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CO_2 EMISSION SAVINGS BY USING HEAT PUMPS IN EUROPE

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ABSTRACT

Heat pumps can support the fight against climatic warming. Such systems are now increasingly used for space heating, cooling, and to provide domestic hot water.

With heat pump systems the use of fossil primary energy sources can be avoided. Since heat pumps are usually driven by electric components the origin of the electricity and the corresponding CO_2 emissions must be considered. A compilation shows that there are great differences in this respect from country to country.

The EU has ambitious goals for 2020: 20% less primary energy consumption, 20% contribution from renewables, 20% reduction of greenhouse gas emissions – relative to the values in 1990. A recent EHPA (=European Heat Pump Association) potential study reveals that –if 70 million new heat pump systems will be installed in Europe in 2020– the increasing deployment of heat pump systems would contribute over 20% of the EU energy saving goal, 20% of the renewable energy input and 20% of the CO_2 emission target. The latter means that 230 Mt of CO_2 emission/year could be avoided.

1. INTRODUCTION

Climatic warming is a fact; it endangers the environmental living conditions as well as the global economy. It is widely recognized that the most probable cause of climatic warming is the increasing content of greenhouse gases (fore mostly CO_2) in the atmosphere. Any reduction of CO_2 emissions can thus contribute to the attempts undertaken in order to mitigate the effects of climatic warming.

Undoubtedly there are two main sources of CO_2 emission: 1) the energy use in the building sector; 2) the energy needs of transportation. The current, most widely applied solution, the burning of fossil fuel, is the major source of CO_2 emissions. Therefore new solutions and technologies are urgently needed; technologies which operate CO_2-free or at least CO_2-poor.

For the building sector, especially for space heating, cooling, domestic hot water production, the heat pumps provide such a technology.

2. HEAT PUMP SYSTEMS

Heat pumps take ambient heat (from air, water, and ground) at low temperature and increase its temperature level by energy input, mostly from electricity. In the air and in the ground, gigantic reserves of thermal energy are present. The heat pump makes it possible to use these renewable energy resources. By using 20-33% electrical energy for the heat pump compressor to raise the temperature of the heating circuit air or water, between 66 and 80% of the heat can be taken from renewable heat sources in the environment. The subsurface has basically two heat carriers: the heat stored in the earth materials, and the heat content of groundwater (if present). Ground-coupled or geothermal heat pumps come in various configurations, which are installed horizontally and vertically (see Figure 1). The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled on site.

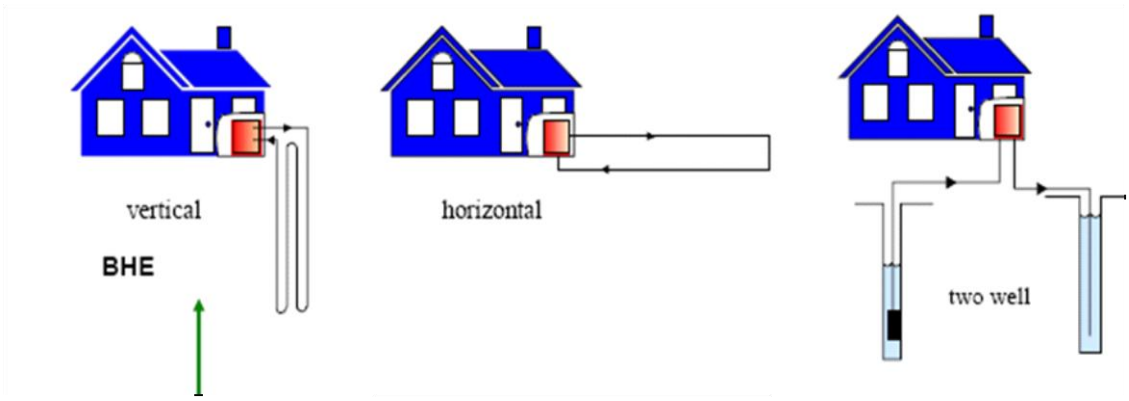

FIGURE 1: Ground-source or geothermal heat pump (GHP) systems. The green arrow indicates the most common system, with borehole heat exchangers (BHE). The heat pump is shown in red. (from Fridleifsson et al. 2008).

