HEAT PUMPS AND THE ENVIRONMENT

H. HALOZAN, Professor,
Institute of Thermal Engineering
Graz University of Technology, Austria

Abstract

Heat pumps offer the possibility of reducing energy consumption significantly, mainly in the building sector, but also in industry. The second law of thermodynamics shows the advantages: While a condensing boiler can reach a primary energy ratio (PER) of at best 105 % (i.e. the boiler efficiency η_B; the theoretical maximum would be 110 %, based on the lower calorific value), heat pumps achieve 200 % and more. Presently about 130 million heat pumps with a thermal output of 1300 TWh/a are in operation world-wide, reducing CO_2 emission by about 0.13 Gt/a. The potential for reducing CO_2 emissions assuming a 30 % share in the building sector using technology presently available is about 6 % of the total world-wide CO_2 emission of 22 Gt/a. With future technologies up to 16 % seem possible. Therefore, heat pumps are one of the key technologies for energy conservation and reducing CO_2 emissions.

1. INTRODUCTION

Heat pumps offer the possibility of reducing energy consumption significantly, mainly in the building sector, but also in industry. The second law of thermodynamics shows the advantages: While a condensing boiler can reach a primary energy ratio (PER) of at best 105 % (i.e. the boiler efficiency η_B; the theoretical maximum would be 110 %, based on the lower calorific value), heat pumps achieve 200 % and more.

Whereas the thermodynamic principle of the heat pumping process was found at the beginning of the 19th century (by Carnot, Kelvin, and others), it was realized about 1834 for refrigeration, and not before 1855 for producing heat: In this year, Peter Ritter von Rittinger put into operation the first heat pump, an open-cycle mechanical vapour recompression (MVR) unit, directly driven by hydro energy, in the saltern of Ebensee, Upper Austria. Much later, also the closed vapour process was used for generating useful heat. Essentially after World War II, heat pumping units for air conditioning of homes and individual rooms became common, somewhat later the “reversible” units for cooling/dehumidifying as well as heating, and after the oil price crisis of 1973 also the heating-only heat pumps for moderate and cold climates.

The refrigerants (working fluids) up to the 1930s were ammonia, carbon dioxide and other fluids, most commonly toxic and/or flammable; later on the “safety refrigerants” (chlorofluorocarbons, CFCs, and hydrochlorofluorocarbons, HCFCs) quickly occupied the market. This remained so until at the Vienna Convention of 1986 and the Agreement of Montreal 1997, the future production of CFCs was limited and in the end essentially banned, for reasons of destroying the stratospheric ozone layer. A few years later (Kopenhagen, 1992) also an agreement for limiting the HCFCs was concluded. The first choice of replacement fluids were HFCs (chlorine-free hydrofluorocarbons) and their mixtures. However, whereas these have no ODP (ozon depletion potential), they have a GWP (global warming potential). There is, therefore, a tendency in some, mostly European, countries to switch again to “natural” working fluids, containing neither chlorine nor fluorine and with a negligible GWP. Already in use are propane and iso-butane (which are flammable), NH_3 (which is poisonous), which has been used all the time in large cold store installations, CO_2 , and water.

So the heat pump has undergone and is undergoing several changes in working fluids and design. However, the efficiency today is generally better than before these changes and keeps rising. Thus, not only the environmental effects of the working fluids are being reduced, but also the effects of power plants producing the drive energy for the heat pumps – due to higher SPFs, higher power plant efficiencies (η_{PP}), and an energy sources mix with lower CO_2 emissions. Therefor the TEWI (Total Equivalent Warming Impact) is reduced significantly.

2. BASICS

The general term heat pumping technologies is used for processes in which the natural heat flow from a higher to a lower temperature level is reversed by adding high value energy, i.e. exergy. The term heat pump is used in a different way in different regions of the world. In Japan and in the USA reversible air conditioning units are called heat pumps. Most commonly air to air units are used; however, ground-coupled systems have an increasing share. 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. For industrial applications the term heat pump is often replaced by other names like mechanical vapour recompression (MVR) system, dryer, dehumidifier etc., and in heat pump based heat recovery systems the term heat pump is very often not even mentioned.

2.1. Efficiencies

Figure 1 demonstrates the efficiencies of thermodynamic heating/cooling. Over the (positive or negative) effective temperature lift ΔT from ambient, the relative exergy E_x/Q is plotted for the ideal process (Carnot process, second law of thermodynamics) and for real processes.

