

Heat Pump or CHP

– which one is *greener*?

Heat pump and combined heat and power (CHP) are two low carbon technologies that are used for heating buildings in order to reduce the operational costs and CO₂ emissions. The amount of CO₂ reduction achieved depends on the emission factor of the grid. In this article these two technologies are compared with each other considering the emission factor of the grid. The results show that there is a balance point for the grid emission factor, above which the CHP produces less CO₂ and below which the heat pump produces less CO₂.

Keywords: building heating system, renewable energy, combined heat and power, heat pump, CO₂ emission, grid emission factor.



FARAMARZ SADR
PhD
fasadr@yahoo.com

Buildings are responsible for 40% of total CO₂ emissions in the world. Combustion of fossil fuels produces CO₂ gas which is recognized as the major greenhouse gas causing global warming. There is a strong aim to reduce CO₂ emissions associated with the building sector. This mainly can be accomplished by increasing energy efficiency of the buildings and utilization of zero and low carbon energy technologies to supply the heating and electricity demands of buildings.

Heat pump and CHP are two low carbon technologies that have been proposed to be used in buildings. These technologies have been considered in the European Directive 2009/28/EC which is the main directive for promotion of renewable energy in the EU's building sector. In addition, the Feed in Tariff and the Renewable Heat Incentive are two significant incentives that have been considered by the UK government for the promotion of renewable energy utilization, including heat pump and CHP technologies.

Electrical heat pumps use grid electricity to extract heat from a heat source. In buildings most of the CHPs are fuelled by mains gas and generate heat and electricity simultaneously. The generated electricity can supply the electrical demand of the building and displace some of the electricity consumption from the grid.

The other major contributor to CO₂ emissions is the power sector. Under the Kyoto protocol, 37 industrialized countries and the European Community committed themselves to binding targets for greenhouse gas (GHG) emissions. In the UK, according to a report by the Committee on Climate Change (CCC), there is a need for early power sector decarbonisation in the context of economy-wide emissions reduction to achieve the 2050 target in the Climate Change Act (A net UK carbon reduction to at least 80% lower than the 1990 baseline). Specifically, the committee set out a range of scenarios for investment in low-carbon generation capacity, and proposed a planning scenario in which emissions are reduced from current levels of around 500 g CO₂/kWh to around 50 g CO₂/kWh in 2030 (**Figure 1**). This could be achieved through the addition of around 35 GW baseload equivalent low-carbon capacity through the 2020s, in addition to planned investments in renewables, carbon capture and storage (CCS) and nuclear generation over the next decade.

CO₂ emissions with a gas fired boiler

Where a gas fired boiler is used to supply the heating demand of building, the annual emission rate e_b can be calculated from the following equation:

$$e_h = F_b k_g = \frac{H}{\eta_b} k_g \quad (1)$$

Where, F_b is the fuel energy input to the boiler, H is the heating demand of the building, η_b is the thermal efficiency of the boiler and k_g is the emission factor of the mains natural gas. From equation (1) the unit heating emission rate is:

$$\frac{e_h}{H} = \frac{k_g}{\eta_b} \quad (2)$$

CO₂ emissions with a heat pump

Where a heat pump is used to supply the heating demand of the building, the annual emission rate e_b can be calculated from the following equation:

$$e_h = E_{hp} k_e = \frac{H}{COP} k_e \quad (3)$$

where, E_{hp} is the electrical energy input to the heat pump, k_e is the grid emission factor, H is the heating demand of the

building and COP is the heating coefficient of performance. From equation (3) the unit heating emission rate is:

