THE SWITZERLAND RESEARCH PROGRAM

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Abstract: The heat pump research program of the Swiss Federal Office of Energy (SFOE) supports projects for improvement of components and cycles, introduction of natural working fluids, magnetic heat pumps, screening for and improvement of heat sources and establishing methods for estimation of COP. Heat pumps are treated as renewable energy in Switzerland, because they allow the use of renewable ambient heat. The annual governmental support for research in heat pump application is around 1.3 million Swiss Francs and covers about 2/3 of total project cost. 1/3 is carried through individual companies or research institutes.

Key *Words: research projects in heat pumps, Swiss energy situation*

1 SWISS ENERGY SITUATION

Switzerland has a surface area of 42,000 km^2, 7.4 mio inhabitants and consumed in 2006 888’330 TJ of end-energy [SFOE, 2006]. This was a decrease of 0.5 % compared to 2005. The energy was used by

Households	259’870 TJ	29.3 %
Industry	177’350 TJ	20.0 %
Tertiary Sector	144’780 TJ	16.3 %
Traffic	292’030 TJ	32.9 %
Agriculture	14’300 TJ	1.5 %

In the household sector, the energy was supplied by the following energy sources:

Coal, wood and solid fuels	18’830 TJ	7.2 %
Liquid petrol fuels	124’620 TJ	48.0 %
Gas	41’080 TJ	15.8 %
Electricity	63’730 TJ	24.5 %
District heating systems	5’860 TJ	2.3 %
Renewable energy	5’750 TJ	2.2 %

The production of electricity is maintained via water power stations (52.4 %), nuclear power stations (42.2 %), fossil power stations (5.0 %) and solar energy (0.5 %). There are two nuclear power stations with 1000 MW_{el} and three with 360 MW_{el} in Switzerland.
Although, there is a remarkable amount of oil products for heating purposes and there is an increasing amount of heat pumps in Switzerland, see figure 1. 2006, around 70 % of new built residential houses were equipped with a heat pump [Rognon, 2008]. Mostly compressor heat pumps with electric drives are sold. There are only few absorption heat pumps which use gas as primary energy. Recent years have seen an increase of air to water heat pumps compared to earth probe heat pumps. There are only a small number of water to water heat pumps in Switzerland. The 100’000st heat pump was installed in autumn 2006. The types of heat pumps sold in 2007 were 55 % air to water, 42 % brine to water, 2 % water to water and 1 % air to air. The evolution of sales is shown in figure 1.
There are many heat pumps in the range of 5 to 30 kW_{therm}. In 2007 4.2 % had a thermal capacity less than 5 kW, 43.8 % between 5 and 10 kW, 41.6 % between 10 and 20 kW and 10.4 % between 20 and 30 kW. [FWS, 2007]