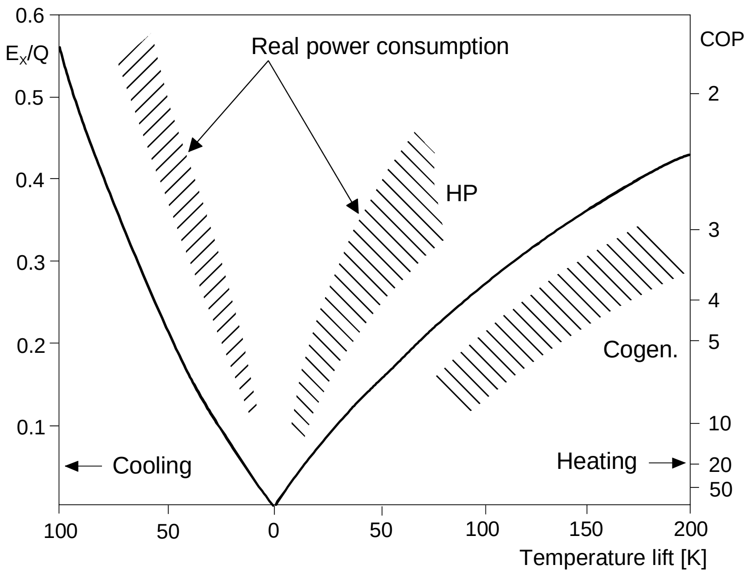

Figure 1: Ideal and real power consumption E_x/Q for cooling (freezing, refrigeration, air conditioning) and space heating by heat pump and by cogeneration district heating

For the ideal process:

$$E_x/Q = 1 - T_a/T = (T - T_a)/T = \Delta T/T = \eta_c$$

where

Ex	Exergy
Q	Heat transferred
T_a	Ambient temperature, K
T	Process temperature, K
η_c	Ideal (Carnot) efficiency

The coefficient of performance (COP) is shown at the right-hand scale: COP = Q/E_x. The internal efficiency is given by the ratio η = COP/COP_{ideal} at ΔT. The left-hand area refers to cooling: freezing, refrigeration and air conditioning including dehumidification. For these applications, E_x/Q ranges from 0.1 to 0.5, the COP therefore from 2 to 10. The right-hand area refers to heating: The heat pump area shows a temperature lift of 5 to 70 K, E_x/Q is between 0.08 and 0.45 and COP therefore between 2.2 and 12.5, the higher value referring to MVR systems. For heat pumping technologies the efficiency η is about 0.4...0.7. The area "Cogeneration" is different. Here the real exergy loss is smaller than the theoretical one because of reduced turbine and condenser losses. Despite this, the COP is, caused by higher operating temperatures, not or not much larger than for the heat pump.

2.2. Performance Factors

The drive energy of heat pumps is most commonly electricity, and for the future improved power generation systems based on renewables and fossil fuels have to be taken into consideration. The power plant efficiency, η_{PP}, is up to 58 % for gas-fired combined-cycle power plants available on the market; with oil as fuel similar values are possible.

The power plant efficiency η_{PP} depends, of course, on the kind of fuel (primary energy source). Table 1 shows the relations for the more important primary energy sources and for SPFs of 4 and 5. PER is highest for direct power generation from renewable sources such as hydro or wind, for which η_{PP} = 1.0 by definition. PER gives an absolute measure of the units of useful heat obtained from one unit of primary energy at power plant input, neglecting for the moment losses upstream of the power plant such as in production, cleaning, transmission (WEC, 1988), and distribution losses between power plant and heat pumps.

