RETROFITTING WITH HEAT PUMPS IN BUILDINGS

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Abstract

The potential market for heat pumps for retrofit is about 3 times larger than the market for applications in new buildings. However, in most countries the actual market for retrofit heat pumps is smaller than the market for heat pumps in new buildings. Market barriers include the high temperature distribution systems, the higher challenges on the economy of the systems and other circumstances, such as lack of space.

This article discusses the market, the background of the market barriers and ways to solve them. Swiss experience has shown that current retrofit heat pumps work well, but have a 10% lower efficiency than applications in new buildings, which is quite favourable considering the the 5ºC higher average distribution temperature. The operation experience supports the conclusion that all market players can benefit by targeted action to promote heat pumps in retrofit situations.

Most results reported here have been gathered as part of the project “Retrofitting with heat pumps in buildings” of the IEA Heat Pump Centre (Eggen and Breembroek 2001).

1. Introduction

The potential market for heat pumps for retrofit is about 3 times larger than the market for heat pumps in new buildings. Building construction rate is about 2% in most countries. If a heating (and cooling) system needs replacement after 15-20 years useful service, 5-6% of the existing building stock is confronted with a heating system retrofit each year.

However, in most countries the actual market for retrofit heat pumps is smaller than the market for heat pumps in new buildings. Even in the US, where the barrier of incorporating a heat pump in an existing air distribution system is smaller than in most North and Central European countries, only about half of the unitary heat pump shipments replace existing heating and cooling systems (HPC 2000). In Switzerland, only about 20% of the residential heat pump market (<20 kW) is for retrofit. This corresponds to 3% of the market for replacing/retrofitting existing heating systems. In Germany, heat pumps for retrofitting existing heating systems is estimated at around 25% of the total heat pump market.

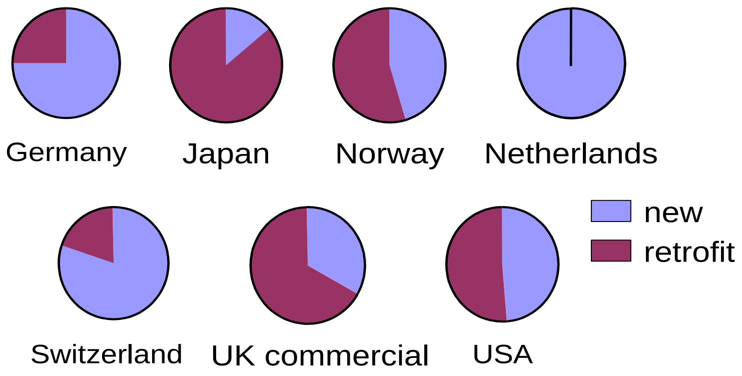

Figure 1: Estimated share of heat pump market intended for retrofitting heating systems (2000).

A significant replacement market exists only in Japan, Norway and - for commercial applications - in the UK. In Japan, residential heating and cooling heat pumps are replaced every 10-11 years. In 1999, the Japanese replacement market for RAC (room air conditioner) type heat pumps was 5,400 thousand units, which is 88% of the total RAC heat pump market. The 1999 replacement market for heat pump PACs (packaged air conditioners) comprised 440 thousand units, which is 70% of total heat pump PAC shipments. In Norway, air-to-air heat pumps of 3 kW to 10 kW comprise 63% of the market volume, and most of these are supposed to be used for retrofitting.

Actions to improve the market chances for heat pumps for retrofit are highly needed, as the Kyoto protocol require a significant reduction of fossil energy use. Heat pumps can reduce current global CO_2 emissions by 6% {HPC 1997). This potential will be realised when 50% of the residences and institutional/commercial buildings are heated with state-of-the-art heat pumps, which save at least 30% CO2 emissions compared to conventional heating methods.