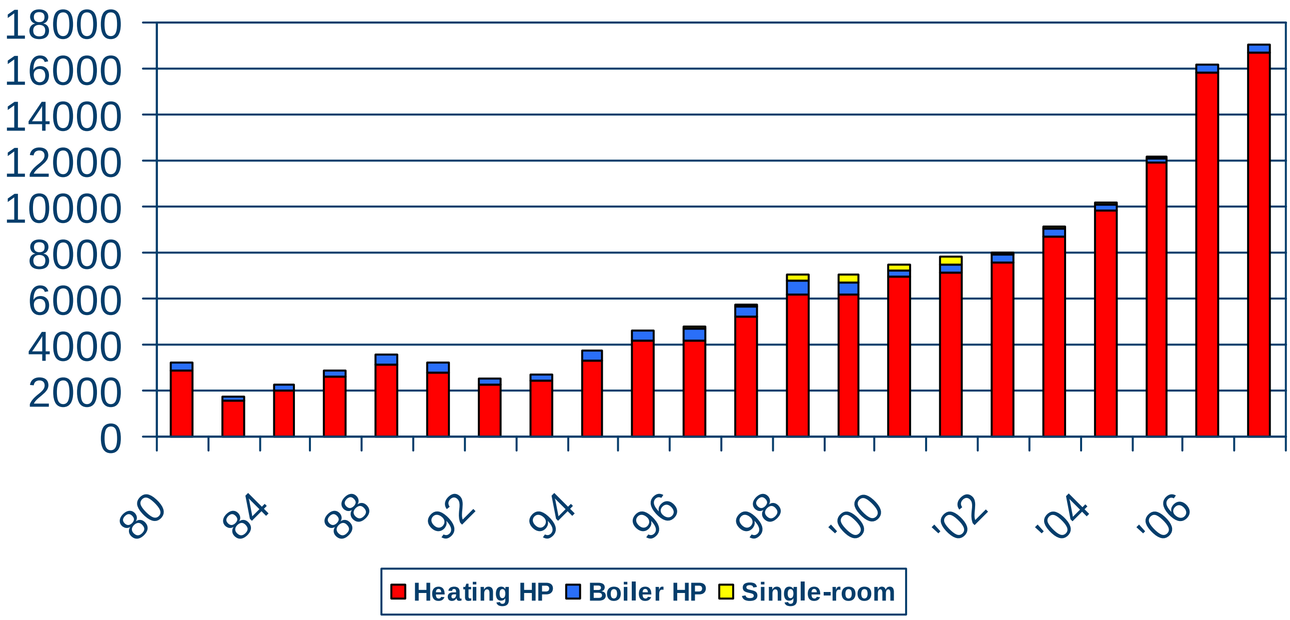

Figure 1: Sales figures of heat pumps in Switzerland from 1980 to 2007

Table 1 shows the distribution of numbers of built-in larger heat pumps in existing buildings in function of thermal power.

Table 1: Thermal power of larger heat pumps for recent years

Year	50 – 100 kW	100 – 300 kW	300 – 900 kW
2002	68	21	5
2003	90	34	7
2004	104	43	12
2005	110	59	16
2006	215	45	34
2007	213	43	34

The Swiss government has signed the Kyoto protocol. Therefore our CO_2 emissions should be reduced to the level of 1990. This is quite a challenging aim and requires a lot of effort. A CO_2-tax was introduced on 1st January 2008 but only on fossil fuels for heating purpose. The tax is 90 CHF per m^3 fossil fuel which is an increase in prices of about 3.5 %. Since October 2006 all consumption of fossil fuels for traffic purpose are taxed with a special Climate-Tax (Klimarappen) of 15 CHF per m^3 of petrol and diesel fuel. Of course, it was noted that heat pumps could have a very strong impact on CO_2 reduction especially when replacing older gas or oil burners in heating installations.

2 SWISS RESEARCH ACTIVITIES AND FINANCING

The CO_2 problem and technological emissions to the environment as GWP (greenhouse warming potential) and ODP (ozone depletion potential) guided the strategy of Swiss research politics in heat pumping technologies. Every four years, a research activity master plan is worked out after intensive discussions among all representatives of different industry sectors, as manufacturers, energy suppliers, installers, research- and energy specialists and

government officers meet to introduce the official government philosophy [CORE 2007].
Since about 1990, the main areas of research in heat pumping technologies have been:
- Increasing the efficiency of all types of heat pumps and all types of components
- exergy analysis
- Examination of heat pumps with natural working fluids
- Development of magnetic heat pumps
- Improvements of heat pumps for hot water production
- Improving the integration of the heat pumps in existing buildings including improvement of control equipment and control strategies
- field tests and methods to measure and calculate coefficients of performance and seasonal performance factors

At the moment, 20 research projects are in progress in different places in Switzerland. 60 % of the projects are co-operations between manufacturers or engineering companies (planners) and research institutes. The project size ranges from 20,000 Swiss francs to 500,000 Swiss Francs per project and the duration from one to three years. In the last five years, an amount of 1.2 million Swiss Francs annually has been spent on average for the research projects and 1.1 million Swiss Francs were invested by the government to support field activities such as market support, advertising, education of planners and installers, testing and standardisation activities. Unfortunately there was a stop of supporting P&D-projects (pilot- and demonstration plants) since 2006 but in beginning of 2008 the government re-realised that P&D projects are important when it comes to transform research results into the market. A special committee in SFOE was established to identify and support P&D projects.
Compared to the 7.4 million inhabitants, every Swiss person spent around 0.5 Swiss francs per year (which is not that much!) for governmental support of activities in heat pumping technologies.

3 RESEARCH PROJECTS

The following chapters describe some research projects of mayor importance which all are financed or co-financed by Swiss Federal Office of Energy. All project results are published by final reports, mainly in German or in French with an abstract in English. All reports and annual reports and annual report abstracts as well are offered to download free of charge from website www.waermepumpe.ch and www.energieforschung.ch .