The property that describes the efficiency of a heat pump system (i.e. the ratio of heat output to electric energy input) is given by the Coefficient of Performance, COP. The higher the COP the more heat can be provided per unit of electricity input. Figure 2 shows that different COPs are characteristic of the various heat pump systems: air-source heat pumps have the lowest, groundwater-source heat pumps the highest COP values.

When the issue of CO_2 emissions is considered then heat pump systems have the great advantage that they can replace fossil-fired systems. Table 1 shows the heat content of fossil fuels along with the CO_2 emission values that result while burning fossil fuels. Such emissions can be avoided when heat pump systems are used instead of fossil-fuelled systems.

In the following the issue will be addressed as to what extent heat pump systems can contribute to the reduction of CO_2 emissions in the building sector. It is obvious that, when heat pump systems are used instead of fossil-fired systems, the source of the electricity that drives the heat pumps must be carefully considered.

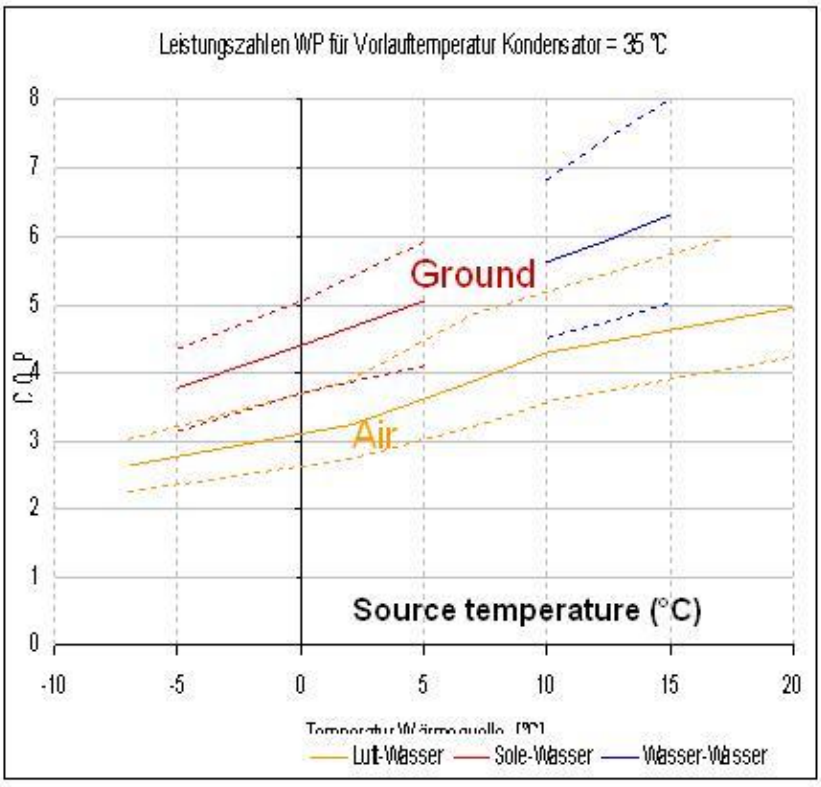

FIGURE 2: COP comparison: Air-source vs. Ground-source heat pumps. COP as the function of source temperature (for a supply temperature of 35 °C). The solid lines indicate average values, the dotted lines encompass the range of values found. The blue lines are for groundwater heat pumps.
(Data from Swiss Heat Pump Test Center, 2008).