2. Market barriers

There are many barriers to the use of heat pumps for retrofit. They may be caused by technical restrictions or by economic factors. The main barriers are:

- High distribution temperatures.
- High temperature lifts, and a low efficiency.
- Less cost effective than in case of application in new buildings.
- Lack of space.

2.1 Distribution temperatures

Figure 2 shows the heat and cold distribution systems in the existing building stock in various countries (Breembroek and Dieleman, 2001):

- In Japan, many rooms are equipped with air conditioners. There is no central unit and no distribution system. The required condensation temperature is close to the required room temperature in heating operation;
- In the US, most residences have central ducted air conditioning systems. The required condensation temperature is close to the required room temperature. However, the ducts may be undersized for the heat pump system;

- In European countries, many residences have an hydronic heat distribution system with central boiler. Distribution temperatures vary from 30ºC for modern floor heating systems to 90ºC as the supply temperature for traditional radiators. There is significant variation over the various countries: Switzerland has a significant share of low-temperature floor heating systems, while in most countries, radiators are dominant. In Norway, many existing houses do not have a heat distribution system, but local electric heaters. Among the European countries, the share of radiators is lowest in Germany, Norway and Switzerland.

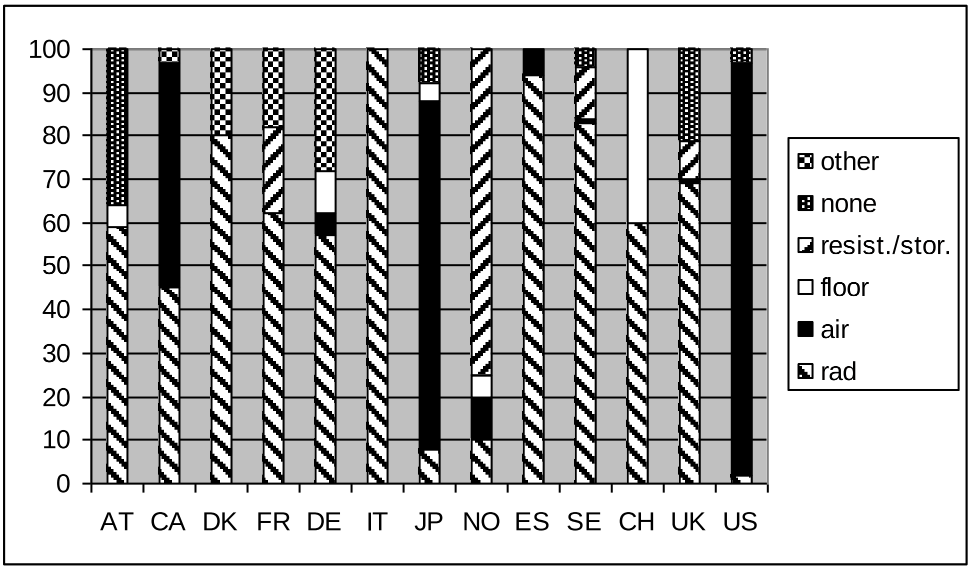

Figure 2: Distribution systems in existing building stock in various countries (1992).
Data for CH represent new houses in 1992.

The traditional hydronic heating systems are high-temperature systems, with design supply temperatures of 90-70ºC. This is a problem, since these temperatures are much higher than the high temperature limits of the heat pump system, which is mostly around 55ºC, depending on the working fluid, see **Table 1.**

Table 1: Saturation temperatures for some refrigerants

Refrigerant	R-404A	R-407C	R-410A	R-507	R-134a	R-290	R-717
Temperature at 25 bar (ºC)	53	55-59	41	52	78	68.3	58
Temperature at 1 bar (ºC)	-46 to –47	-37 to -44	-52	-47	-26	-42.1	-33.3
Critical temperature (ºC)	74.4	86.4	71.8	71	100.6	96.7	130

2.2 Efficiency and economy

Due to the fact that the efficiency of a heat pump system is inversely proportional to the temperature difference between source and sink, heat pumps for retrofit can be less energy efficient that those applied in new buildings. In new buildings, heat source and heat sink can be optimised for heat pump heating.