3.1 Increasing the Efficiency of Heat Pumps and Components

Air to water heat pumps are getting more and more common in Europe. Therefore the COP (Coefficient of Performance) and SPF (Seasonal Performance Factor) has to be increased. In the project LOREF (optimization of an air cooler evaporator via the reduction of ice- and frost formation) the ice and frost formation was studied and mathematically simulated [Berlinger et al., Sahinagic et al., 2008]. The theoretical results have been validated by a number of experiments in which the parameters air temperature and air humidity, temperate difference and the air velocity have been systematically varied. A pilot plant test rig was built (see Figur 2) where different evaporators with different geometric shape in tube diameter and fin geometry could be mounted and tested. The results show that the geometry is of major importance concerning the behavior of defrosting. An optimized geometry was compared with a serially manufactured air cooler evaporator but the measured difference was only 1.8 %. This means that serially manufactured air cooler evaporators can't be improved further. A second result of the project was that the ventilator configuration has to be optimized to the heat exchanger device. Most ventilators are not optimized to the usage in heat pumps yet. It was claimed that operation of air to water heat pumps should be with variable speed control

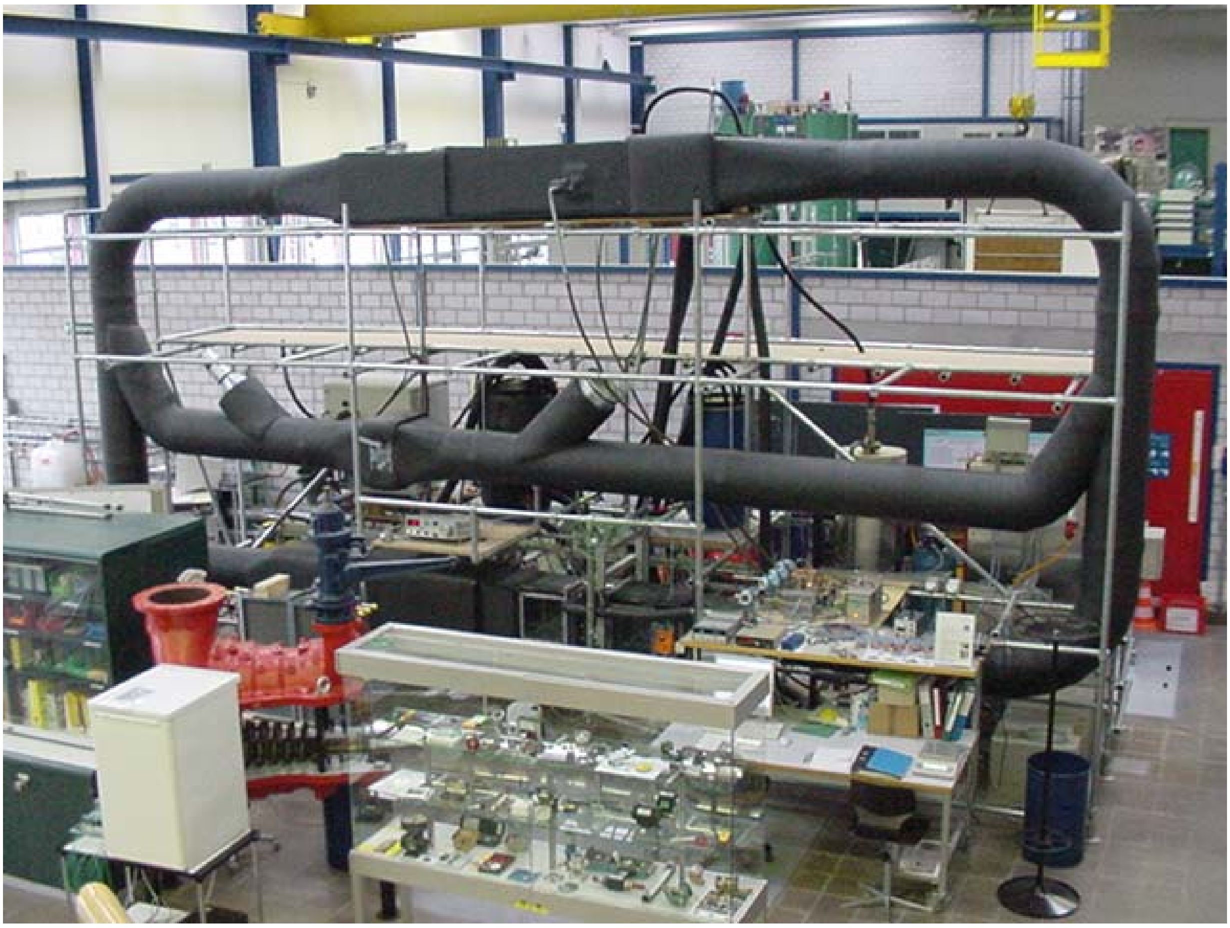

Figure 2: Pilot plant test facility for air cooled evaporators [Berlinger et al., Sahinagic et al.