Table 1: Typical Primary and Useful Energy Ratios

	Coal (and Biomass)	Gas	Electricity from Renewables (hydro, wind)	Nuclear
Efficiencies				
Power plant, η_{PP}	0.4	0.55	1.0	0.33
Boiler (local conversion), η_B	0.8	0.98	1.0	1.0
PER for SPF = 4				
PER = SPF. η_{PP}	1.6	2.20	4.0	1.33
UER = PER/η_B	2.0	2.24	4.0	1.33
PER for SPF = 5				
PER = SPF. η_{PP}	2.0	2.75	5.0	1.67
UER = PER/η_B	2.5	2.81	5.0	1.67

More information than by PER is, however, given by comparing, for a given fuel (primary energy source), the efficiency of the indirect path via power plant and heat pump (PER) to the efficiency of the direct path of conversion (η_B), e.g. in a heating boiler. The ratio may be called Useful Energy Ratio UER = PER/η_B. Comparing the same fuel means that all upstream effects cancel each other out. The downstream effects, i.e. the local distribution losses, also cancel each other out in the case of electric heating from hydro, wind, or nuclear plants whereas they may be considered of equal value as a first approximation when comparing electricity for the heat pump, and fuel for the boiler. If, in the latter case, the distribution efficiencies η_d should be markedly different, a more exact formulation would be:

$$UER = (PER/\eta_B)(\eta_{d,,el}/\eta_{d,fuel})$$

where $\eta_{d,,el}$ relates to electricity, and $\eta_{d,fuel}$ to the fuel distribution efficiency.

The data of Table 1 show that

- UER is larger or – for η_B = 1.0, as for electric heating – equal to PER. Only for η_B somewhat higher than 1.0 – as may be the case for very efficient gas-fired condensing boilers – or for $\eta_{d,el} < \eta_{d,fuel}$ could UER become lower than PER.
- For direct electricity from renewables, the efficiencies are 1.0, and UER = PER = SPF.
- For the basic data of Table 1, UER ranges from 1.33 to 5.0.
- Boiler efficiencies near 1.0 are close to the theoretical limit (i.e. for the gas-fired condensing boiler). A SPFs of around 5.0 is far below the theoretical limit of heat pumps; SPFs of 6 or more may be possible and will be economic in the future.

For absorption heat pumps, PER is the ratio of heat output to primary energy input (not to the power plant but to the heat pump).

2.3. Renewable energy gain by 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 E_x (in the case of electricity, $E = E_x$):

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

Obviously, if the drive energy is electricity from renewable sources, all the energy used for the heat pump is renewable energy.

3. APPLICATIONS

The sectors where heat pumps are used can be divided in the building sector (residential and commercial), where the majority of heat pumps is in operation, and in the industrial sector. The majority of heat pumps in operation in the residential sector are reversible air-to-air air conditioners for both heating and cooling. The types most commonly used in the small to medium capacity range are

1. Window-type: They are mainly popular in the USA, Brazil, Australia, Saudi Arabia, the Philippines, India, Thailand and Hong Kong.
2. Split-type room air-conditioner (Cooling capacity under 5 kW): They are popular in Japan and China, and also becoming the predominant type in South Korea, Thailand and Malaysia.
3. The unit packaged type air conditioner (unitary air conditioner) which are manufactured and sold mainly in USA. They are also becoming the major types in Australia, the Middle East, Canada and Mexico.
4. The split-type and multi-split-type packaged air conditioner (cooling capacity over 4 kW) are popular mainly in Japan, South Korea and China. Split-type and especially multi-split-

type units have been improved significantly as the market expands, including the development of inverter-control methods which regulate air-conditioning performance by varying compressor speed according to thermal load; and simultaneous cooling and heating functions in the multi-split-type air conditioner.

These reversible air-to-air units are very cost-effective due to the fact that the additional feature of dual-mode operation is relatively cheap and due to the long annual operation time.

Europe has been concentrating on heating-only units with ground water, the ground or outside air as heat source, integrated into hydronic heat distribution systems. Ground-coupled systems combined with low-temperature heat distribution systems achieve seasonal performance factors of 4 and higher. However, the market share of air-to-air split air conditioners is rapidly increasing.

In larger systems, especially in commercial buildings, chillers and heat pump chillers are in operation, sometimes water-loop heat pumps are used instead of four-pipe distribution systems with fan-coil units. In Asia sorption - both absorption and adsorption - systems become popular, the main purpose of these units is load levelling of electric power requirement. Drive energy is most commonly gas, but more and more systems driven by heat from co-generation plants are in operation. The alternative are electrically driven units with ice-storage systems.

Two other types in operation in the residential sector are heat pump water heaters and large units for district heating systems. Large heat pumps with two-stage centrifugal compressors for district heating supply have been built and are operated mainly in Sweden. The heat capacities of these units are usually 10 to 14 MW per unit, but unit capacities go up to 45 MW. The drive energy is electricity, heat sources are treated sewage water, sea water or industrial waste heat.

