THE SWITZERLAND HEAT PUMP 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, screening for and improvement of heat sources including combination of heat pumps and solar energy and establishing methods and field tests for estimation of COP. The paper gives an overview of research projects which are supported by state budget, supplementing the papers which were presented at the previous IEA Heat Pump Conferences in Zürich (2008) and Las Vegas (2005) [Kopp 2005 and 2008]. The annual governmental support for research in heat pump application has unfortunately decreased to around 0.6 million Swiss Francs. At the moment, around 15 projects are running which are additionally financed by industry and other institutions with around 1.3 million Swiss Francs per year.

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

1 SWISS ENERGY SITUATION AND HEAT PUMP MARKET

Switzerland has a surface area of 42’000 km^2, 7.8 million inhabitants and consumed 877’560 [TJ] of end-energy in 2009 [SFOE, 2009]. This was a decrease of 2.5% compared to 2008. The energy was used by

Households	252’280 TJ	28.7 %
Industry	167’380 TJ	19.1 %
Tertiary Sector	140’270 TJ	16.0 %
Traffic	305’000 TJ	34.8 %
Agriculture and statistical difference	11’630 TJ	1.4 %

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

Coal	400 TJ	0.2 %
Wood	19’510 TJ	7.7 %
Liquid petrol fuels	111’160 TJ	44.1 %
Gas	42’660 TJ	16.9 %
District heating systems	5’970 TJ	2.4 %
Electricity (nuclear, fossil)	30’118 TJ	11.9 %
Electricity (renewable, mainly hydro power)	34’392 TJ	13.6 %
Renewable energy (biofuels, biogas, solar, ambient heat)	8’070 TJ	3.2 %

The production of electricity (all sectors) is maintained via hydro power stations (55.8 %), nuclear power stations (39.3 %), fossil power stations (3.0 %) and renewable (others than hydro power) energy (1.9 %). 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, there is an increasing amount of heat pumps in Switzerland. In 2009, 20’596 heat pumps were sold and 83 % of new built residential houses were equipped with a heat pump [FWS, 2010]. Mostly compressor heat pumps with electric drives are sold. There are only few absorption heat pumps which use gas as primary energy. In recent years, we 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 types of heat pumps sold in 2009 were 55.8 % air to water, 41.3 % brine to water, 2.9 % water to water and some few air to air. End of 2010, nearly 150'000 heat pumps were installed in Switzerland, which consumed 1.3 % of the total electrical energy. Swiss Federal Office of Energy estimates to have 400'000 heat pumps in Switzerland in 2020 which will consume 4 % of the total electrical energy. The evolution of sales is given in the paper of Phillips in the present proceedings [Phillips, 2011].

2 SWISS HEAT PUMP RESEARCH ACTIVITIES AND FINANCING

The CO_2 problem and technological emissions to the environment such as GWP (greenhouse warming potential) and ODP (ozone depletion potential) are still guiding the strategy of Swiss research politics in heat pump 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 2010]. 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
- Heat pumps with natural working fluids
- Large heat pumps (non serial heat pumps)
- Development of magnetic heat pumps
- Improving the integration of the heat pumps in existing buildings including improvement of control equipment and control strategies, also for combined systems heat pump and solar
- Field tests and methods to 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 3'000'000 Swiss Francs per project and the duration from one to three years. In the last three years, an amount of 1.0 million Swiss Francs annually has been spent on average for the research projects. Unfortunately, there has been a decrease in research budget down to around 0.6 million Swiss francs in 2011. Compared to the 7.8 million inhabitants, every Swiss person will spend in 2011 around 0.08 Swiss Francs per year for governmental support of research activities in heat pumping technologies.

3 RESEARCH PROJECTS

The following sub-chapters describe some research projects of major importance which are all financed or co-financed by the 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 final reports, annual reports and English abstracts are offered for free download from the website (in English) www.energy-research.ch .
All of the following project descriptions are based on project abstracts of the published annual or final reports (see chapter 5 references), which were fully or partially quoted or re-summarized.