The first cost of a heat pump for retrofit will be higher than for a competing system (gas- or oil-fired boiler). The investment must be paid back by energy cost savings. And energy cost savings are lower than in the case of new buildings. Best market chances are there were long operating hours translate to high energy cost savings.

3. Market chances

To stimulate the market for retrofit heat pumps, the following strategies have been implemented:

- Lowering the temperature required from the heat pump
- Developing and implementing technologies that can produce the required higher temperature.
- Special designs that meet other specific problems

Lowering the temperature required from the heat pump is very important and should always be considered, since the efficiency of the heat pump system will benefit.

3.1 Reducing heat sink temperature

3.1.1 Buildings measures

There are several methods to reduce the heat sink or distribution temperature of an existing heating system. Old hydronic systems in existing buildings have often been designed for higher heating capacities than the actual design heat demands. Therefore, the heat distribution temperatures may be reduced below the actual design values. The heat distribution temperatures may be lowered further by reducing the heat demand through improved insulation of the building envelope. Changing the strategy of reduced room temperatures at night will lead to a lower heat demand in the morning, and lower distribution temperatures will then be sufficient to keep the building warm.

Retrofitting with a new, low-temperature distribution system is another way to improve operating conditions. The best solution from an energy viewpoint is to replace the existing high temperature hydronic system with a new floor heating system, but this may be expensive. Another way to overcome the problems associated with high distribution temperatures is to install additional heat transfer surface in specific rooms.

3.1.2 Ductless air-to-air systems

Ductless air-to-air systems are attractive especially when no heat distribution system is in place. In Japan, the market is dominated by such systems and they are also successful in other countries. Such systems can be easily and successfully retrofitted. The performance is similar in retrofit applications and in new buildings. However, most units are not optimised for heating-only applications in cold climates, but for heating and cooling in warmer regions.

3.2 High sink temperatures

3.2.1 Refrigerants

The application range of HFC-refrigerants is limited to 60-65°C as the highest recommended temperature limit in one stage small and medium-size heat pump systems. For small and medium sized heat pump systems, higher temperature limits may be achieved by using natural working fluids such as hydrocarbons, ammonia and carbon dioxide.

For both hydrocarbons and ammonia, there are practical restrictions to their use in retrofit applications, which are related to their nature. Hydrocarbons are flammable. Ammonia is toxic, slightly flammable and operating pressures are high. Carbon dioxide is neither toxic nor flammable. Residential CO_2 heat pumps could be a breakthrough on the retrofit market, since the efficiency of the transcritical process is favoured by a high temperature difference over the gas cooler. This corresponds with a high temperature difference over the distribution system and a relatively high supply temperature. At present, the CO_2 heat pump is in the prototype stage. For a successful development of this promising heat pump technology, compressors and other components will have to become commercially available.

3.2.2 Cycles and controls

Two stage compression for higher temperatures, compression with liquid injection, and transcritical cycles with hydrofluoroethers (Brandes et al. 1999) could in principle lead to heat pump systems with improved chances on the retrofit market.

Switzerland plays an important role in developing heat pumps with increased chances on the retrofit market. In this country, the research and development programme 2000-2003 of the federal government (SFOE) focuses specifically on heat pumps for retrofit. The programme supports research on new cycles for high thermal output at high temperature lifts, systems with natural working fluids, and intelligent control concepts. **Figure 3** shows an example of the first type, a two-stage cycle. Additional information on the activities of SFOE in this field can be found on their website (SFOE 2002). The paper of Mr Zogg, presented at this conference, deals with the same subject.