The industrial heat pump (IHP) in the strict sense is a unit operation, usually heat recovery, within an industrial process, (IEA HPC, 1997) mostly in the chemical, food and lumber industries. The heat pump may be seen as a heat exchanger, working on a negative temperature difference, i.e. the temperature of the heat receiving flow in higher than the one of the heat supply flow. Then, the heat pumps yields more freedom in designing a process integration chain. The heat pump may be of the closed-cycle type using a separate working medium as in other energy sectors, or of the open-cycle, where the process medium is also the working medium of the heat pump; one heat transfer loss can be omitted, which increases the efficiency of these systems. Absorption units are used if cheap process heat is available as drive energy. The heat transformer if used if there is excess heat available at a medium temperature level and high temperature heat is required.

4. PRESENT SITUATION

The application of heat pumps strongly depends on the climatic conditions and on the building standards.

- The main market are regions with moderate winters - not below –5°C - and summers which require cooling and dehumidification. This is the area prefabricated air/air heat pump air conditioners, which can be easily installed and which, due to a long annual operation time, are highly cost-effective.
- In regions with cold winters, where additionally cooling is required in summer, the heat pump has to compete with conventional heating systems. Air as heat source for heating purposes is due to low SPFs not the best solution in this case.
- Regions with cold winters and no real need for cooling in summer can be a market for heat pumps if heat sources like ground water or the ground can be used. Heat from the ground can be extracted either by horizontally installed collectors (cost-effective in the case of a new building, if enough area is available) or through bore holes .

The world regions were defined as follows: The majority of heat pumps is in operation in Japan, China and in the US, most commonly air-to-air dual-mode (reversible) units for both heating and cooling. In Europe, heating-only heat pumps are used mainly in the Northern and in the Central part, reversible units in the Southern part. Remaining countries are grouped under "Others".

4.1. Markets in Regions

4.1.1. Japan

The number of heat pumps installed in Japan was 39.3 million in 1992, and 58 million units (68 % of the world total of 85 million units) in January 1997 (Breembroek, 1999). In the year 2000, the number may have reached about 67 million. The number of room air conditioners (RAC) shipped in 1996 has reached a peak of about 8 million in 1996 of which 92 % were equipped for heat pump operation; in 1997 the figures were more than 7 million and 94 %, respectively (Figure 2). The diffusion rate of heat pumps was 62 %, up from 35 % in 1987; it is gradually approaching saturation (Nishimura, 1999). The annual production of packaged air conditioners, mainly for commercial/office buildings, is around 800,000 (Dinghuan, 1999).

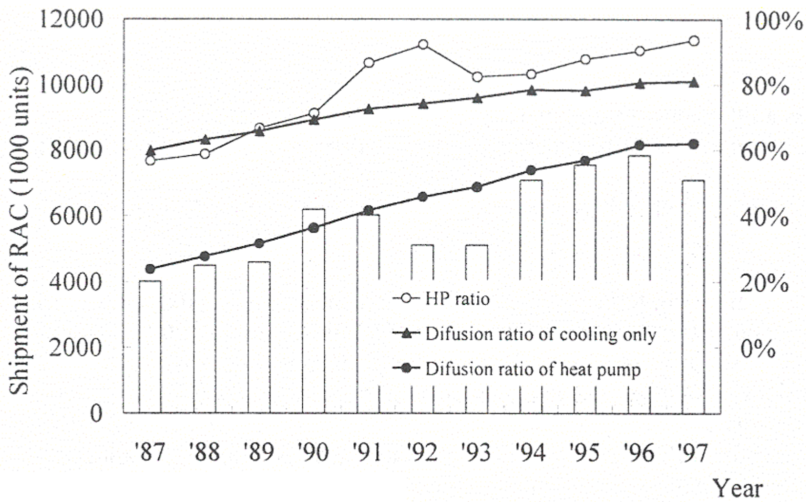

Figure 2: Domestic shipment of Room Air Conditioners in Japan (Dinghuan, 1999)

An increasing number of larger heat pump systems are equipped with thermal storage systems (Figure 3): water storage up to 1993, mainly ice storage after that date.

