HEAT PUMPS FOR DECARBONIZING THE BUILDING SECTOR

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Abstract

The building sector is responsible for about 40% of the total energy demand and 33% of the CO_2 emissions. Until 2050 the building sector should become CO_2 free. Measures are improving the building envelope, proper architecture and advanced heating and cooling systems, based on renewable energy sources.

In the case of new buildings a lot of standards and codes exist to minimize the energy consumption, at least for heating operation. The problem especially in Europe is the existing building stock, in depth renovation is expensive or without subsidies not economic, the result is a renovation rate of about 1 to 2%, much too small to achieve the 2°C goal until 2050. Additionally, the majority of renovations achieves only a reduction of the energy demand of about 30%, far away from the nZEB (nearly Zero Energy Building) standard; for net Zero Energy Buildings no mandatory standard exists.

Another case is heating: in the majority of the larger cities district heating is very common, mainly based on fossil-fuel fired cogeneration plants. Outside district heating networks natural gas, oil and mainly in rural regions biomass is used as fuel. In this sector ground source (ground water, lake water, soil) and outside air heat pumps play an increasing role. Heat pumps are the main devices to achieve the goal to decarbonize heating and cooling by using renewable sources. Other advantages are: they can use renewable electricity from fluctuating sources like wind and solar PV, in combination with stores they can enable the operation of electric and thermal smart grids. They will act as the main heat generation system for low temperature – especially low return temperatures - DHC systems, using renewable sources as well as heat recovered from industry, data centers, supermarkets and air conditioning systems, acting also as booster units suitable for high heat source temperatures. They will be a key technology for efficient and CO_2 free heating and cooling.

1. Introduction

In Europe, the building sector is responsible for 40% of the total energy demand and for about 33% of the CO2 emissions. Until 2050, this sector should become CO2 free, that means the heating demand has to be reduced by improving buildings, and the remaining heating and cooling demand has to be covered by renewable energy sources.

Heating has a long tradition in Europe, it is necessary to survive in our climate. Cooling, at least in Central and Northern Europe, is relatively new. It depends not only on the climatic conditions, it also depends on the size of the building, i.e. the ration of volume to surface, and on the utilization of the building; i.e. the internal loads caused by persons and equipment. Improved thermal insulation means a higher impact of internal gains; one person in a 100 m2 passive house can increase the temperature by 1 K.

An additional problem is architecture, presently glass is a favorite construction element, double skin facades are modern, and this means that solar gains become very fast tremendous solar loads, which have to be removed by a powerful air conditioning system.

Additionally, besides the climate change we are producing heat island in our cities with temperatures significantly higher than in the surrounding areas
In the European Technology Platform on Renewable Heating and Cooling the sectors mentioned are Solar Heating and Cooling, Biomass, Geothermal divided in deep and shallow geothermal sources, Cross-Cutting Technologies covering district heating and cooling, thermal energy storage, heat pumps, and hybrid renewable energy systems, and additionally as a fifth sector Heat Pumps.

The sectors are suitable for single family houses up to large systems like district heating and cooling applications or industrial processes. Similar investigations have been made in the International Energy Agency 2010, besides improving buildings to the passive house standard or even to energy plus buildings they have concentrated their investigations on solar thermal, heat pumps, district heating and cooling, and energy storage; additionally they have investigated combined heat and power systems (OECD/IEA 2013). The goal is de-carbonization (Fig 1).

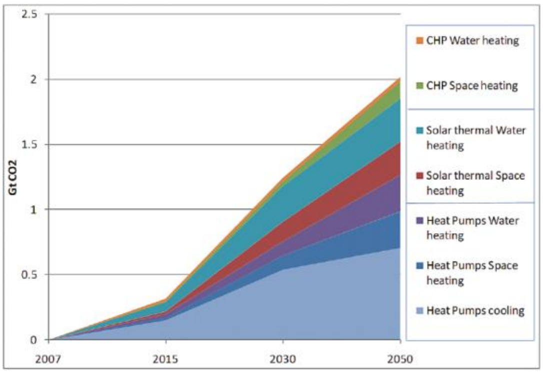

Fig. 1: CO2 emissions reductions in buildings from heating and cooling ETP 2010 (Source IEA)

2. Renewable Heating And Cooling Platforms

Renewable Heating and Cooling covers Solar Heating and Cooling, Biomass, Geothermal Systems and Cross Cutting Technologies like District Heating and Cooling, Thermal Energy Storage, Heat Pumps and Hybrid Renewable Energy Systems (RHC 2014). However, taking new technologies like smart grids, wind and solar PV have to be added.

Solar radiation and outdoor temperature are highest in summer and lowest in winter. Solar thermal systems with direct utilization of solar radiation for summer are favorable, for all year utilization good and for winter time only relatively poor.

The main application is hot water production, and such a system consists of solar collectors and a store to enable hot water utilization also in the morning and in the evening without sunshine. In Central Europe with such systems a solar fraction of about 60% can be achieved; solar combi systems for DHW and space heating have a size of typically 10 to 15 m^2 collector area and can provide a solar fraction of about 30%, depending on the size and the efficiency of the building and the climate conditions on site.