TABLE 1: Heat content and CO_2 emission of traditional fossil fuels
(Data from Swiss Federal Office of Energy, 2008)

Fuel	**Heat content (GJ/t)**	**CO_2 emission (t CO_2/TJ)**	**CO_2 emission (t CO_2/t fuel)**
Coal	28.1	94.0	2.64
Oil light	42.6	73.7	3.14
Natural gas	46.5	55.0	2.56

3. CO_2 EMISSION OF ELECTRICITY PRODUCTION

Numerous technologies are in use world-wide to produce electricity. Whereas some technologies like hydropower are characterized by low CO_2 emissions, others –like coal-fired power plants– emit lots of CO_2. In a given country there is a specific "mix" that gives an average value of CO_2 emission per produced kWh electricity. Table 2 shows the wide range of country mix values

TABLE 2: National CO_2 emission values in Europe (from Nowak, 2008)

Country	**kg CO_2 per kWh electricity produced**
Austria	0.239
Belgium	0.311
Cyprus	0.974
Czech Republic	0.922
Denmark	0.680
Estonia	1.015
Finland	0.403
France	0.108
Germany	0.626
Greece	0.882
Hungary	0.695
Ireland	0.706
Italy	0.565
Latvia	0.443
Lituania	0.367
Luxembourg	0.367
Netherlands	0.619
Norway	0.015
Poland	1.108
Portugal	0.630
Slovak Republic	0.382
Slovenia	0.392
Spain	0.493
Sweden	0.076
Switzerland	0.041
United Kingdom	0.558
EU average	**0.486**

Obviously there are large differences in the national mix values. Besides, there is considerable import / export of "clean" and CO_2-heavy electricity across national boundaries; unfortunately there is –especially in the CO_2 emission context– no detailed statistical material available.

4. CO_2 EMISSION AVOIDANCE AND SAVINGS BY HEAT PUMPS

GHP installations need no fossil fuel, do not use combustion processes to generate heat, and thus produce no air polluting substances. This is the environmental advantage of GHP systems. The heat pump (HP), a basic system component, needs auxiliary power to accomplish the temperature rise needed in the system. In most cases, HPs are driven by electric power. With proper system design, seasonal performance coefficients in the heating mode of 4.0 (heating energy supplied by the GHP system / electricity input for HP and circulation pumps) can be reached. This means that GHP systems need 75% less fuel than fossil-fired systems.

This represents the "saving" of fossil fuels – and the corresponding CO_2 emission. But one should not fall into the trap to think that it would mean also CO_2 emission reduction, it only

avoids additional emission. It must be emphasized that new GHP installations do not provide any emission reduction – unless they replace old, fossil-fuelled systems. Therefore it needs to be stressed that

- New heat pump systems need new (additional) electricity
- The production of this electricity is usually accompanied by CO_2 emission
- Not even systems installed during renovations fully reduce CO_2 emissions (except when the electricity comes from completely CO_2-free sources).

Let's assume the installation of 10,000 new GHP units per year (easily done in many European countries), each with a standard heating capacity of 12 kW_{th}. Further assumption: heat pump COP = 4.0, thus the electric power needed per unit is 3 kW_e.
With a heat pump running time of 1,500 hours/year the electricity demand for the new GHPs is $45 \cdot 10^6$ kWh. When the electricity is produced by a reasonable national "mix" (emits 500 gCO_2/kWh_e, cf. Table 2) then the additional CO_2 emissions amount to $45 \cdot 10^6 * 0.5 = 22.5 \cdot 10^6$ kg = 22,500 tons of <u>new</u> CO_2 per year.

Therefore, true CO_2 emission reduction results only when heat pump systems are mainly installed during renovation.

When GHPs are used for space cooling in the "free cooling mode", there is even more fossil fuel savings: since the heat pump is bypassed, there is no need for electricity during this time. But again here real CO_2 emission reduction can only be achieved when an "old" air-conditioning system fed by "dirty" electricity gets replaced. In any case the source and CO_2 emission characteristics of the electricity consumed by the heat pump needs to be carefully considered.