of compressor and ventilator. Defrosting should be made by blowing ambient air over the evaporator surface to defrost the heat exchanger tubes with a reported energy demand of 1/10 compared to defrosting by reverse operation of the heat pump process.

3.2 Exergy Analyses

During the LOREF project it was found that variable speed components lead to a better performance. Therefore a special project WEXA was started: Exergy Analysis to increase the performance of air to water heat pumps [Gasser et al., 2008]. It was found that in the ON/OFF mode of the heat pump and an ambient temperature of -10 °C the highest exergetic losses were produced by the compressor, followed by the expansion device, and the two heat exchangers evaporator and condenser. This result changes when the ambient temperature is 15 °C: exergetic losses of the compressor are nearly equal to the losses in the evaporator and the losses in the expansion valve are lower than the losses in the condenser. According to these results it’s understandable that an operation mode with variable speed of compressor and ventilator leads to increased SPF of 6.3 compared to ON/OFF mode with SPF of 3.11.

3.3 Heat Pumps with Natural Working Fluids

SFOE (Swiss Federal Office of Energy) tend to convince heat pump manufacturers to switch to natural working fluids. In the last years two projects could be supported which try to increase the acceptance of CO_2 (R744). One project observed the behavior of a CO_2 heat pump for the production of hot sanitary water in the hospital of the small town Le Locle which is situated at a height of 1000 m above sea level. Outdoor temperatures can fall below -20 °C in that part of Switzerland called Jura mountain chain [Anstett 2006]. The heat pump was a prototype which was specially adapted to the local situation. The thermal capacity was 60 kW and the hot water had to have a temperature between 60 °C and to prevent the occurrence of salmonella part time up to 80 °C. Cold water temperatures were between 10 and 15 °C and ambient temperature between -20 °C to 35 °C. The installation showed in average a COP of 3.2 with a water inlet temperature of 15 °C, a hot water temperature of 75 °C and the ambient temperature varied during these measurements between 0 °C and 17 °C.

Figure 3: CO_2 heat pump to produce hot sanitary water for a hospital [Anstett 2006]

A recently started project tries to improve the earth probes by using free convectional flow of CO_2. The aim is to reach same sizes as with conventional glycol earth probes. This means for Switzerland lengths up to 300 m, diameters between 25 and 40 mm and material of polyethylene and not copper [Wellig et al.]. The project was started by creating a theoretical study to examine heat and mass transfer situation in long vertical tubes. In parallel, material studies were started to find solutions with polyethylene which can support the pressure situation of CO_2 in two phase state at the relevant diameters for two-phase flow. Unfortunately we face a break in the projects to development of small heat pumps with Ammonia because the work started by SFOE didn't convince the industry in Switzerland to continue the development of a new prototype. But there are larger heat pumps and refrigeration plants which are manufactured by specialized industrial companies which went into operation in commercial and industrial buildings in the last three years. They mainly work with ammonia but also some propane plants came up [Burger, 2008 and Renold, 2008].

3.4 Magnetic Heat Pumps

Since the last conference (8th International IEA Heat Pump Conference, Las Vegas 2005) Egolf et al. started an intensive research project on magnetic heat pumps. Magnetic heat pumps work with temperature changes in special materials when brought in to or taken out

from a magnetic field. They therefore don't use any classic working fluid and therefore don't have any problems with environmental impact of these substances. In the project phase 1 a theoretical study was established to examine the commercial feasibility of a magnetic heat pump under boundary conditions as they occur in Switzerland [Egolf et al. 2006]. As a result it was seen that only the combination with earth probe and floor heating system had a commercial chance. After that it was decided to support a phase 2 where a real prototype has to be built and tested. At the moment there are still no results from this prototype.
In parallel to the development of a magnetic heat pump Sari et al started to build refrigeration systems based on magnetic processes. A small device of a magnetic refrigerator was presented at the world trade fair in Hannover in 2007 [Sari et al.].