3.1 Increasing the Efficiency of Heat Pumps and Components

In the recent research projects 'Optimisation of fin tube evaporators by reduction of ice and frost formation' [Berlinger et al., 2008 and Sahinagic et al., 2008] and 'Exergy analysis for increasing the efficiency of air/water heat pumps' [Gasser et al., 2008] the efficiency of air/water heat pumps was examined. The main measure to improve the efficiency is to continuously adapt the generated heating capacity to the heat demand of the building. Three different heat pump prototypes with capacity control have been evaluated and measured in the project ‘Efficient air to water heat pumps by continuous capacity control’ [Wellig et al., 2010]. The authors summarize the result in their abstract (partly quoted from annual report 2010): *The investigations show that the optimal control strategy and the efficiency of the capacity controlled heat pump strongly depend upon the partial load efficiencies of the compressor and the fan. The experimental investigations approve the great potential of the capacity control. As a result of the capacity control the seasonal performance factor can be increased by approximately 20–50% compared to air/water heat pumps with on/off control. Therefore, the seasonal performance factors can be even as high as the values of brine/water heat pumps with on/off control.*

An efficient method to increase efficiencies of heat pump is using simulation models to avoid time consuming experiments. The project ‘Dynamic modeling of heat pumps’ [Uhlmann and Bertsch, 2010] investigated the effect of on/off cycling on the Coefficient of Performance of heat pumps. The abstract is given in the final report (partly quoted from final report SFOE 2010): *…On/off cycling is the most commonly used mode of capacity control in heat pumps. Air to water and brine to water (geothermal) heat pumps were simulated using a physics based model. The dynamic model then has been validated using data from field and laboratory measurements. Subsequently several parametric studies were carried out in order to evaluate the effects of cycle time and the ratio of on-time on the performance of the system. It can be shown, that on/off cycling leads to a reduction of the performance of air-source heat pumps. The performance penalty is in the area of 2-5% for very short cycle times of the heat pump system. Running the water pump of the heat sink for a couple of minutes can reduce these losses. Furthermore, the performance losses are insignificant if the heat pump is run for 15 minutes or longer at a time. Geothermal heat pumps on the other hand profit from short cycle times, since the borehole can regenerate during the off-time of the heat pump. Performance improvements in the area of 5% are possible in case of an intelligent control of the cycle time.*

The production of DHW (domestic hot water) is still a matter of discussion and is of increasing importance in low-energy buildings. The project ‘Investigation of circulation losses in domestic hot water heat pump systems’ [Bertsch, 2010] has recently started. The project description is quoted from the abstract in the annual report 2010: *Aim of this study is the investigation of circulation losses in multiple-family dwellings with central domestic hot-water heating. Domestic hot water circulation is mainly used in multiple-family dwellings, hotels and hospitals in order to achieve the required water temperature at the water plug. This minimum water temperature is necessary in order to achieve an effective protection against the Legionella disease. Lately, often heat pumps with stratified heat storage tanks have been used in order to heat and store domestic hot water. The efficiency of these systems reacts heavily on mixing the hot water in the heat storage due to circulation of the domestic hot water. The same problem can be experienced with condensing boilers, although not as severe. In order to prohibit the mixing of circulating water with the hot water in the heat storage, nowadays electric trace heating systems are used which severely increase the electrical power consumption for domestic hot water heating. The main aim of this study is to investigate the heat losses due to circulation and to propose and assess alternative concepts of compensating or reducing the heat losses. Possible options are the use of several heat storage tanks or the use of a small heat pump just to compensate the circulation heat losses. Several alternative ways should be investigated with respect to cost, feasibility and energy consumption using simulation and field measurements. The electric power company EKZ owns more than 300 heat pump systems that are equipped with an online monitoring system. These heat pump installations can be used in order to evaluate existing and new approaches. Practical and cost-effective directives for planners should result at the end of this project.* This project will hopefully be continued in 2012.