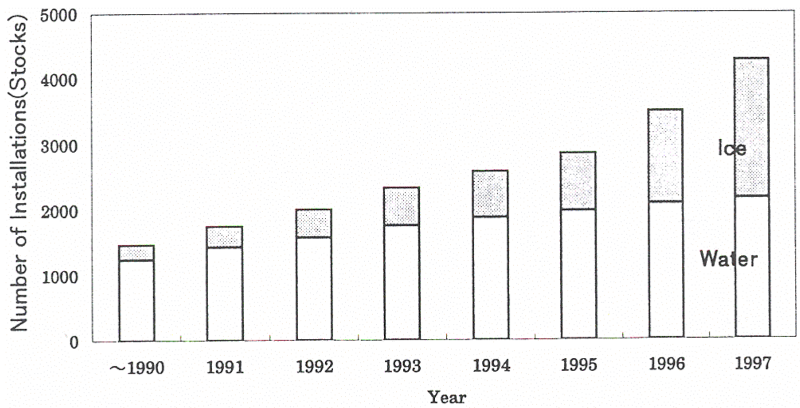

Figure 3: Thermal storage type heat pump systems in Japan (Nishimura, 1999)

The shipment of engine-driven heat pumps in Japan has reached more than 40,000 units in 1997 (Figure 4), 95 % of them utilising gas engines (GHP), the remainder kerosene (KHP). The number of Sorption systems is increasing, although mainly for cooling. Figure 5 shows the cumulative cooling capacity in 106 RT, being 21 GW.

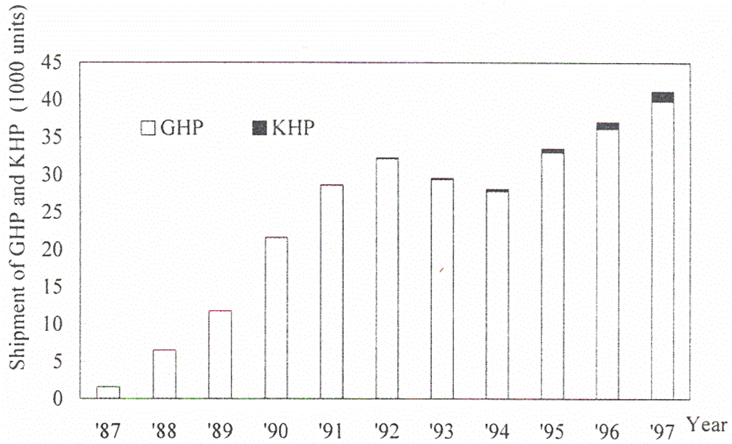

Figure 4: Domestic shipment of engine-driven heat pumps in Japan (Dinghuan, 1999)

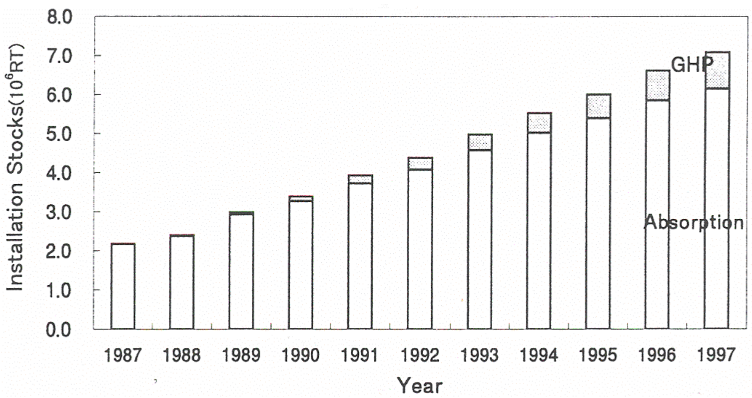

Figure 5: Absorption Systems and GHPs in Japan (Nishimura, 1999)

4.1.2. China

Production of RACs in China was low until 1990, when a rapid upswing started, bringing the production to about 5 million units in 1997, probably around 7 million in 2000, and more in 2001 (Figure 6). This means that China has already the largest industry world-wide for producing air conditioners. The heat pump share was 60 % in 1997, and the number of heat pumps installed was 11.4 million in 1997, slightly more than in the US (Breembroek, 1999). Presently, the heat pump stock may be of the order of 25 million.

