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 retrofit heat pumps, improvement of components and cycles, introduction of natural working fluids, 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 1.5 million Swiss Francs and covers about 2/3 of total project cost. One-third is carried through individual companies or research institutes.

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

1 INTRODUCTION

The paper deals with the Swiss energy situation and shows the research activities in the heat pump sector. Research work is carried out by working communities consisting of companies and research groups at universities, especially at Universities of Applied Sciences. The author works as Professor for thermodynamics and as supervisor of all research projects in Switzerland, which are sponsored by the Swiss government.

2 SWISS ENERGY SITUATION

Switzerland has a surface area of 42,000 km^2, 7.4 mio inhabitants and consumed in 2003 873,060 TJ of end-energy. This was an increase of 2.3 % compared to 2002. The energy was used by

Households	284 260 TJ	28.4 %
Industry	171870 TJ	19.7 %
Tertiary Sector	151 320 TJ	17.3 %
Traffic	287 070 TJ	32.9 %
Agriculture	14540 TJ	1.7 %

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

Coal, wood and solid fuels	8630 TJ	3.5 %
Liquid petrol fuels	129540 TJ	52.2 %
Gas	40330 TJ	16.2 %
Electricity	60040 TJ	24.2 %
District heating systems	5220 TJ	2.1 %
Renewable energy	4500 TJ	1.8 %

The production of electricity is maintained via water power stations (60 %) and nuclear power stations (40 %). There are two nuclear power stations with 1000 MW_{el} and two with 600 MW_{el} .

Although there is a remarkable amount of oil products for heating purposes and there is an increasing amount of heat pumps in Switzerland, 60 % of newly built residential houses are equipped with a heat pump. 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 is only a small number of water-to-water heat pumps in Switzerland. In 2003, 85,000 heat pumps were installed: 59.5 % air-to-water, 37.3 % brine-to-water and 3.2 % water-to-water. The evolution of sales is shown in Fig. 1.

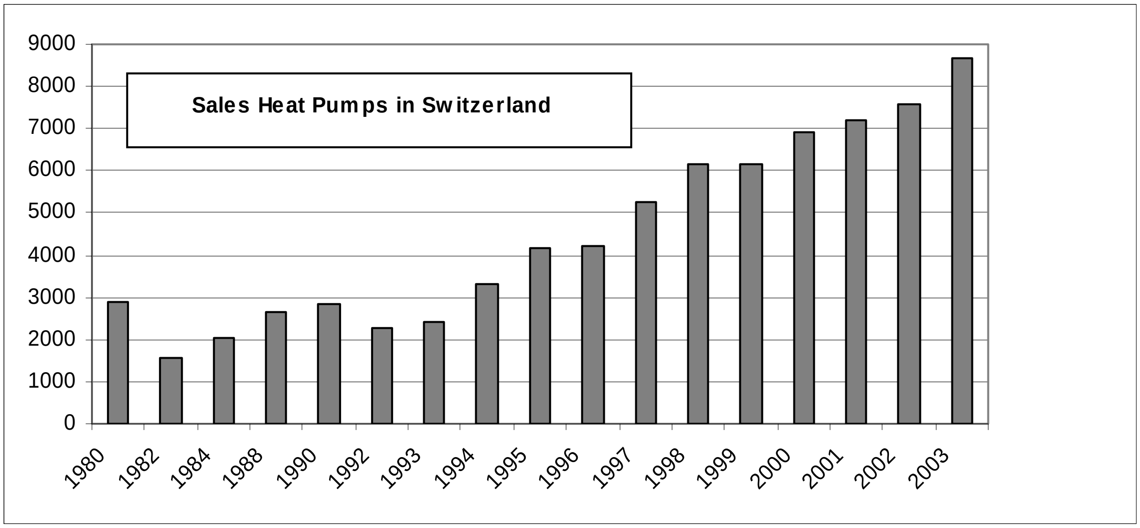

Fig. 1. Sales figures of heat pumps in Switzerland from 1980 to 2003.