$$\frac{e_h}{H} = \frac{1}{COP} k_e \quad (4)$$

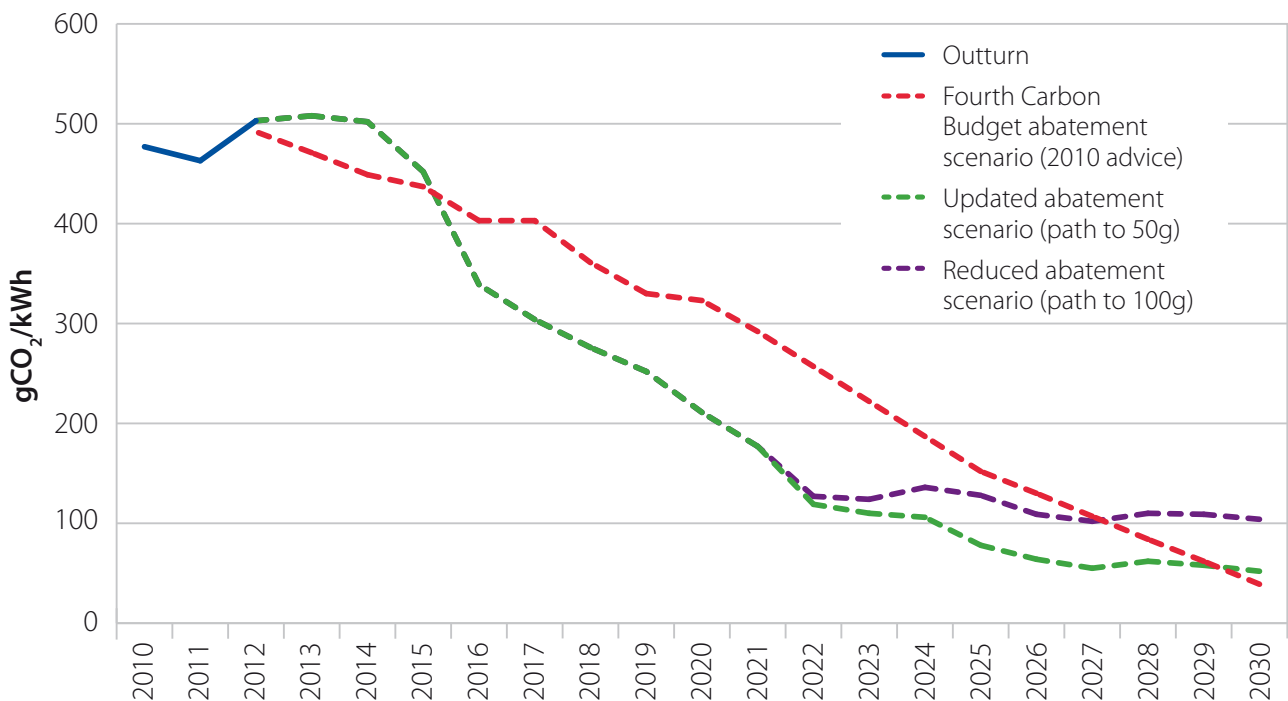
CO₂ emissions with a CHP

Where a CHP is used to supply the heating demand of the building (in heat led operation), the emissions associated the heat supply can be reduced by the displaced grid electricity emissions. It is assumed that the CHP is fuelled by mains natural gas. The annual emission rate e_b can be calculated from the following equation:

$$e_h = F_{chp} k_g - E_{chp} k_e = \frac{H}{\eta_h} k_g - \frac{H}{\eta_e} \eta_e k_e \quad (5)$$

where, F_{chp} is the fuel energy input to the CHP, E_{chp} is the electrical energy generated by the CHP, H is the heating demand of the building, η_h and η_e are the heating and electrical efficiencies of the CHP respectively, k_g and k_e are the mains natural gas and grid emission factors respectively. From equation (5) the unit heating emission rate is:

$$\frac{e_h}{H} = \frac{k_g}{\eta_h} - \frac{\eta_e}{\eta_h} k_e \quad (6)$$



Source: CCC calculations (2010 Fourth Carbon Budget advice); CCC calculations based on Redpoint (2012 & 2013) modelling.

Notes: Intensity is based on energy supplied from major power producers and all renewable generators and is net of transmission and distribution losses.