Heat pumps are used for heating purposes but due to elevated summer temperatures and modern architecture, also cooling is required. Cooling and heating should be delivered by one single and optimized system. The project 'Heating and cooling with heat pumps in Swiss residential buildings' [Dott et al. 2010] is presented in this proceedings and attempted to find the most effective heat pumps for heating and cooling. The original project which was supported by Swiss Federal Office of Energy was the project 'SEK – Standardlösungen zum energieeffizienten Heizen und Kühlen mit Wärmepumpen' [Dott et al. 2010, SFOE] and the results are summarized in the abstract of the final report (quotation): *The SEK project intends to point out how to increase the summer thermal comfort in residential buildings with heat pumps in an energy-efficient way. An advantage is that heat pumps can, besides space heating and domestic hot water, provide space cooling too. Increased heat loads and increasing thermal comfort demands in summer can cause a cooling demand even in residential buildings. However, due to focussing on energy efficiency the priority still is an effective reduction of heat loads with good thermal insulation and effective shading. In a theoretical comparison, three heat pump concepts were analyzed and evaluated including a multi split heat pump air-conditioner (air/air unit with variable refrigerant flow (VRF)), an air/water- and a brine/water heat pump system. The geothermal system reaches the highest efficiency with a generator seasonal performance factor over all modes of 4.7, for heating with 4.4, for cooling with 12.9 and for domestic hot water generation with 3.5. Only a small additional investment is necessary to add a passive cooling to brine/water-heat pump. A VRF multi split air/air-conditioning unit achieved comparable high efficiency for active heat pump operation with 3.7 for heating and 4.1 for cooling operation. But with convectors as heat supply system in the room, special attention has to be paid to draft and noise phenomena. All systems achieve a good thermal comfort. The solution with the highest efficiency, the ground source heat pump system with a passive cooling mode, has been evaluated in two field measurements. This system showed a high efficiency and suitability for daily use with a good thermal comfort for a low-energy house with an overall seasonal performance of 3.7 as well as for a low-energy apartment building with an overall seasonal performance of 3.9. Two models to calculate the influence of the passive space cooling on the space heating and domestic hot water generation with ground coupled heat pumps achieve low inaccuracies for the borehole outlet temperature in periods of intense space cooling usage with an accuracy of better than 0.4 K and over the entire cooling period better than 0.2 K. Model 2 – short time adiabatic heat storage – shows even with a restricted considered heat storage in the ground only for one day and the disregard of seasonal storage effects a good consistency with the detailed simulation for the application on single boreholes.*

3.2 Heat Pumps with Natural Working Fluids

Although the new refrigerants HFO-1234yf and HFO-1234ze are appearing in heat pump applications, the Swiss Federal Office of energy is still supporting projects with natural refrigerants. Some years ago, the combination of Ammonia and small heat pumps was investigated but Swiss industry wasn't likely to proceed on this concept. Nowadays, CO_2 is in the focus and several projects are showing interesting results.
The projects 'Oil-free turbo-compressor stage for large-scale (100 kW) CO_2 heat pumps' [Uhlenhaut et al., 2010 and Uhlenhaut et al., 2011] describes the development of an oil-free compressor for CO_2 for application in large scale heat pumps. The project development from beginning until end of 2010 is reported in the annual report 2010 (quotation from abstract): *This work describes the progress in developing a compressor for the natural working fluid* CO_2*, for application in large scale heat pumps. To obtain a reasonable product life time, the compressor is designed to be oil-free, which can more easily be achieved by building a turbo compressor due to the small lateral bearing loads. Further advantages of being oil-free are the resulting simplification of the system as well as potentially higher efficiencies of the heat exchangers. The resulting span between applied science and engineering requires a*

separate treatment of the components used to build the compressor. These partial technological challenges include amongst others the development of an electrical drive, which is hermetically built into the compressor, as well as numerical and experimental quantification of rotor dynamics. During the past year, significant progress could be achieved in both fields. As a result of this work, a first compressor is currently being built, which will be sufficiently equipped with sensors to verify the aerodynamic as well as the mechanical design.