There are many heat pumps in the range of 5 to 30 kW_{therm}, although the SFOE also tries to increase the number of large scale heat pumps. Table 1 shows the distribution of numbers of built-in heat pumps in existing buildings in function of thermal power.

Table 1. Thermal Power of heat pumps in Switzerland for recent years.

Year	50 – 100 kW	100 – 300 kW	300 – 900 kW
2002	68	21	5
2003	90	34	7
2004	will be published in March 2005		

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. The Swiss government wants to reach the reduction first on a voluntary basis, but intends to force the emissions down with a special CO_2 tax if all else fails. 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.

3 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 2004]. Since about 1990, the main areas of research in heat pumping technologies have been:

- Development of retrofit heat pumps to replace oil and gas burners
- Screening and improvement of heat sources such as air coolers, earth probes and waste water channels
- Examination of heat pumps with natural working fluids especially ammonia and CO_2
- Improving components such as compressors, heat exchangers and other equipment
- Improving the integration of the heat pumps in existing buildings including improvement of control equipment and control strategies
- Investigating and improving methods to measure and calculate coefficients of performance and seasonal performance factors

At the moment, 15 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 40,000 Swiss francs to 550,000 Swiss Francs per project and the duration from one to three years. In the last ten years, an amount of 1.6 million Swiss Francs annually has been spent on average for the research projects. In addition, 1.1 million Swiss Francs were used to support P&D-projects (pilot- and demonstration plants) and 2.66 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 [Peterhans and Rognon 2005]. Compared to the 7.4 million inhabitants, every Swiss person spent 0.73 Swiss francs per year (which is not that much!) for governmental support of activities in heat pumping technologies. Unfortunately, this amount had to be lowered (final amount still under discussion) in 2005 because the total budget of the SFOE of 55 million Swiss Francs in 2004 was brought down to 45 million for 2005 due to governmental budget restrictions.

4 RESEARCH PROJECTS

4.1 Retrofit Heat Pumps

In 1996, the SFOE launched a ‘Swiss Retrofit Heat Pump’ competition to develop an air to water heat pump with high temperature rise to replace oil and gas burners. The thermal capacity should be 15 to 20 kW with an air temperature of – 12 °C and a water temperature of 60 °C. Four project teams started their planning, two teams chose a scroll compressor with additional side port to feed cold vapour of mid pressure to bring down the compressor outlet temperature. R 407C was used as working fluid. One team worked with ammonia and a rotovane compressor. In 2002, the SFOE could officially close this competition and declared the SWISSTOP heat pump as the winner [Friap 2005]. Table 2 shows its characteristic figures. Another team chose a slightly different development. Their results were used to create the product NATURA by the VIESSMANN Company [Viessmann 2004].

Table 2. SWISSTOP air to water heat pump with external air cooler for replacing oil and gas burners (tests at WPZ Buchs, data from FRIAP AG, www.friap.ch)

Temperature Air in	°C	- 13	- 7	- 7	2	2	10
Temperature Water out	°C	60	55	50	50	35	35
Capacity Heat out	kW	6.07	7.12	7.26	8.97	9.48	12.33
COP measured	-	1.59	1.95	2.13	2.49*	3.23*	3.88
COP Carnot	-	4.56	5.29	5.67	6.73	9.34	12.33
= $COP_{measured}$ / COP_{Carnot}	-	0.35	0.37	0.38	0.37	0.35	0.32

* These data include the defrosting process.

4.2 Improvements of Heat Sources

4.2.1 Air as Heat Source

It is easiest to use air to gain heat from the environment. Unfortunately, heat exchange in gases leads to lower heat exchange coefficients. This can be compensated with fins, but it increases the cost of the exchanger and the pressure drop. Another problem is the freezing of surfaces due to the moisture in the air with temperatures lower than 4 °C. When launching the 'Swiss Retrofit' competition, it was noticed very soon that not only the heat pump itself had to be improved, but also the heat source needed additional research. It had been decided that the heat should be extracted in a separate air cooler placed outside the building and then transported from the cooler to the heat pump by a liquid carrier media. In the project 'air as heat sources for retrofit heat pumps' [Deller and Kopp 2002], two industrially manufactured air coolers were investigated in terms of pressure drops of air and carrier media, best choice of transport media and ventilator efficiency. The results were rather disappointing. The ventilator had a poor efficiency of 14 %, and the pressure drop in the hydronic circuit of the transport media was four times higher than in the air cooler itself. A theoretical comparison of eight different media showed that Temper-20 [Aspen 2002] is 6.5 % better than Aseol-Solera (polypropylenglycol 45vol%) [Aseol 2002]. Temper-20 should not get in contact with galvanized steel and with soft-solder materials. So it was clear that all existing air coolers in the refrigeration market are not optimized for installation as heat source for heat pumps.