Figure 1. Predicted reduction of emission intensity of electricity (grid emission factor) in the UK according to three scenarios (2010–2030)

Grid emission factor at balance point

From equations (4) and (6) it can be seen that by reducing the grid emission factor, the unit emission of the heat pump is decreased and the unit emission of the CHP is increased. To determine at what grid emission factor (k_{eb}) these two emission rates are equal we equate the right hand side of the equations (4) and (6):

$$\frac{1}{COP} k_{eb} = \frac{k_g}{\eta_h} - \frac{\eta_e}{\eta_h} k_{eb}$$

$$k_{eb} = \frac{k_g}{\left(\frac{\eta_h}{COP} + \eta_e\right)} \tag{6}$$

We name k_{eb} *balance emission factor*. The unit emission of heat pump and CHP and the balance emission factor are graphically shown in **Figure 2**. In this figure, the unit emission of a gas boiler is shown as well. This emission rate is constant and independent from the grid emission factor. There are also 3 interesting points in **Figure 2**. At point a, the emission rates of the heat pump and gas boiler are equal:

$$k_e = \frac{COP}{\eta_b} k_g$$

Where k_e is greater than this value, the gas fired boiler produces less CO₂ than the heat pump. At point b the emission rates of the CHP and the boiler are equal:

$$k_e = \frac{k_g}{k_e} \left(1 - \frac{\eta_h}{\eta_b}\right),$$

and where k_e is less than this value, the boiler produces less CO₂. Finally at point c

$$k_e = \frac{k_g}{\eta_e},$$

the net emission rate of the CHP is zero.

Results

Equation (6) shows that the balance emission factor does not depend on the heat and electricity demands of the building; it only depends on the COP of the heat pump and the thermal and electrical efficiencies of the CHP.

In this section we calculate the balance point of electricity emission factor for a sample heat pump and

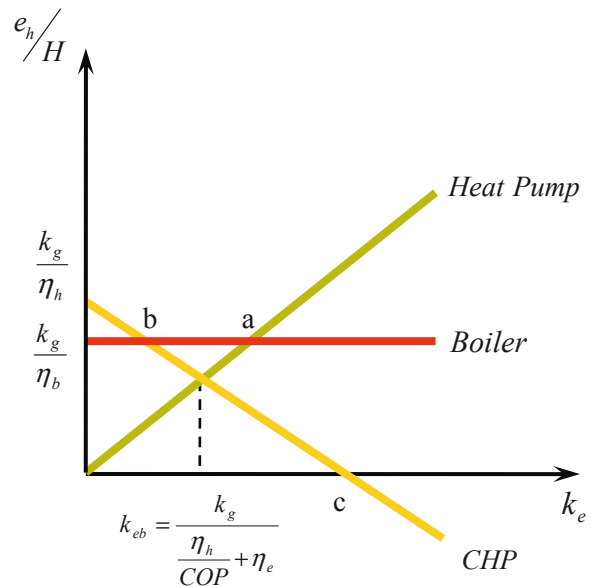


Figure 2. Balance emission factor k_{eb} is the value of the grid emission factor k_e where the unit heating emission rate e_h/H is equal for heat pump and CHP.

micro-CHP in the UK. We select a heat pump with a COP of 2.4 and a micro-CHP with electrical and thermal efficiencies of 0.13 and 0.79 respectively. According to SAP 2012 the mains gas emission factor is 0.214 kg CO₂/kWh and the imported and displaced electricity emission factors is 0.502 kg CO₂/kWh. With these data the calculated balance electricity emission factor is 0.466 kg CO₂/kWh.

Currently the emission factor of the grid is 0.502 kg CO₂/kWh which is greater than the balance emission factor. If a residential building has annual heating and electrical demands of 20 000 and 4 000 kWh respectively, with a heat pump the unit heating emission rate and the total emission rate will be 0.209 kg CO₂/kWh and 6 191 kg CO₂ respectively. With CHP these figures will be 0.188 kg CO₂/kWh and 5 774 kg CO₂.