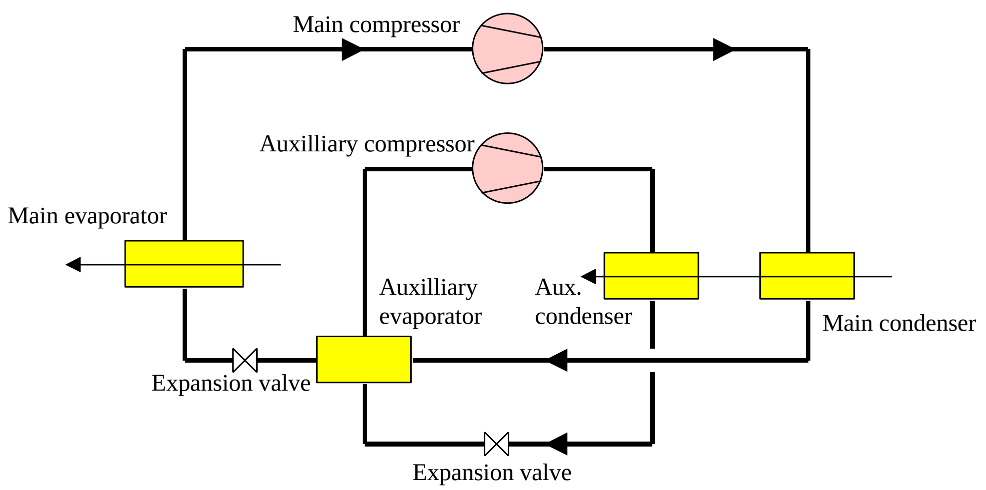

Figure 3: Heat pump process with separate loop for condensate supercooling. Example of Swiss R&D intended for application in the retrofit market.

In 1998, the SFOE has also initiated the competition “Swiss retrofit heat pump (SRHP)”. Manufacturers were challenged to develop a monovalent heat pump for the Swiss retrofit market. The SRHP should:

- Achieve a higher seasonal performance factor than existing heat pumps, with a smaller storage volume;
- Permit efficient operation with ambient air as a heat source and supply temperatures up to 60°C;
- Where possible, use natural working fluids; and
- Be cheaper than present-day heat pumps, through modular construction and serial production.

The proposal of KWT (KWT 2002) has been selected for field testing for the 2000–01 heating period. The tests have shown very promising results, but also the possibility for some further improvements. Two more prototypes will therefore be built and field tested in the 2001–02 heating season. A group of Swiss heat pump manufacturers is planning to introduce the SRHP on the market in 2002.

3.2.3 Absorption systems

Thermally activated heat pumps have the advantage of a high-temperature driving energy. Gas-fired and absorption heat pumps are therefore particularly interesting for the retrofit market. The German/Dutch company Nefit Buderus is developing a diffusion-absorption heat pump, based on the work of Dr Stierlin in Switzerland. The heat pump will be marketed as the next generation of high-efficiency gas-fired heating appliances. The heat pump has been field tested in the heating season 2000-01. The average efficiencies of the tested heat pumps varied between 1.25-1.5. In 2002, 250 improved heat pumps will be installed and monitored.

Heliotherm in Austria has also developed a gas-fired absorption heat pump, also for application on the retrofit market. The 18 kW heat pump can be used with various heat sources. A prototype will be tested intensively in the 2000-01 heating season and a large field test is planned in 2001.

Finally, at the trade fair ISH 2001, the Swiss company Entex presented their development of a gas-fired diffusion absorption heat pump. The system was announced for 2002. It has base load capacity of 4 or 6 kW, and a 11 kW peak load burner. The company aims to bring the heat pump to the market in 2002. More information can be found on (Entex 2002).

3.3 Designs that meet other specific problems

Some manufacturers have developed specific products for the retrofit market. These products aim at lower investment costs, or lower space requirements than otherwise. An example of lower investment cost systems is the retrofit heat pump water heaters, which can use an existing storage tank and avoid an investment of about USD 400. An example of a system with less space requirements indoor than competing systems is the Paradigm system, developed by ClimateMaster (GHPC 2002). This is a ground-coupled heat pump system, with a compressor for outdoor installation. This cancels the need to connect ground loop piping indoor. The special design also allows a quick installation of less than one day.