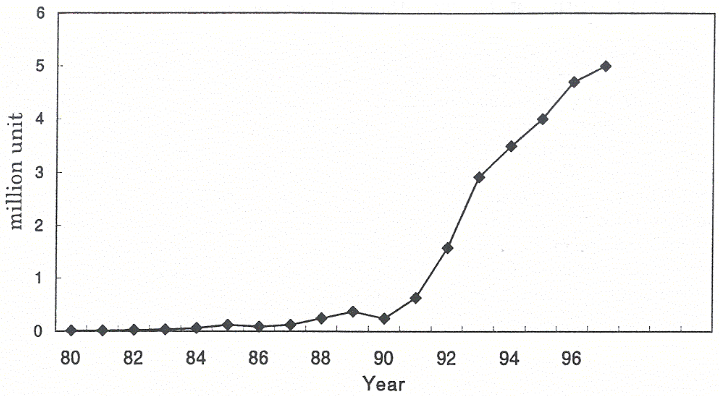

Figure 6: Room Air Conditioners installed in China (Nishimura, 1999)

4.1.3. USA

The number of heat pumps installed in the USA was 9.5 million in 1992 and 11.1 million in 1997 (Breembroek, 1999). Annual sales are about 1.2 million, partly for replacement. The present number may therefore be 13 or 14 million. Numbers include annual sales of 60.000 ground-coupled (geothermal) heat pumps. The problem in the USA are the climatic conditions. Almost in the whole country air conditioning is required, but air-to-air units cannot cover the winter peaks with extremely low temperatures. This results in systems where air conditioners are used for cooling and gas furnaces for heating. The situation in Canada is very similar, considering the populated regions of this country.

4.1.4. Europe

After the oil crisis Europe has been concentrating on heating-only hydronic heat pumps and heat recovery systems, but nowadays sales of dual-mode units are growing. The number of heat pumps in Europe is given as 4.3 million units in 1997 (Breembroek, 1999; Bouma, 1999). The majority of these are reversible air-to-air systems in the residential and commercial sectors in Southern Europe, mainly imported from USA and Japan. The share of these units is increasing. The number of heating-only units and heat recovery units is in the range of 1.5 million units.

A real heat pump market exists in Sweden, other countries have started heat pump programmes - Switzerland, Germany, and the Netherlands – or they are just preparing programmes to increase the market break-through of this technology. The deregulation of the electricity market promises lower tariffs for electricity, which could be an advantage.

4.1.5. Others

In the 1993-1996 market review of the IEA Heat Pump Centre (Breembroek, 1997), there were only 0.6 million units listed for regions other than the four mentioned above (0.5 million for Canada, and less than 0.1 million for South Korea). So the total of

Japan	57.6 million
China	11.4 “
USA	11.1 “
Europe	4.3 “
Others	0.6 “
	85.0 million

was obtained for 1996/beginning of 1997. But there are other markets (Dinghuan, 1999) such as

- Hong Kong,
- South East Asia (Indonesia, Thailand, Malaysia, Singapore, Philippines),
- India,
- Australia/New Zealand

with RAC/PAC annual scales of about 3 million units per year, from which a total number of installed units of about 25 million may be estimated. However, these are mainly cooling-only units and not heat pumps, except the ones in Australia/New Zealand (in total perhaps 3 million units). Adding another estimated 7 million units for South America, Mexico, South Africa, Middle East and the remaining countries, the global number for 1996/97 may be 95 million rather than the above 85 million units for 1997.

The world total number of the RAC and PAC market (cooling only as well as reversible) is estimated to be of the order of 33 million units sold per year (Nishimura, 1999). The split-up of the above 85 million units quoted by the IEA HPC for 1997 is 75 million residential, almost 10 million commercial and about 20,000 industrial units.

4.1.6. Total

According to the HPC market study (Breembroek, 1999) the world-wide heat pump stock has increased in the four years 1992 to 1996 from 55 to 85 million units, i.e. by 55 %. Assuming for the four years from 1996/97 to 2000/01 a slightly lower increase (due to lower economic growth in Asia during that time), the global number in the year 2001, starting from the 95 million deducted above rather than the 85 million units, may be of the order of 130 to 140 million heat pumps in operation world-wide.

4.2. Thermal output

The thermal output of the world`s heat pumps is estimated for 2001 from the data of Table 4 presented in the next chapter as follows:

-	Residential: 75 million units, 10.000 kWh/a each:	750 TWh/yr
-	Commercial	350 "
-	Industrial	200 "
	Total	1300 TWh/yr.