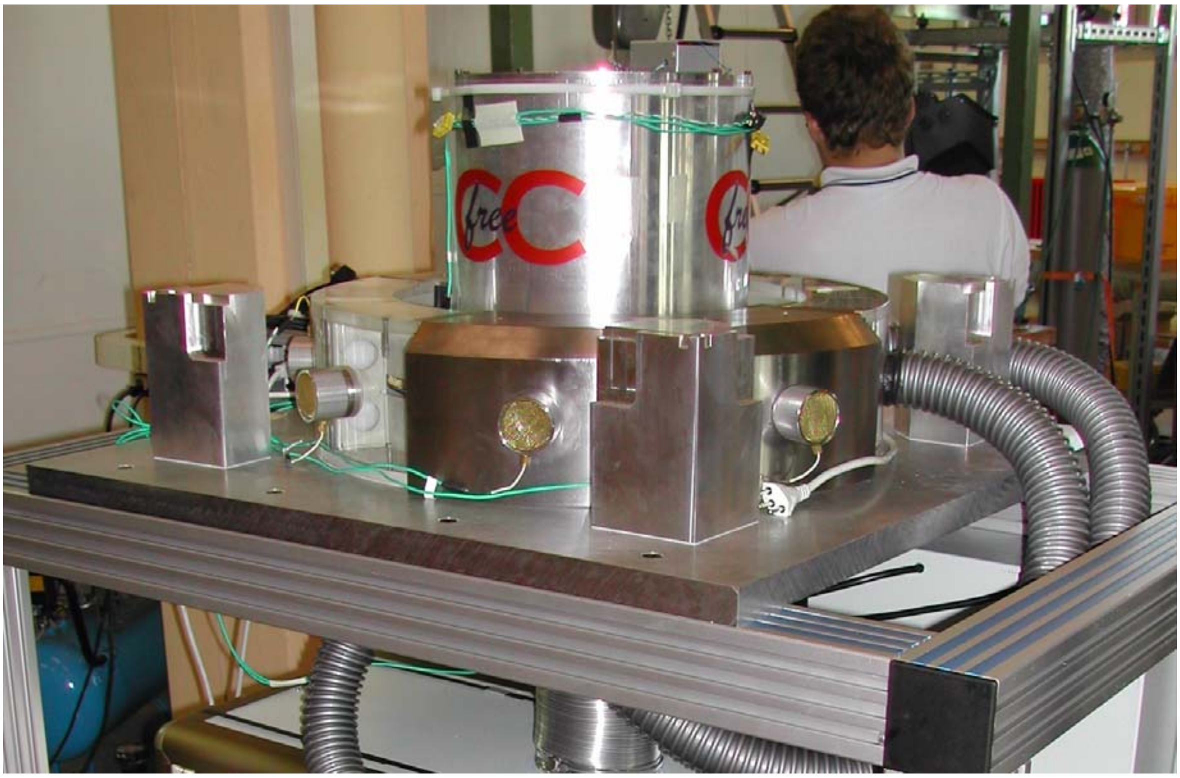

Figure 4: Prototype of a refrigeration machine with magnetic thermo-cycle [Sari et al. 2007]

3.5 Heat Pumps for Hot Water Production

Hot sanitary water can also be produced by heat pumps. In Switzerland there are special heat pump boilers commercially available mainly for single family houses which use ambient heat of the basement rooms where most water heaters are installed. For larger installations hot tap water can be produced by ordinary heat pumps which work either to the heating system or to the tap water heater. Swiss Federal Office of Energy supported a project 'Sanitary hot water production with heat pumps' [Gabathuler et al. 2007] which examined the best way to produce hot water with heat pumps. The project compared internal and external heat exchangers and different loading strategies. It turned out that it is always useful and possible to produce the hot water with the heat pump instead of using electric resistor heating. The heat pumps in this project were R407C machines which were able to produce a maximal output temperature of 65 °C. The research team installed the largest possible heat exchanger into the existing water tank of the experimental set up and could heat up the water up to 51 °C. With installation of an external heat exchanger and a stage loading process, water temperatures up to 57 °C could be reached. It would be possible to reach 60 °C by means of a temperature control in the secondary loop but then the COP drops to 2.5

compared to 3.3 when using no secondary loop control. In order to answer all remaining questions a second phase of this project started end of 2007 ‘Domestic hot water heating using heat pump and storage temperature control in the secondary circuit’ [Gabathuler et al. 2008]. The main questions are how reliable would be the storage temperature control in the secondary loop in practice, how the maximal performance factor could be reached in the secondary loop and which would be the optimal regulation concept.

