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The Role of Heat Pumps in Renewable Heating and Cooling

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Abstract

The building sector is responsible for about 40% of the total energy demand and 33% of the CO2 emissions. Until 2050 the building sector should become CO2 free by renewable energy sources. The European Technology Platform on renewable heating and cooling uses the technology panels solar thermal, biomass, geothermal and the cross-cutting technologies district heating and cooling, energy storage, electric compression and thermally driven heat pumps and hybrid systems; in the meantime heat pump became an additional technology panel.

In the case solar heating and cooling, heating is possible with solar thermal energy alone, cooling can only be realized using thermally driven heat pumps like absorption, adsorption or DEC units; however, in the small capacity range PV combined with compression systems is presently the better choice. Biomass can be used directly for heating, however, cooling is only possible with thermally driven heat or compression systems driven by electricity from biomass power plants. The majority of geothermal systems are shallow systems, they require heat pumps to rise the temperature to a level required for heating. Heat pumps can do both heating and cooling using renewable sources. Other advantages are: they can use electricity from fluctuating sources like wind and PV, in combination with stores they can enable the operation electric and thermal smart grids; they will act as the main heat generation system for future DHC systems, using natural sources as well as heat recovered from industry, and they will be the key technology for CO2 free heating and cooling in smart cities.

Keywords: Heat Pumps; Hybrid Renewable Systems; District Heating; Biomass; Solar Thermal; PV; Geothermal Energy; Energy Storage;

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 (Fig. 1).

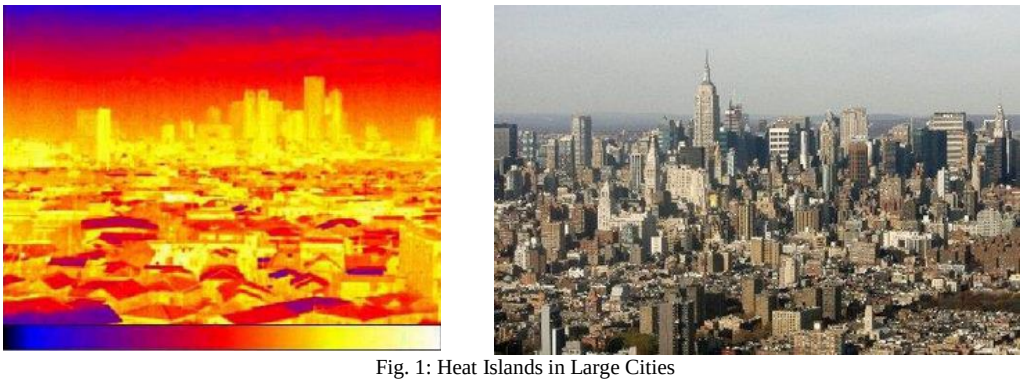


Fig. 1: Heat Islands in Large Cities

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 (IEA) [1], 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. The goal is de-carbonization (Fig 2).

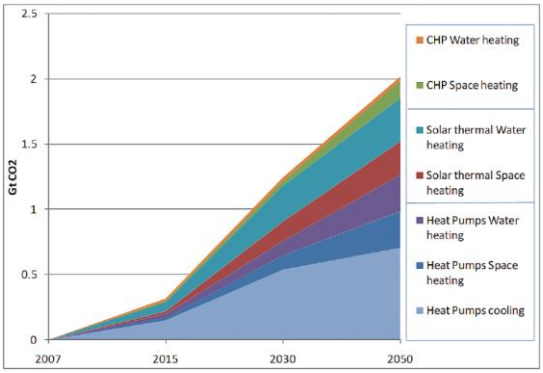


Fig. 2: CO2 emissions reductions in buildings from heating and cooling ETP 2010 from International Energy Agency

2. Solar Heating and Cooling

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 [2].