Another problem of air coolers is the freezing of the surfaces. Ice and snow slurries increase the heat resistance. Periodically these layers have to be removed. This can be done by heating the heat exchanger surface above 0 °C usually with hot transport media from a storage tank or hot gas supply into the cooler. Instead of heating the whole heat exchanger walls, it would be much cleverer to heat only the boundary layer between the ice and the metal wall and ensure that the ice and snow glides from the fins due to gravity. The project 'Surface treatment to reduce formation of icing' [Hoffmann et al. 2003] tried to treat the surface of the aluminium fins with different mechanical and chemical methods to improve the gliding of the ice when defrosting and to reduce the formation of ice itself. The highest water repellence was achieved by high surface roughness and application of a strongly hydrophobic surface coating consisting of perfluorsilanes. Surprisingly, this led to the worst defrosting behaviour when testing three differently treated materials. The ice held much stronger on to the rough surface than on the originally smoother material in the untreated state. The best surface, called ORGPHOS, consisting of smooth and hydrophobic fins, showed 25 % less condensed ice when starting a new cycle after defrosting compared to the original fin state and therefore led to a longer working period between two defrosting operations. The danger was noted that coating effects are lowered during long time running due to rain and fouling.

The results showed that there is definitely a potential to improve air coolers for air to water heat pumps. Therefore the SFOE initiated a new competition 'improvement of air coolers for retrofit heat pumps' and a first part of research was started in 2003 with the project LOREF 1 'Investigation of the frost formation in fin and tube heat exchangers in heat pumps' [Sahinagic et al. 2004]. This project develops and tests theoretical principles of the mechanism of frost formation, the simultaneous heat and mass transfer of humid air to frost surfaces and the increase and the properties of the frost layer. A special experimental set-up was built in the form of a flat plate channel which was cooled on one side. A second plate was equipped with small cylindrical tappets to simulate the tubes of the fin and tube exchanger. Main results of the tests with the flat channel were that the heat flow through the increasing frost and ice layer remained constant over a period of 8 hours due to an increasing density of the frost layer which therefore also showed an improved thermal conductivity. It has to be noted, that the volumetric flow was held at a constant rate which is not the same case in field applications. The second result was that the roughness of the frost layer had negligible effect on heat and mass transfer. Finally, it was found that the measured correlation between heat transfer and mass transfer was according to theory. Figure 2 shows the plate with the tappets with frost layer.

