2010 the corresponding emissions reduction is 0.441 Mt, which amounts to approximately 3% of the CO_2 emissions reduction required in 2010 under the Kyoto Protocol targets established for the UK (based on the time frame of 2000 to 2010).

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