A doubled positive effect can be reached by using pump-less CO_2 earth probes. The heat transporting fluid circulates by free convection and the condensation of the CO_2 enhances the heat transfer to the heat pump. If, in future, oil-free compressors could be used, the CO_2 could be the same refrigerant in the earth probe and in the heat pump and the heat resistance between earth probe and heat pump could be eliminated. The project 'CO_2-earth probes' [Grüniger and Wellig, 2009; Wellig and Grüniger, 2011] project examined the fluid dynamics and thermodynamics inside a CO_2 geothermal heat probe. The results are summarized in the abstract of the final report 2009 (partly quoted): …*The functionality of such a probe, which works like a thermosyphon, was analyzed by means of a simulation model in MATLAB. The model couples the behaviour inside the heat probe with the heat conduction in the earth. A parameter study revealed that the self-circulation character of such a probe leads to flattening of the vertical earth temperature profile near the probe and, hence, leads to more uniform heat removal along the probe. The circulation of CO_2 even goes on when the heat pump is off. This might be advantageous for the regeneration phase. The heat transfer resistance of the evaporating CO_2 film flowing down the probe wall is very small compared to the conduction resistance of the earth. Therefore, no difference has been found between the performances of a conventional heat pipe and a configuration where the liquid phase injection is distributed on different height stages along the probe. It is estimated that the seasonal performance factor of heat pumps can be improved by 15-25% with a CO_2 geothermal heat probe. The main advantage is that the heat transfer to the evaporator of the heat pump (condensation of CO_2 / evaporation of refrigerant) is much more efficient than in a conventional brine probe without phase change. Furthermore, no circulation pump is needed.* It has to be added the disadvantage of CO_2 geothermal heat probes: they cannot be used for cooling because in this case, the heat and mass transfer with free convectional flow is physically not possible.

Due to large pressure difference between evaporator and gas cooler, a significant cycle loss has to be accepted in CO_2 cycles in heat pump and in refrigeration applications. The project 'Use of expansion energy in CO_2 cycles' [Gerber, 2010] investigates a mechanical expansion machine which works as an expansion-compression unit with a two stage expander based on a free piston design. It was designed, machined and assembled at the Technical University of Dresden (Germany) and then integrated into the main refrigeration plant at the Cash&Carry market Prodega in Basel, Switzerland. Further information is given in the annual report 2010 (partly quoted): *...Future operation will give the possibility to adapt and optimize controls and allow measurement data to be collected in order to analyze the operation of the system and its performance. First measurements prove the transition of extracted expansion work into the compression process and thus improvement of the COP at certain conditions. Technical problems have partly been solved in terms of fluid flow, control strategy, dynamics and mechanics ...*More measurements will follow during 2011.

3.3 Large heat Pumps (non serial Heat Pumps)

Heat Pumps are often serial products which are manufactured in large quantities. Regarding energy transfer, large heat pumps with heat capacities of 100 kW up to several MW become more and more important. All these heat pumps are single engineered products and no serial production optimization could be done. The project 'Field measurements and analysis of large non-serial heat pumps – Phase 2' [Hubacher et al., 2010] examined the performance of 24 larger heat pumps with thermal capacity between 100 kW and 2.4 MW. Experience to date has shown that the seasonal performance factor (SPF) of large heat pump installations is significantly lower than in smaller installations. Detailed results are given in the final report 2010 (partly quoted): *...The major discovery is that the differentiator between small and large heat pump systems is not the heat capacity, but instead the number of connected buildings (complexity). One needs to differentiate between heat pump systems for a single building or for a building complex. Four factors make up this difference.*

- *The heat pump supplies the buildings via a local heating network. This network has heat losses and requires pump energy for the distribution*
- *When decentralised heat pump system is supplied from a common sink/source (Ground, surface or waste water) are used, the SPF is reduced due to the pump energy required*
- *When the domestic hot water is centrally produced then significant heat losses are to be found in the distribution network (only in summer operation)*
- *Large heat pump systems are normally multistage. If the support systems are not regulated then under partial load the SPF sinks dramatically*

The comparison shows that the average value of SPF for single buildings is 3.87 and for multiple buildings is 2.52 (local heat distribution network) and thus a difference of 1.35 (SPF). It is clear that the average operating system temperature for single building systems is lower than for multiple buildings. This however does not put the result of the analysis in question. A centralised system for domestic hot water is not energy efficient under summer operating conditions due to the heat lost within the distributions network (system). A further aim of phase 2 was to compile a price reference data bank to enable future large heat pump systems to be effectively classified for price vs. performance. Unfortunately, data was only available for 5 heat pump systems.