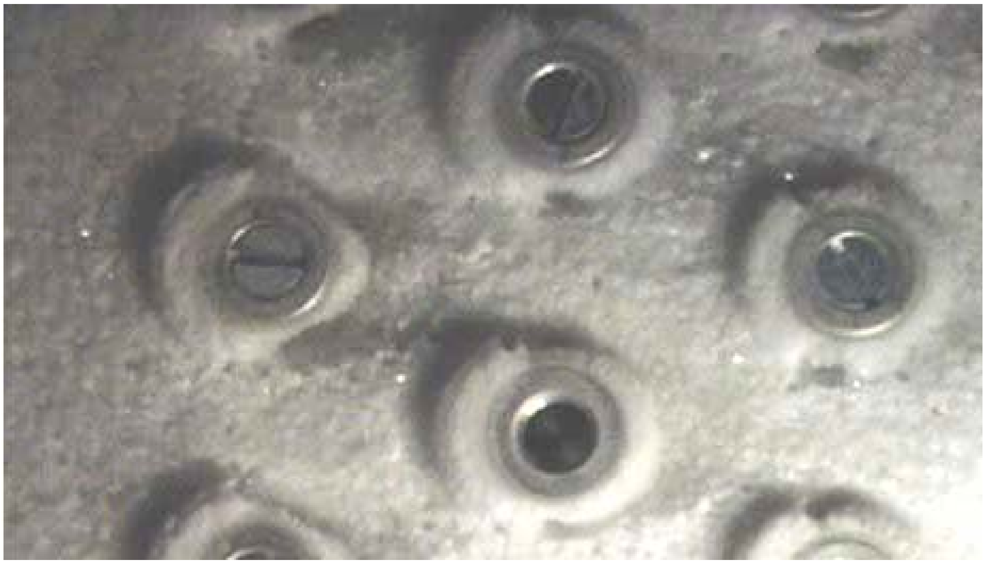

Fig. 2. Plate with tappets with frost layer; experiment duration was 7 hours.

As initially planned, the project is now in phase 2. In LOREF 2, all results from phase 1 are invested to engineer, fabricate and test several air coolers with optimised fin geometry for the special purpose of heat pump application. Tests of these coolers with heat pumps are currently performed in climate chambers and in ambient air until spring 2006.

4.2.2 Ground source heat pumps

40 % of installed heat pumps use ground and ground water as heat source. The technology to lower the bore holes is well established and does not require anymore research. Probe depths in Switzerland are 150 to 500 meters. Usually the double U-probes are installed. Glycol filled earth probes have the disadvantage that they need a pump to circulate the glycol and an additional heat exchanger to transport the earth's heat to the evaporating working fluid of the heat pump. SFOE supported a research project "Pumpless earthprobe, Phase 1 potential and feasibility study" [Peterlunger et al. 2004] with natural flow convection in the probe with CO_2 as working fluid. It was shown that for the depths needed in Swiss installations, a probe length of 75 m, as seen in Austrian probes, is not sufficient. Probes with depths of 350 meters should have a minimum diameter of 40 mm. The general improvement in COP of a pumpless thermosyphon with CO_2 is 12 to 15 % compared to a brine ground source probe. Further improvements could be reached with a common working fluid for the thermosyphon probe and the heat pump cycle. An oil free compressor should then be used because of potential ground water pollution.

4.2.3 Heat source from waste water systems

Larger villages and cities are equipped with an underground waste water system. Waste water flows through pipes towards the sewage treatment plant. The temperature of the waste water is about 15 °C and can be used as heat source for heat pumps. In Switzerland, there are about 1000 possible locations for such waste water channel heat exchanger systems and several exchangers have been built. It was realized that the fouling of the surfaces is not the same on each installation; some installations were gravely affected by severe fouling problems which could lower the capacity to 50 %. SFOE supported a project which examined the conditions for prevention of fouling and the behaviour of the sewage treatment plant for the cases with heat exchangers in the waste water channels 'heat recovery from waste water systems' [Wanner 2004]. Experiments with a pilot scale heat exchanger in a small waste water channel showed that the best antifouling effect is attained by regular short term increase of the flow velocity. Other measures as coating or obstacles in the channel had less influence. The measured heat transfer capacity could range from 60 % without any measures to 83 % with intermittent flushing where 100% stands for clean surface. The sewage treatment plant is not harmed in cases where the channel diameters are larger than 1 meter, the initial temperature before the heat exchanger is above 15 °C and the flow rate in rain-free periods exceeds 20 to 40 litres per second.