5. FUTURE PROSPECTS IN CO_2 SAVINGS WITH HEAT PUMPS IN EUROPE

The European Commission has set ambitious goals for the energy future of the European Union (EU), the so-called 20% - 20% - 20% targets (reduction relative to the situation in the year 1990):

- 20% reduction of primary energy consumption;
- 20% contribution to the energy supply from renewable sources;
- 20% reduction of greenhouse gas emissions.

The EHPA performed a study (EHPA, 2007) to investigate the potential of increasing deployment of heat pump units in the EU in order to help meet the above-mentioned goals in 2020. For this, a number of assumptions have been made:

- all new and renovated one-family houses would be equipped with heat pump systems (about 1 million new houses and 4 million in renovation per year);
- seasonal performance coefficients according to Table 3;
- CO_2 emissions according to the value of the EU average electricity mix (486 g CO_2/kWh);
- replacing the traditional heating mix (50% gas, 30% oil, 10% solid fuel, 10% electricity.

TABLE 3: Assumed seasonal performance coefficients* in the EHPA study

Heat pump system	**SPF new house**	**SPF renovated house**
Air source	3.5	3.0
Borehole heat exchanger	4.0	3.5
Groundwater	4.5	4.0

*) Seasonal performance coefficient, SPF: ratio of heat provided (in kWh) to total electricity input (for heat pump and circulation pump). SPF is higher for systems in renovation due to the higher delivery temperature needed.

The EHPA study counts on annual growth rates of 5.4 million heat pump units per year from 2008 to 2020; i.e. in 2020 there would be 70 million units installed. The results of the EHPA estimates are: the increasing deployment of heat pump systems would contribute over 20% of the EU energy saving goal, 20% of the renewable energy input and 20% of the CO_2 emission target. The latter means that compared with the above mentioned traditional heating mix, 230 Mt of CO_2 emission could be avoided. Geothermal heat pumps can play the main role in the heat pumps dissemination and CO2 emission avoidance process.

Even within the uncertainty of the assumptions the EHPA study reveals very significant contributions of heat pump systems to reduce the dependence from –mainly imported– fossil fuels and to avoid further or reduce existing CO_2 emissions.

6. CONCLUSIONS

The building sector is a major source of CO_2 emissions. Especially for space heating, cooling, domestic hot water production, the heat pumps provide a suitable technology to avoid additional and to reduce current CO_2 emissions. Especially geothermal heat pumps (GHP) can also be used for space cooling, an increasing demand in the days of climatic warming. Unfortunately there is no sufficient statistical database so far to quantify the Europe-wide CO_2 emission benefits of GHP systems in the cooling mode.

Most heat pumps operate with electric compressors, therefore the source of electricity must be carefully considered. At present, the electricity mix (production from fossil fuelled, renewable-based like hydroelectric, nuclear power plants) varies largely from country to country, resulting in quite different CO_2 emission numbers per kWh electricity produced. It can be expected that in the future the emission number will generally decrease, due to the substitution of traditional plant types by more environmentally friendly technologies. The current average value of 486 g CO_2/kWh is expected to decrease by 20 % to 408 g CO_2/h in the EU (Nowak, 2008).

Also in the heat pump technology the further increase of efficiency (COP improvement, special heat pumps for renovation, new solutions like direct expansion, CO_2 as working fluid) can add to the mitigation of climatic change. A special R&D program of the EU 6FP, GROUNDHIT, is devoted to such developments (GROUNDHIT, 2008).
A potential estimate of EHPA reveals that –if 70 million new heat pump systems will be installed in Europe in 2020– the increasing deployment of heat pump systems would contribute over 20% of the EU energy saving goal, 20% of the renewable energy input and 20% of the CO_2 emission target. The latter means that 230 Mt of CO_2 emission/year could be avoided.

When complemented by measures in improved construction solutions like efficient thermal isolation to reduce the energy consumption of buildings, the heat pump systems to provide space heating, cooling and domestic hot water can and will contribute significantly to avoid and to reduce CO_2 emissions in the future. By this means the climatic warming could be –at least to some extent– mitigated.

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