4. Heat pumps for retrofit in practice

4.1 Some design considerations

- A retrofit heat pump installation should be designed for maximum operating hours. Integrated systems for space heating and hot water production are preferable. Heat pumps for retrofitting the heating system of an elderly home with a constant heat demand may be more successful than in a school, which is only occupied eight hours a day.
- The hydronic concept should guarantee a minimum supply and return temperatures in order to achieve maximum heat pump efficiency.
- There are often practical limitations to the space for the new installation and large buffers are often not feasible.

A step-by-step overview of how to design a heat pump for retrofit in residences is available on the Internet (Gabathuler 2001).

4.2 Results Swiss monitoring programme

In Switzerland, the FAWA project monitors the efficiency of existing heat pump installations, both in new buildings and in retrofit situations (Erb 2001). The project started in 1994/95 with about 30 installations. Every year, about 30 installations are added to the monitored stock. There are now 120 installations being monitored, of which some 60 are retrofit applications.

The following conclusions could be drawn concerning the retrofit installations after more than 5 years of monitoring:

- The average supply temperature was 47ºC, 5ºC higher for retrofit applications than for application in new buildings. Radiators were used as the only heat distributing system in 50% of the cases, compared to 3% in new buildings. Floor heating is the preferred alternative in new houses.
- The SPF of the retrofitted installations is about 10% lower than for application in new buildings. A rough indication of the values: SPF = 2.4 for air-to-water, SPF = 3.3 for brine-to-water retrofit heat pumps.
- The monitoring has shown that the retrofit installations are slightly better adapted to the prevailing heat demand than the installations in new buildings, which tended to overdimensioned. Back-up heat was seldom used in the monitoring period.
- The SPFs of retrofitted do not decrease over the years and the installations are nearly maintenance-free. As a rule, 70% of the heat pumps will operate without problems for over 15 years.

The efficiency data confirm that heat pumps for retrofit are in general less efficient than heat pumps for application in new buildings. The fact that distribution temperatures are 5ºC higher roughly explains the discrepancy. However, these heat pumps with 10% lower efficiency still save primary energy and CO_2 emissions compared to oil fired boilers and electrical heating. Compared to gas-fired boilers, it is also true for the world average CO_2 emissions for electricity generation.

5. Support measures

The number of targeted support programmes for heat pumps for retrofit is significantly lower, worldwide, than the number of general support programmes for heat pumps. Except for the actions of SFOE, that have already been mentioned, there is at least one US programme that explicitly stimulates heat pumps for retrofit. It is run by the Tennessee Valley Authority, in collaboration with local utilities [10]. According to North Carolina EMC, one of these utilities, the programme has been very successful. In addition, some US utilities promote retrofit heat pump water heaters. Specifically designed retrofit heat pump water heaters are available on the market. They are connected to the existing water heater tank.

Even though targeted action is missing, heat pumps for retrofit are mostly included in general support programmes. However, because of the different market needs in the retrofit segment in most countries, targeted action is required to meet Kyoto requirements.

6. Conclusions

There is a large potential market for retrofit heat pumps. However, there are several technical barriers to the use of retrofit heat pumps in existing buildings. These problems are especially related to high distribution temperatures, which cause reduced energy efficiency and poor economy of the heat pump system. Measures to reduce the hydronic distribution temperatures or the use of specially designed heat pumps may solve these problems.

Heat pumps for retrofit merit targeted action to increase their use. This recommendation is supported by the results of the Swiss monitoring programme of retrofit heat pump installations. Though the installations are on average 10% less efficient than similar installations in new buildings, they will still save CO_2 emissions in most countries. The lower efficiency is a result of the higher distribution temperature.

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