4.3 Heat Pumps with natural working fluids

Due to ODP and GWP, the Swiss government and the SFOE decided to support research projects with natural working fluids. As natural working fluids, propane, ammonia and CO_2 are considered at the moment. Some heat pumps which were refilled with propane instead of R22 were sold also in Switzerland, but caused severe problems due to failures of lubrication in compressors. Therefore neither manufacturers nor suppliers show a great interest in propane nowadays. Ammonia is used in larger refrigeration plants in the food and beverage industry and in ice rinks without any problems. A research activity is trying to build small heat pumps for residential houses also with ammonia. The project 'Small heat pumps with ammonia' [Geisser and Kopp 2003] designed an ammonia heat pump with a thermal output of 17 kW equipped with a rotating blade compressor Rotovane. This compressor requires a remarkable amount of oil for sealing, lubricating and cooling. The pilot installation could be tested properly, but the COPs were rather disappointing. Figure 3 shows that the COP depends on the oil flow, the higher the oil flow, the lower the COP. This behaviour is logical when compared to the thermodynamic Rankine cycle. The oil has no possibility to multiply the mechanical energy invested for compression into heat of condensation given into the condenser, because it can not perform gas to liquid phase changing.

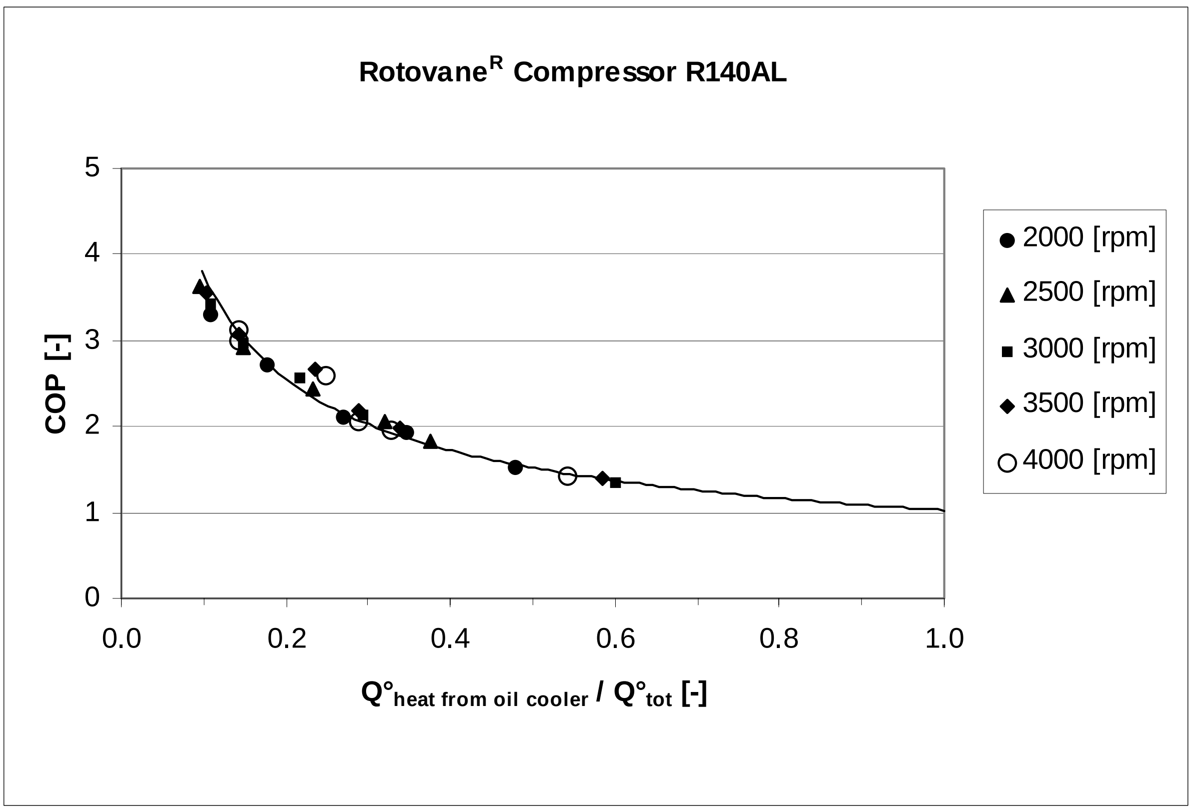

Fig. 3. COP of an ammonia HP with rotovane^R compressor (17 kW_{therm}) in function of oil flow.