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; that means that an additional heat generation system is necessary, most commonly it is the boiler of the heating system. To avoid problems with control and installation the development of Solar Compact Hybrid Systems (SCOHYS), which include the solar system and the backup-heater in one compact unit is planned. It should be a compact solution at reduced costs due to simplified design, with only one controller, high grade of prefabrication and reduced installation effort.

A relevant contribution of solar energy to space heating requires an increase of the solar fraction per building, which is the share of solar energy on the overall heat demand for DHW and space heating. Today, in Central Europe, solar-combi systems for DHW and space heating have a size of typically 10 to 15 m2 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. Since in Central and North Europe, the level of solar radiation is much lower in winter time than in summer time, a solar fraction close to 100% requires the shift of a significant amount of solar heat generated during the summer to the heating season and the installation of a very large seasonal storage water tank. Based on

improved insulation standards for buildings and improved solar heating technology, the so called Solar-Active-House with a solar fraction of about 60% is a good compromise of high solar fraction at acceptable storage volume. In Central Europe a typical single family Solar-Active-House needs a collector area of 30 to 50 m^2 and a water storage tank of only 5 to 15 m^3. However, at least 40% have to be covered by an additional heating system.

Larger solar thermal systems for several multi-family houses of even for supplying district heating networks, heat pumps are used to increase the solar fraction by cooling down the bottom of the store and charging the upper region (Fig. 3). Additionally the heat pump is used for supplying the grid if the temperature in the store is lower than required by the distribution system. Another application is cooling, and taking a thermal heat source adsorption and absorption systems are possible solutions. These systems are heat pumps, and these systems again need a store. In the case of the store on the solar side it should be a sensible water store, on the cold side it can also be a latent ice storage system.

Solar cooling solutions are an option for the non-residential sector due to a high cooling demand, especially if there is a high demand on domestic hot water and Heating and Cooling, like in hotels. Most of the cooling demand in the service sector is currently supplied by electrical systems, causing consumption peaks. Therefore, thermally driven cooling technologies constitute promising alternatives and are set to play a key role in the efficient conversion of energy in the field of building air-conditioning and refrigeration, especially in southern Europe. However, there is another option, the combination photovoltaics and an electrically vapor compression system driven system with the advantage of a much smaller cooling tower.

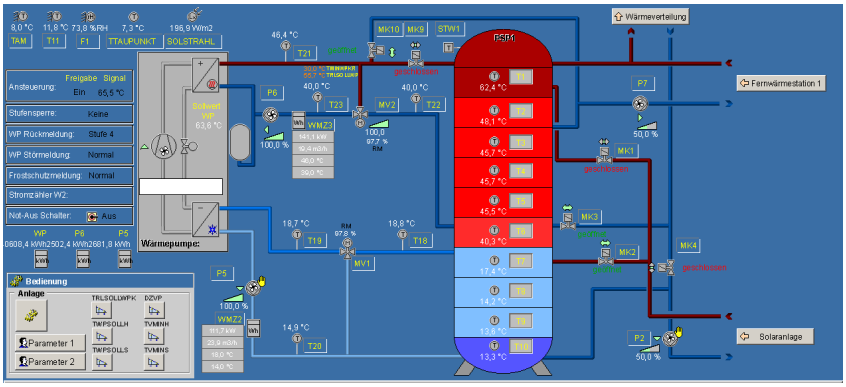


Fig. 3: Large solar store with heat pump

3. Biomass

Biomass [3] 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. As for solar thermal (and probably all other RHC technologies) the development of package solutions reducing the diversity of system solutions and reducing the potential for mistakes in the practical installation of the systems is a key requirement for technical solutions for the residential RHC sector. While firewood will remain the most relevant fuel for the individual room heating systems, upgraded and advanced biofuels will gain importance in automatically fired boilers and stoves.

In 2013, biomass based solutions for the residential sector included approximately 442,000 pellet boilers installed at residential scale (<50kW) in eight member states 9 and more than 2 million pellet stoves in six member states 10 according to a study published by the European Pellet Council (EPC). Due to their commercial viability in several European member states, significant growth of such applications is foreseen up to 2020.