In larger solar thermal systems for several multi-family houses of even for supplying district heating networks with large water stores, heat pumps are used to increase the solar fraction by cooling down the bottom of the store and charging the upper region.

Additionally the heat pump is used for supplying the grid if the temperature in the store is lower than required by the distribution system.
The cooling demand in the service sector is currently supplied by electrical systems, causing consumption peaks. Therefore, thermally driven cooling technologies – absorption or adsorption – can contribute However, there is another option, the combination photovoltaics and an electrically driven vapor compression system the advantages of a higher COP and a much smaller cooling tower.

Biomass based technologies can serve almost any residential application either as an individual biomass-only solution, or as part of hybrid packages providing heat, hot water, and ventilation and air conditioning / cooling to residential buildings.

Taking geothermal systems there are two different types, deep geothermal systems with temperatures up to 250°C sufficient for direct use, and shallow geothermal systems with temperatures in the range of the annual average outside temperature or higher; such systems are used in combination with heat pumps.

Nevertheless, in order to realize these potentials it is necessary to exploit synergies among the renewable energy production, distribution and consumption, by investing in “Cross-cutting technologies”. This term is used by the RHC-Platform to describe any energy technology or infrastructure which can be used either to enhance the thermal energy output of a RES, to enable a greater fraction of the output by the system to be used, or to allow the exploitation of RES which would be difficult or impossible to use in building-specific applications.

- District Heating and Cooling increases the overall efficiency of the energy system by recycling heat losses from a variety of energy conversion processes. Heat which otherwise would be removed is recovered and used to meet thermal demands in buildings and industries. Renewable sources which otherwise would be difficult to use, such as many forms of biomass and geothermal energy, can also be exploited. By aggregating a large number of small and variable heating and cooling demands, District Heating and District Cooling allow energy flows from multiple RES to be combined while reducing primary energy demand and carbon emissions in the community served.

- Thermal Energy Storage is the solution for a key bottleneck against the widespread and integrated use of RES, since the renewable supply does not always coincide with the demand for heating or cooling. Numerous technologies in sensible, latent or thermo-chemical form can time-shift renewable energy supply to periods of greatest demand, each of them characterized by different specifications and specific advantages.

- Heat Pumps transform thermal renewable energy available at low temperatures from natural surroundings to heat at higher temperatures. The heat pump cycle can be also used to provide cooling. Heat pumps use aerothermal, hydrothermal and geothermal energy, and can be combined with heat from other RES in hybrid systems (see below). These sources might be renewable in origin or waste energy from industrial processes and exhaust air from buildings. Heat pumps can be highly efficient, although their overall primary energy efficiency depends on the efficiency of the electricity production (or other thermal energy source) they use.

- Hybrid Renewable Energy Systems, combining two or more energy sources into a single system, can overcome the limitations of individual technologies, especially for large scale systems, suitable for district heating and cooling or industrial processes. The combination of RES available at different times within the system is especially useful if a more constant demand for heat exists, with the overall efficiency of the system depending strongly on the way the different sources are combined.

3. Heat Pumps

It should be noted that the heat pump, which in most cases grades up free heat from the environment and from waste heat, is a major source of renewable energy. The renewable heat R gained by the heat pump is the difference between the thermal output Q and the drive energy Ex (in the case of electricity, E = Ex); obviously, if the drive energy is electricity from renewable sources, all the energy used for the heat pump is renewable energy.

$$R = Q - E = Q - Q/SPF = Q(1 - 1/SPF)$$

In Europe the term heat pump is used for a unit producing useful heat. In Japan and in the USA reversible air conditioning units are called heat pumps. Chillers are more or less always called chillers, even if they are used as heat pump chillers producing also useful heat. In Europe the term heat pump is used for heating-only units with the heat sources outside air or exhaust air from the ventilation system, ground and ground water, combined with hydronic heat distribution systems. The most important item is the development of systems. The interaction of user, building, heating/cooling equipment and control has to be considered very carefully, and only such a system approach can achieve highly efficient systems. Free cooling, direct cooling and shifting heat from one side of the building to the other side have to be criteria for the design of the system (Halozan, H., (2003)).

For a long time ground-source heat pumps (ground water, the ground itself) have dominated the market of single-family houses; presently air-source heat pumps are dominant. Reasons are lower investment costs and reduced heat pump outlet temperatures caused by better thermal insulation if the buildings and the possibility of low-temperature heat distribution systems. However, ground-source heat pumps still have higher SPFs.

Ground-source heat pumps can be applied for different climates, different ground properties, for small and large systems, and for heating-only as well as heating and cooling applications. The common characteristic of small systems is natural ground recovery, mainly by solar radiation and precipitation collected by the ground surface. Small systems are in use for heating as well as heating and cooling (IEA HPC (2010)) (Fig 2).