According to **Figure 1**, in 2020 the grid emission factor will be 0.33 kg CO₂/kWh. If we assume that the mains gas emission factor remains constant, the unit heating emission rate and total emission rate with heat pump will be 0.138 kg CO₂/kWh and 4 070 kg CO₂ respectively. With CHP these figures will be 0.217 kg CO₂/kWh and 5 652 kg CO₂. **Figure 3** shows the balance point and **Table 1** shows the summary of the calculations.

Discussion

From equation (6) we can see that the balance point of the grid emission factor depends on the emission factor of mains gas, the COP of the heat pump and the electrical and thermal efficiency of CHP. So for each heat pump and CHP, the balance point of the grid should be calculated separately. It can also be shown that by increasing the COP, the balance emission factor is shifted to higher values. Higher values of COP can be achieved by reducing the supply flow temperature of heat pump. Also by increasing the electrical efficiency of CHP the balance emission factor will be shifted to the lower values.

Traditionally in Europe the use of heat pumps is common in the countries that have cheaper electricity due to the higher penetration of renewables like wind and hydropower in Scandinavian Countries (Denmark and Norway with 0.374 and 0.002 kg CO₂/kWh), or nuclear power plants (France with 0.0709 kg CO₂/kWh) or both (Sweden with 0.023 kg CO₂/kWh). In the UK,

which had cheaper fossil fuel, use of micro-CHP (mainly natural gas fuelled) has been common more than heat pumps.

Deregulation of the electricity market and decarbonisation of electricity can alter the tendency to use heat pumps and CHPs in different countries which should be considered by the industry.

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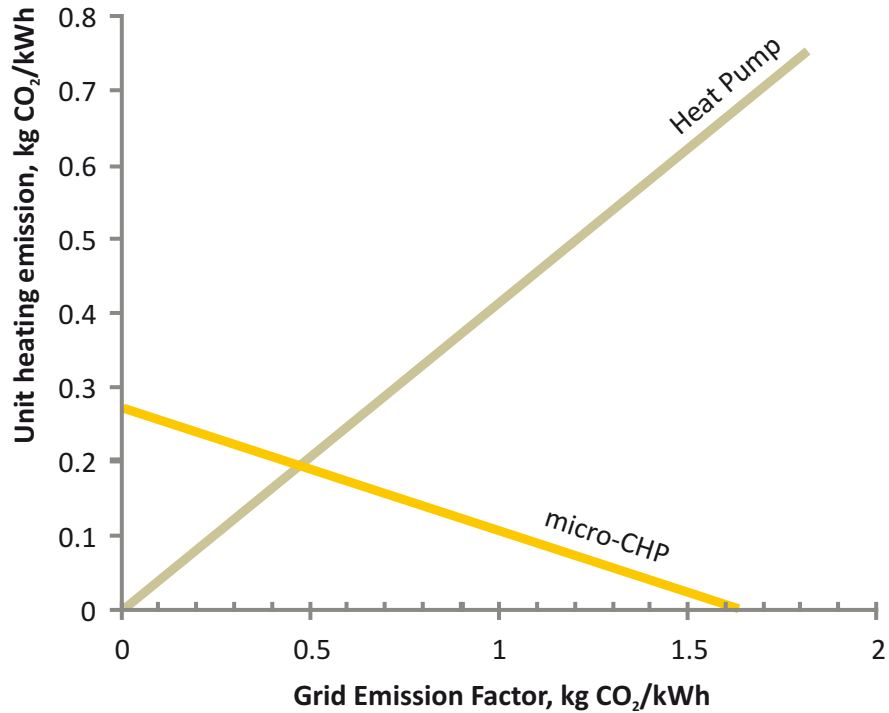


Figure 3. The balance point of a sample heat pump and CHP for grid emission factor.

Table 1. Unit heating and total emission in 2014 and 2020.

	2014		2020	
	Heat Pump	CHP	Heat Pump	CHP
e_h/H , kg CO ₂ /kWh	0.209	0.188	0.138	0.217
$e_t = e_h + e_e$, kg CO ₂	6191	5774	4070	5652

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