Figure 5: Heating room [Gabathuler et al. 2007]. At left storage tank, at right heat pumps

3.6 Integration of Heat Pumps in Buildings and Control Strategies

Due to the recent improvements in the heat pump as a part of the whole heating system it’s becoming more and more important to integrate the heat pump optimally in the heating system and to improve control strategies as well. The project ‘Condenser regulation using weather conditions’ [Hubacher and Ehrbar 2008] examine a new control strategy by adjusting the water flow through the condenser dependent to the out door temperature. Hereby it can be avoided that the temperature difference between the condensing working fluid and the water gets too high when the outdoor temperature is relatively high and therefore the heating power of the heat pump (ON/OFF mode, no frequency control) is significant. Two field installations are monitored for two heating periods.
Also in Switzerland large heat pumps are getting more and more common and they contribute to a significant reduction in CO_2 emissions. The project ‘Large heat pump systems’ [Hubacher and Ehrbar, 2008] continues a former project to examine why large heat pumps show reduced COP compared to smaller heat pumps. It was found that the reason lies in non-optimal engineering of the non-serial heat pumps installations and in additional problems with heat distribution and heat source. The analysis of the heat source as waste water, earth probes and lake water is the main aspect in this project. One project uses waste water coming out of a railway tunnel.

One project of the ongoing IEA-HPP Annex 32 is the project ‘Standard solutions for energy efficient heating and cooling with heat pumps’ [Dott et al. 2008] which examines the application of heat pumps in low energy buildings for heating and also for cooling. Cooling is not so popular in smaller buildings in Switzerland yet but due to climate change and to architectural concepts market is asking more information how to do it with performance factors as high as possible. After concentrating on a market research and different system layouts, several configurations were simulated. They will be compared with field measurements. New guidelines for the practice should be the final result of this project.
Ambient heat as source for heat pumps is considered as renewable energy in Switzerland. In moderate climate zones in not-mountain areas temperature is not too low during wintertime and during Fall and Spring there is quite much of solar radiation. Therefore a combination heat pump and solar energy can be interesting especially if the building owner can afford higher investment costs. Two projects focus on the possibilities of combining solar heat and heat pumps. The project ‘PAC-SOL Performance assessment of a heat pump coupled with solar collectors [Citherlet et al. 2008] aim to assess the energetic and environmental performances of coupling a heat pump with thermal solar collectors. Comparisons of different configurations of solar collectors coupled to the cold loop of an air/water heat pump and the potential of an intermediate storage tank filled with water and phase change material are investigated. Another project ‘Simulation of heat pumps in the Polysun 4 simulation software’ [Marti et al. 2008] implements a heat pump module in the existing software Polysun 4 which is widely used in design companies in the thermal solar business.

3.7 Field Tests and SPF calculation methods

In 2007, the joint project IEA-HPP Annex 28 ‘Test procedure and seasonal performance factor of residential heat pumps with combined space and domestic hot water heating’ [Wemhöner and IEA HPC 2007] could be finalized and closed. The Swiss national project for this annex was the project ‘Calculation method for the seasonal performance of heat pump compact units and validation [Wemhöner et al. 2007] which established and investigated a Bin-method called FHBB-method to calculate the SPF (Seasonal performance factor) out of 5 measured COP points of stationary test operation. The method was tested by investigating two field plants where a deviation between calculation and measurements of less than 6 % was found.
Since several years SFOE and the test facility WPZ have measured COP values of heat pumps. The main parts of these tests are published on internet website www.wpz.ch . A summary of all tests over the recent years was worked out in the project ‘Quality tests of small heat pumps by normative tests and selected field measurements, increase of efficiency and long term behavior’ [Nani and Hubacher 2007]. The measurements showed that there was a constant increase in efficiency before 2003 to 2004 but then the trend doesn’t continue. Due to price pressure production cost had to be lowered and some manufacturers offered cheaper but less efficient systems to the market. Nowadays heat pumps differ quite substantially in efficiency. It’s up to the consumer to buy the most efficient heat pump. This trend was stronger with air to water heat pumps than with brain to water heat pumps and water to water heat pumps. Figure 6 shows the trend for air to water heat pumps between 1992 and 2006.
The field tests are continued in the project ‘Field analysis of small heat pump installations: long term investigation 2007 – 2008’ [Hubacher and Ehrbar, 2008].
The gas suppliers in Switzerland are organized in a branch organization which tries to increase the market share of gas for heating purpose. One possibility is the gas driven heat pump either on absorption principle or by means of a gas engine. To achieve clear comparable situations the branch organization worked out a test procedure for gas driven heat pumps [SVGW, 2008]. At the moment it’s discussed among all branch organizations and the suppliers how a gas driven heat pump can reach a quality label and if a gas driven heat pump can get the same quality label as a heat pump with electric drive.