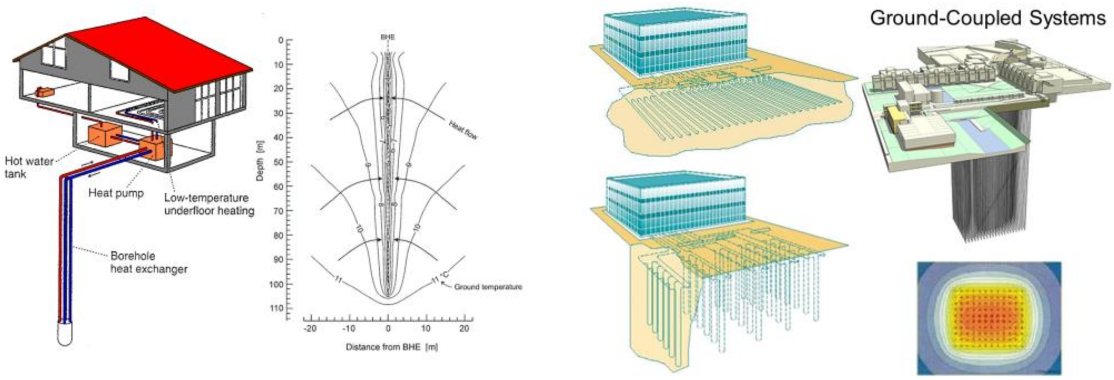

Fig. 2: Small and Large Ground-Coupled Systems

Another application is retrofitting existing buildings without or without deep renovation of the building envelope. Thermal insulation – façade, ceilings and windows – is expensive, and it should only be done if a renovation is necessary by the age of the building or the time since the last renovation, most commonly 20 to 30 years. If an in-depth renovation is made, most commonly the heat distribution system has to be changed or at least modified to fit to the new loads.

The installation of an air source heat pump in such non-renovated buildings make sense, because they are operated only down to outside temperatures in the range of +5 to -5°C, which allows despite of a medium-temperature heat distribution system relatively high SPFs. For lower outside temperatures the existing boiler is used. In the case of a renovation, the same heat pump can be used the cover the total load without bivalent operation.

The efficiency of ground source heat pumps can be improved by designing a seasonal thermal storage. If heat loss from the ground source is sufficiently low, the heat pumped out of the building in the summer can be retrieved in the winter. Heat storage efficiency increases with scale, so this advantage is most significant in commercial systems. Possibilities for a seasonal thermal store are

- Heating and cooling operation with a balanced heat extraction/heat removal into the store or
- A hybrid heating and cooling system where the balance is achieved by additional cooling of the store by a cooling tower ore additional charging of the store by solar energy.

The seasonal thermal storage can be formed as aquifer thermal energy store, multiple standing column well systems, borehole thermal energy storage in the ground, or using the building foundation as a storage.

Other heat sources for heat pump operation are subway tunnels, sheet pile walls, sewage water tunnels and treatment plants, which can be easily equipped with integrated heat exchangers. Another source is waste heat from industry, which can be used either directly or by means of heat pumps, and all cooling and refrigeration applications like data centers, cold stores, supermarkets, large air conditioning systems, mainly with a booster heat pump for charging district heating networks.

But heat pumps can be used for power-to-heat operation in the case of a surplus of electricity from wind or solar PV, using the storage mass of the building or an additional store. Business models for such an operation have to be developed.

4. Summary

Originally the renewable energy sources in Europe have been biomass, deep geothermal, solar thermal and wind. In the meantime heat pumps have been added. This acceptance of heat pumps was the beginning of the market break through of this technology in Europe.

In the past ground source heat pumps – sources are the ground, ground water and surface water – have dominated the market, nowadays air source heat pumps are dominating; however, some countries show a revival of ground source systems. But other heat sources become more and more interesting like waste heat from industry, data centers, sewage water, subway tunnels, and cooling and refrigeration applications

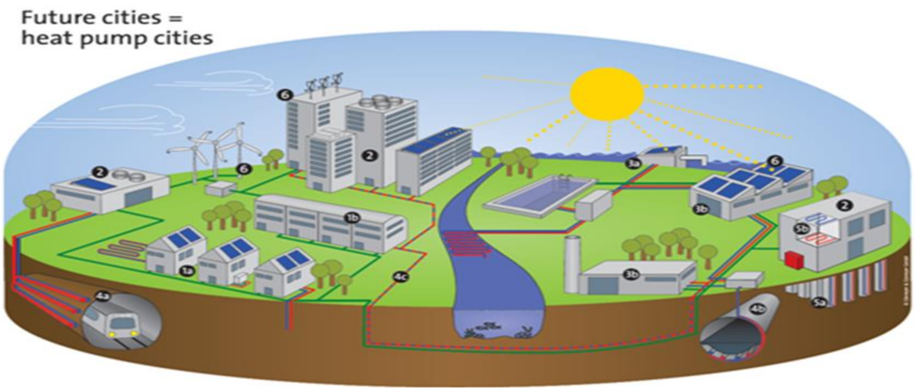

Fig. 3: Smart Heat Pump City

But there are some other advantages of heat pumps: they can use electricity from fluctuating sources like wind and PV, in combination with stores they can contribute to smart grids. They will act as the main heat generation system for district heating and cooling systems, using natural sources as well as heat recovered from industry and they will be the key technology for making the heating market energy efficient and CO_2 free.

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