Responsible for roughly half of the final energy demand in Europe, the heating and cooling sector is a cornerstone of the EU's energy and climate strategy. As 92% of all renewable heat is produced from biomass, bioenergy will play a key role in reducing the greenhouse gas footprint of the heating and cooling sector.

Technological innovation is vital in ensuring that reliable, cost-competitive and environmentally-friendly biomass-based heating and cooling solutions are delivered to different types of consumers in Europe.

4. Geothermal Systems

There are two different types of geothermal systems:

- deep geothermal systems with temperatures sufficient for direct use, and
- shallow geothermal systems with temperatures in the range of the annual average outside temperature.

Currently, geothermal energy sources provide more than the equivalent of 4 million tons oil (Mtoe) per year for heating and cooling in the European Union, where geothermal Heat Pump systems contribute the largest part. But still the potential is huge. Geothermal can be used virtually anywhere in residential and tertiary sectors, but also in industry up to temperatures in the range of 200-250°C [4]

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The total installed capacity for geothermal power in the EU now amounts to around 946 MWe, producing some 5,56 TWh of electric power yearly. Combined Heat and Power (CHP) plants are marginal, with less than 1 GWth capacity for heating, but the development of Enhanced Geothermal Systems (EGS) will provide further opportunities for CHP systems.

The technological challenges for an accelerated deployment of geothermal heating & cooling across Europe are to develop innovative solutions especially for refurbishing existing buildings, but also for zero and plus energy buildings, as the systems are easier to install and more efficient at low temperature for both heating & cooling. Secondly, to develop geothermal District Heating (DH) systems in dense urban areas at low temperature with emphasis on the deployment of Enhanced Geothermal Systems.

5. Cross Cutting Technologies

Nevertheless, in order to realize this potential it is necessary to exploit synergies among the renewable energy production, distribution and consumption, by investing in “Cross-cutting technology” [5]. 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.

5.1 District Heating and Cooling

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.

5.2 Thermal energy storage

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 (Fig. 4).

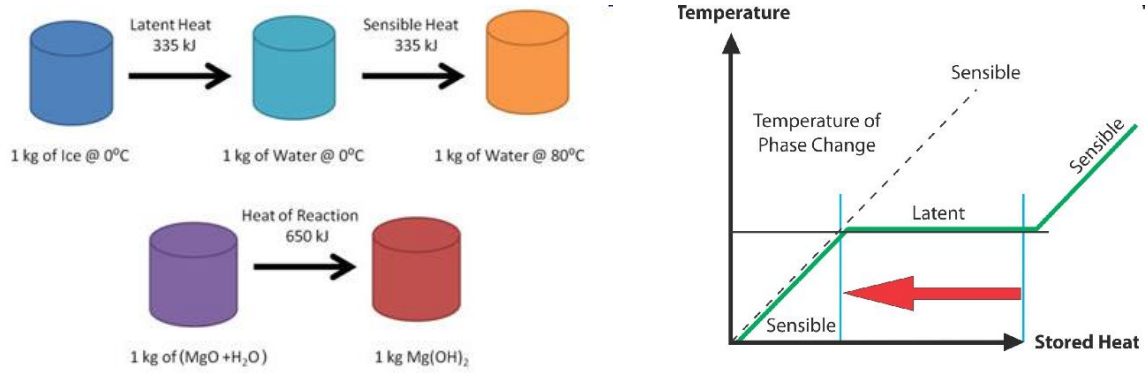


Fig. 4: Different Thermal Storage Systems

5.3 Heat pumps

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.

5.4 Hybrid renewable energy systems,

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.

6. Heat Pumps

It should be noted that the heat pump, which in most cases grades up free heat from the environment (air, water, ground) 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.

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

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 [6]. 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 (Fig. 5).