According to the relation given in chapter 2.3, the renewable energy R gained by heat pumps becomes 870 TWh/yr.

4.3. Diffusion

The diffusion of the heat pump, i.e. the share of useful heat produced by it, is negligible in the transport sector, low in industry, but already substantial in the residential/commercial sector of some countries, as is shown in Figure 7. In Japan, this share has reached 20 % for the building stock, in Sweden 9.4 %, in the US 6.9 %, in Spain 5 % (Laue, 1999). The share is increasing since for new building it is much higher. In Switzerland, more than one third of new homes is heated by a heat pump, so the present share of 1.7 % will increase quickly.

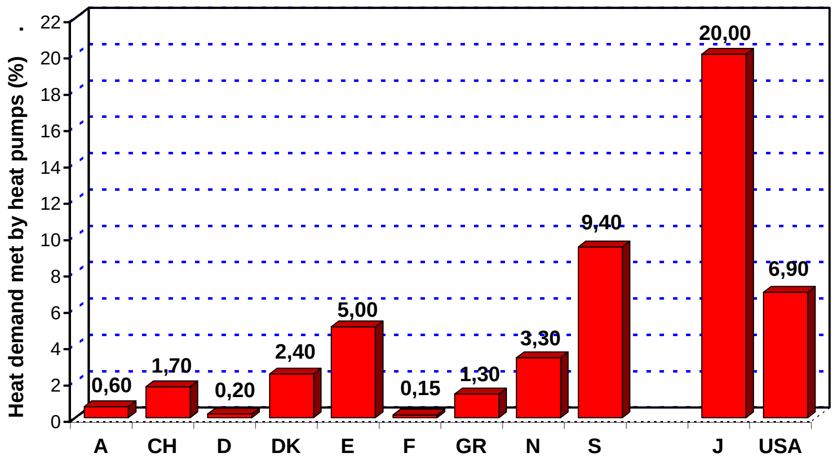

Figure 7: Diffusion of heat pump in the residential sector (heat demand met by heat pumps), %

5. POSSIBLE FUTURE DEVELOPMENT

5.1. Technological development

An example for the development is the increase of COPs, e.g. for Room Air Conditioners from a cooling/heating COP of 2.2/3.1 for the 1982 model to 4.1/4.3 for the 1999 model (Itoh, 1995). Similar data (COP = 4.29) are given by Stuij (1995). One of the driving forces for improvements are labelling schemes.

- In the small to medium size capacity range the reciprocating compressor has been practically replaced by the scroll compressor, and liquid/refrigerant heat exchangers have changed to welded flat plate heat exchangers.
- Ground-coupled heating-only heat pumps, especially direct-evaporation systems in Europe, have increased their SPF to 4 and lately to 5 and more. Besides better components, improved building codes with the possibility of reducing supply temperatures required to values below 35°C are responsible for this development.

5.2. Market development

The possible future development can be assessed in two ways: by extrapolating the annual production as per Table 2, part (1), and adding it to the total installation, part (2), accounting for numbers to be taken out of service, and by subsequently assessing the overall thermal output as per parts (3) and (4) of Table 2 (bottom-up method), or by taking the final energy or the three main sectors (industry, residential/commercial, transport) from statistics estimating a maximum share of each sector to be possibly and sensibly covered by heat pumps; also a (lower) share to be covered by some point in time, say the year 2020, which has to be related to the data of Table 2, part 4 for the year 2000 (top-down method).

6. REDUCTION OF GLOBAL WARMING BY THE HEAT PUMP

According to the Kyoto Agreement, the global emission of greenhouse gases, in particular of industrialised countries, is supposed to be reduced. Of the six greenhouse gases mentioned in the Kyoto Agreement, CO2 is the most important one (it is responsible for considerably more than 50% of the global warming effect) and at the same time it is the one the emissions of which are most difficult to be reduced world-wide. However, it can be shown that the heat pump is one of the key technologies for energy conservation and reducing CO2 emission (IEA HPC, 1997).

Table 2 gives present and estimated future savings of CO2 emissions due to the utilization of heat pumps in the residential and commercial sector as well as in industry. The first column is based on or derived from the data of IEA HPC (1977). It shows that in 1997 the heat pump saved already 0.5 % of the total global CO2 emissions. The second column is an extrapolation of the 1977 data to 2001 according to the data of chapter 4.