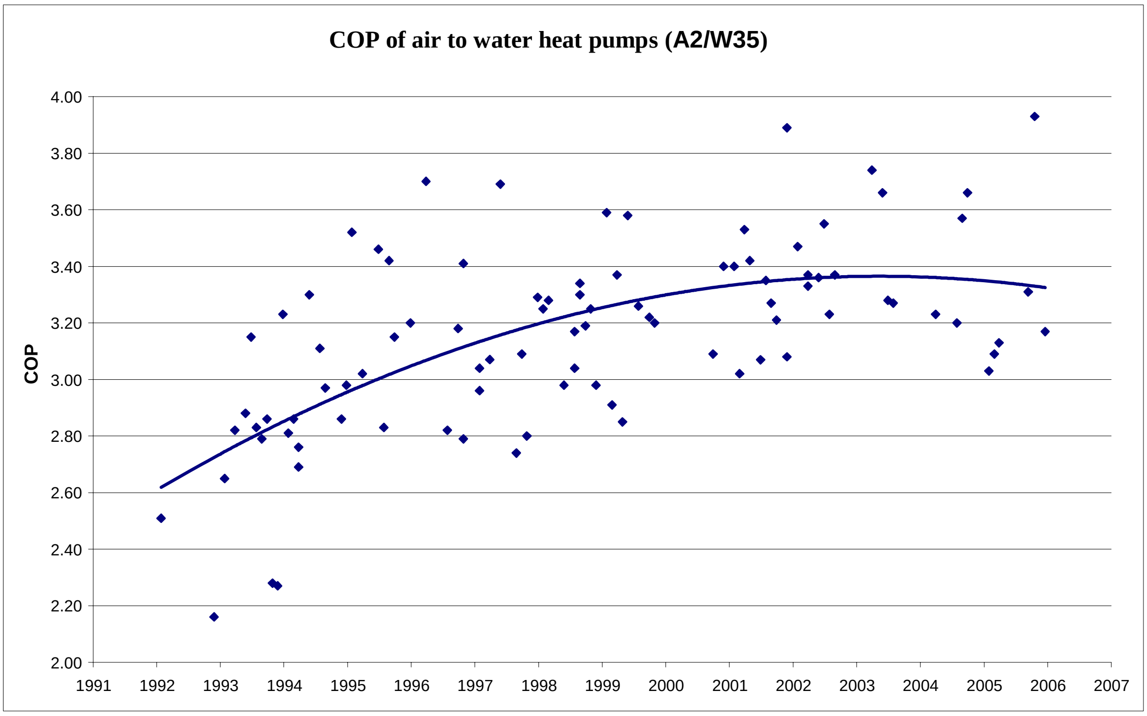

Figure 6: COP in function of year for air to water heat pumps Air 2°C / Water 35°C [Nani 2007]

4 OUTLOOK

In the last decennium, research activity in the field of heat pumps has been quite significant in Switzerland and led to improve the technology, the dissemination and the acceptance of heat pumps in the market. Due to budget restrictions, Swiss Federal Office of Energy was forced to slightly reduce governmental support for heat pump activities. But it can also be declared that the initial effort to establish heat pumps in the Swiss market can actually be reduced to some extent, because nowadays heat pumps have got more market share compared to oil or gas burners, especially in the market of small buildings.
From the research part, there are still some fields in need of activity, mainly in improvements of components and in introducing natural working fluids. The variety of suitable components in the market for heat pumps should be enlarged. Improvements of components should be more guided through exergetic analysis. Furthermore, there is a necessity to lower the cost by optimising the production.

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