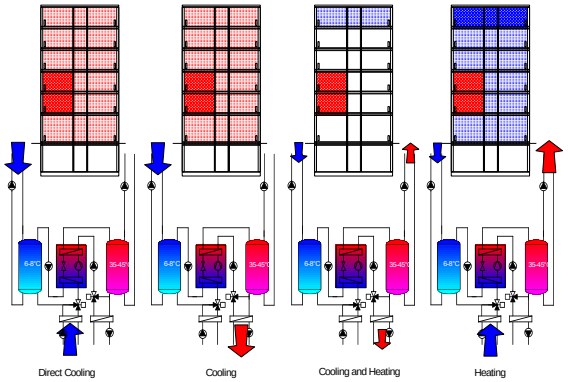


Fig. 5: Commercial Building with a Ground Storage System for both Heating and Cooling

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. For large system recovery of the ground has to happen by heat removal and heat extraction. Sometimes additional systems for recharging the store have to be provided (Fig 6).

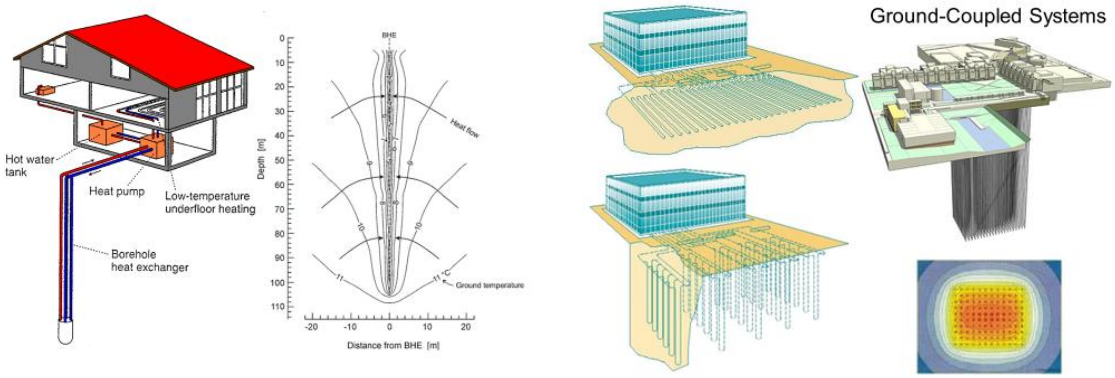


Fig. 6: Small and Large Ground-Coupled Systems

Heat removal can happen by direct cooling (without heat pump operation) and active cooling (with heat pump 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 or district heating 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.

7. Summary

Originally the renewable energy sources in Europe have been biomass, deep geothermal, solar thermal and wind. In the meantime heat pumps as devices that use renewable energy have been added; the discussion on this topic was relatively simple for ground source systems, but it was complicated for air source heat pumps. 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, even the investment costs are higher; advantages are higher efficiency and no problems with noise. Ground source systems enable monovalent heating operation even in cold climates, and for utilities they are tool for demand side management measures. In the case of large systems the ground can be used as a store, which offers in the case of heating and cooling operation at least improved conditions at the beginning of both the heating and the cooling season.

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, they are and will be used in industrial processes and they will be the key technology for making the heating and cooling market energy efficient and CO_2 free (Fig. 7).



1 Residential Heat Pumps
1a Single-Family Houses
1b Multi-Family Houses
2 Commercial Heat Pumps
3 Industrial Heat Pumps
3a District Heat
3b Process Heat
4 Infrastructure
4a Tunnels
4b Waste Water
4c Cold DH
5 Building as Source
5a Foundation Piles
5b Structure Activation
6 Electricity/Thermal Energy
Source: ehpa

Fig. 7: Smart Heat Pump City

Heat pumps have shown up as the most important devices for both heating and cooling as well as heat recovery for reducing CO2 emissions and increasing the efficiency.

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