The project is now in phase 4 [Stauffer et al. 2004], where an oil-free two stage compressor is tested. Again, the research team has to fight with the old known, boring facts, that suppliers have no experience with ammonia. The equipment delivered is not resistant to ammonia, although in the whole ordering process, every item was clearly ordered for use with ammonia (!). Due to fresh problems of this nature, the team has not yet been able to obtain the first experiment figures with this compressor at present (January 2005).

There is, in Switzerland as elsewhere, a huge amount of hope for CO_2 as natural working fluid. The SFOE supports in cooperation with the German company Stiebel-Eltron a project 'heat pump with CO_2 for heating and hot tap water production' [Friedl et al. 2004] with an amount of 50 % heat for heating and 50 % heat for tap water production. After theoretically analysing different cycles, the researchers built a prototype with a Danfoss piston compressor. They made the same experiences as the ammonia research team: there is a lack of components in the market for installations with natural working fluids, especially in small scale applications! The author hopes that increasing pressure towards natural working fluids will lead to an increased choice for components in the near future.

Another project with CO_2 was supported at the hospital in the small town of Le Locle, situated in the Jurassic mountains in the western part of Switzerland at an altitude of 1000 meters. A 60 kW_{therm} heat pump was installed to produce hot tap water of up to 80 °C 'Investigation of a CO_2 heat pump for production of hot tap water in a hospital' [Anstett 2004]. The heat source is ambient air. The heat pump was bought as a prototype and equipped with sensors to create values for COP for various seasonal ambient conditions. Outside temperature in Le Locle can vary from -20 °C on very cold days to 35 °C in summertime. The research team created a website www.pac-co2.com where all data is published in nearly real time.

4.4 Improvement of Components

As already mentioned in section 4.3, good heat pumps can only be built with reliable equipment. Exergetic analyses show clearly that the compression is still the element where most improvements are possible. Swiss research projects for the retrofit heat pump could also help to bring the scroll compressor with side port into market. Another path towards better compressors is followed in the project 'Small turbo compressor for two-stage heat pumps, phase 2' [Schiffmann et al. 2004, 2002]. The team plans, builds and investigates a turbo compressor for a one-stage heat pump with R134a. The small turbo compressor with gas bearings has a diameter of 2 cm (same as a Euro coin) and rotation speed up to 240'000 rpm. The first tests are not finished yet due to delivery delays and an unexpected rupture of the shaft housing. Figure 4 shows the compressor compared with a Euro coin.

Fig. 4. Turbocompressor for R134a compared with a Euro coin.

Former projects examined the question of how to improve the thermodynamic cycle of heat pumps. It was clearly realised that two-stage cycles are advantageous. Unfortunately the market does not offer enough equipment for smaller heat pumps. A less ideal possibility is to build the two stage cycle with two single compressors which are connected in serial mode. There, the problem of oil migration from the high pressure compressor to the low pressure compressor is obvious and was examined and proved in the project 'Analysis of oil migration in one-stage and two-stage heat pumps' [Zehnder and Favrat 2003].

The German company Bitzer recently launched the new OCTAGON compressor series. These piston compressors can be used in two-stage mode. A compressor of such type was mounted in an air to water heat pump of about 12 kW_{therm} and examined in the project ‘speed controlled heat pump PIONEER’ [Eggenberger et al. 2004]. Special focus was given to the effect of speed variation in the compressor and in the ventilator for the air cooled evaporator. Speed of the compressor can be varied from 17 to 117 Hertz and for the ventilator from 5 to 50 Hertz. By this strategy, the heat for the building can be accurately supplied dependent on seasonal demand. The results of the prototype proved the reliability of the heat pump and showed quite good COPs when working to a heating temperature between 20 and 60 °C, see Table 3.

Table 3. Results of the PIONEER air to water heat pump with frequency control, test results from laboratory of Solartis GmbH.