The saving potentials shown in the third and fourth column is again based on data of IEA HPC (1997). The third column refers to the potential savings (6 %) of CO_2 emissions by improved market penetration (30% in the building sector) using presently available technologies. These 6% are one of the largest contributions to CO_2 reduction a single technology available on the market can offer. The fourth column is based on greatly advanced future technologies of heat pumps and power plant efficiencies. It yields a 16 % saving of global total CO_2 emissions.

7. CONCLUSIONS

Heat pumps are an old technology, which has not been extensively used as long as both energy prices and the efficiency of electricity generation have been low. The oil crises have changed this situation, and Kyoto is a further reason for the increasing market deployment of this technology. Based on recent developments, the following conclusions can be drawn:

Table 2: Present and estimated future savings of CO_2 emission by the use of heat pumps

		1997[1]	2001[2]	Savings Potential[1]	
				Present	Future
(a) Residential					
Annual heat demand per residence	kWh	10,000	10,000	9,000	8,000
Specific CO_2 emissions					
from heat pump	kg CO_2/kWh heat	0.215[3]	0.2	0.18	0.12
from oil-fired boiler	"	0.713[4]	0.7	0.67	0.64
Number of residential HP	10^6	65	70	670	1,550
CO_2 emissions					
from oil-fired boilers	MtCO_2/yr	204	215	1672	3,500
from heat pumps	"	140	140	1022	1,500
savings by HP		64	75	650	2,000
(b) Savings Commercial	MtCO_2/yr	30	35	350	1,100
(c) Savings Residential + Commercial	MtCO_2/yr	94	110	1,000	3,100
(d) Savings Industry	MtCO_2/yr	20	22	200	600
(a) Total Savings	MtCO_2/yr	114	132	1,200	3,700
(f) Percentage CO_2 emission savings by heat pumps[5)]		0.5%	0.6%	6.0%	16.0%

1. from IEA HPC (1997) or deducted from it
2. estimated
3. 0.215 kg CO_2/kWh heat (for 0.55 kg CO_2/kWh electric energy according to the European fuel mix and SPF = 2.5), decreasing to 0.12 for improved power plant efficiency and SPF and reduced fossil fuel in the mix.
4. for 80 % efficiency in 1997, increasing to 90 %.
5. 1997 annual global CO_2 emission: 22 billion tonnes.

- Heat pumps offer the possibility of reducing energy consumption significantly, mainly in the building sector, but also in industry. Basic second law thermodynamics show the advantages: while a condensing boiler can reach a primary energy ratio (PER) of 105 % (the theoretical maximum would be 110 % based on the lower calorific value), heat pumps achieve 200 % and more, with hydro or wind energy even 400 % and more.
- The majority of heat pumps is in operation in Japan, in China and in the US, most commonly air-to-air dual-mode units for both heating and cooling, China has already the largest industry for producing air conditioners, and in South East Asia the trend to this technology is rising rapidly.
- Europe has been concentrating on heating-only hydronic heat pumps and heat recovery systems, but sales of dual-mode units are growing.
- The drive energy is most commonly electricity, and for the future improved power generation systems based on renewables and fossil fuels have to be taken into consideration. The efficiency of gas-fired combined-cycle power plants available on the market is presently about 58 %, with oil as fuel similar values are possible. Ground-source ("geothermal") heat pumps combined with low-temperature heat distribution systems achieve seasonal performance factors (SPFs) of 4 and higher, which means PERs of 220 to 280 %. Further improvements are possible in the future.
- Sorption systems - absorption, adsorption and DEC systems - also gain importance. The efficiency of sorption units has been improved significantly by introducing welded flat plate heat exchangers for reducing heat transfer losses.

Presently more than 100 million heat pumps with a thermal output of 1300 TWh/a are in operation world-wide, reducing CO_2 emission by about 0.13 Gt/a. The potential for reducing CO_2 emissions assuming a 30 % share in the building sector using technology presently available is about 6 % of the total world-wide CO_2 emission of 22 Gt/a. With future technologies reductions up to 16 % seem possible. Therefore, heat pumps are one of the key technologies for energy conservation and reducing CO_2 emission.

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