Air Temperature	°C	-10	-4	0	4	8	12
Water out Temperature	°C	57.5	50	45	40	35	30
Thermal Power	kW	12.8	10.4	8.5	6.9	5.1	3.4
COP measured	-	1.95*	2.3*	3.0*	3.7*	4.7*	5.8*
COP Carnot	-	4.90	5.98	7.07	8.70	11.41	16.84
= $COP_{measured}$ / COP_{Carnot}	-	0.40	0.40	0.42	0.42	0.41	0.35

* Without defrosting process

4.5 Better Integration of Heat Pumps in Buildings.

For several years, the SFOE has supported projects to improve the integration of heat pumps in buildings. Special activities were made to study the method of pulse-width modulation where heat packages are delivered to the building via the ordinary hydronic system. The frequency and the duration of the packages or pulses are varied according to the ambient outside temperature. Results form former activities in this project have been implemented in commercially available control equipment of two companies. The project ‘pulse width modulation, phase 4’ is now examining the mentioned method for heat pump systems with hot water production and heating production and implements an adaptive control strategy [Shafai and Bianchi 2004]. It is planned to connect the control strategy via internet with weather forecast information which is published by MeteoSwiss, the federal weather forecast organisation.

During the SFOE activities undertaken so far to improve heat pumps, a lot of data was collected by the different research teams. Until now, seven data sets are available mostly from smaller heat pumps in different buildings. So a small additional effort has been made to transform these data into a compatible form and to offer them for public use. From the project ‘measured test data of seven (Swiss) heat pump installations’ [Gabathuler and Mayer 2004] data can be extracted on CSV files consisting of daily or weekly values summed or averaged over 1.5 to 10 minute intervals. The periods of observation cover several months, mostly extending over one or more heating periods. Of course, data and technical explanation of the heat pump system and of the building are also included.

4.6 Methods for Measuring and Calculating COPs.

Comparing heat pump systems needs accurate data and a common basis for the comparison. Dealing with this item, definition problems occur very soon, especially when comparing heat pumps with additional hot water production. M. Zogg, former responsible project coordinator in the SFOE, initiated annex 28 of the IEA HPP ‘Test procedure and seasonal performance calculation for residential heat pumps with combined space and domestic hot water heating’. Annex 28 started in 2003, in collaboration with ten countries [Wemhöner et al. 2004]. All relevant information can be seen on the www.annex28.net website. Results of annex 28 were also presented at this conference in a special workshop.

As Swiss contribution to annex 28, the project ‘Calculation method of seasonal performance factor of heat pump compact units and validation’ is carried out [Afjei et al. 2004]. Two commercially available pilot plants are monitored and the seasonal efficiency is calculated with a new FHBB-method which uses a bin-strategy [Wemhöner and Afjei 2003]. This method has now been sent to public enquiry and could be integrated in the new European standard prEN 14335. The choice of suitable test procedures is still more sophisticated than initially expected, since different testing standards for the evaluation of the system characteristics currently exist.

4.7 Other Projects

Heat pumps in Switzerland are mainly of small size, around 8 to 30 kW_{therm}. But there are some large heat pumps extracting heat from ground water or from water of lakes or streams with thermal heat output of up to 500 kW_{therm}. Scattered measurements showed that COPs of large heat pumps which were each specially engineered are slightly smaller than COPs of standardised products. Therefore the SFOE decided to start a new project ‘field analysis of performance of large scale heat pump installations’ [Hubacher and Ehrbar 2004] with the aim to establish rules for dimensioning and proper design including rules for an ideal integration of the heat pump in the heat distribution system of the building.

The whole ‘mess’ with working fluids and compressor efficiencies could be avoided if completely different ways of heat pumping effects would be taken in account. A Swiss research group is working on magnetic heat refrigeration processes and had several ideas which led to new patent announcements. They proposed the project ‘feasibility study for magnetic heat pumps and their application in Switzerland’ [Egolf et al. 2004]. The project will refer to two particular cases which are of special interest for Switzerland. These are the hot water heating up to 55 °C and domestic heating up to 35 °C (brine to water heat pump and floor heating system) and up to 60 °C (air to water heat pump with radiator heating system). It includes cost estimation and an exergetic analysis.

5 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, we are forced to reduce governmental support for heat pump activities. But we can also declare that the initial effort to establish heat pumps in the Swiss market can actually be reduced to some extent, because heat pumps have definitely found their position in the market.

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 and for the Swiss market in particular, this means to enlarge production volumes and to lower the cost per the piece.

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