3.4 Development of Magnetic Heat Pumps

Several projects investigating magnetic heat pumps and refrigeration processes were supported by the Swiss Federal Office of Energy in recent years. In the beginning, magnetic heat pumps looked quite promising because they showed the possibility to overcome the discussions concerning working fluids. In the last project 'Magnetic heat pump with ground heat source – optimized prototype' [Egolf et al., 2010] the intention was to examine a prototype of a magnetic heat pump. Unfortunately, the research group could not decide on the magnetic materials and tried to constantly improve the design with new materials. The result of the project was quite interesting in terms of theory but the initial aim, realization of the prototype, was not reached. At the moment, Swiss Federal Office of Energy is observing the worldwide progress in the field of magnetic heat pumps but is not starting a new project in the near future.

3.5 Combined Systems Heat Pumps and Solar Energy

Some time ago, the combination of heat pumps and thermal solar additional heating systems partially entered the market. Some few plants in Switzerland were built but the planning of the combination solar / heat pump was technically difficult and needed a serious and time consuming engagement. Unfortunately, some plants worked completely unsatisfactorily. In the most extreme plant, the heat pump heated the brine in the solar panels during night and therefore 'heated' the sky. So also Switzerland appreciated it very much when a joint annex working program of the IEA Implementing Agreements SHC (Solar Heating and Cooling) and HPP (Heat Pumping Technologies) could be established. Switzerland supports two projects within the HPP annex 38.
The project 'SOFOWA – combination of solar thermal, PV and heat pumps' [Dott and Afjei, 2010 and Dott et al. 2011] investigates what an optimized combination between thermal solar

collectors, PV-panels and heat pump should look like. Details are given in the abstract of the annual report 2010 (partly quoted*): ...The project aims to identify promising combinations of heat pump and solar technology through simulation whereof one is to be verified in practical field test as well as to provide a guideline....For further investigations, two pre-studies contribute fundamentals; one on fully solar generated energy for a single family dwelling and the other on ecological and economic comparison of heat pump systems in combination with photovoltaic or solar thermal systems for hot water generation. The combination PV / heat pump results in the lowest total cost, but this mainly due to the fact that no long-term energy storage is included. The combination PV / solar thermal results in the highest degree of autonomous supplied energy since the heat is stored seasonally, but it also generates the highest total cost. The integration of electricity and heat production in PV / T collectors leads to the smallest area on the building envelope and comes with average performance and average degree of autonomous supplied energy. Due to the cost development of photovoltaic systems, at the present time solar thermal and photovoltaic systems that meet 50% coverage of the hot water energy with renewable energies are equally expensive and their ecological impact is nearly equivalent. Climate data from the station Basel-Binningen will be used for the simulation study in the project. For a comparison of the internationally developed systems the climate data for the locations of Helsinki, Strasbourg and Athens were defined to be used. Furthermore, a reference building with three energetic qualities has been defined according to Minergie-P, legal standard and an old building for retrofit...*

Another interesting project is based on a $28m^3$ vessel which was taken from a milk transportation lorry, integrated in a single family dwelling, filled with water and used as heat storage system. This project 'Improved integration of a 28 m^3 seasonal thermal storage in the heating and domestic hot water supply of a single family home with geothermal heat pump and flat plate solar collectors' [Kurmann et al., 2010 and Kurmann et al. 2011] models a pilot object. The single family home with $185m^2$ heated surface area was built in 2009. The heating system consists of solar panels ($40m^2$), a W/W heat pump (6.4kW) with a geothermal probe (150m) and two thermal water tanks. One of them was non-stratified ($28m^3$) and the other one was stratified ($1.65m^3$). The project progress is described in the annual report 2010 (partly quoted): *...In a first stage of this task, the building and its technical installations were examined. Additionally, a simulation of the annual heating energy consumption was established. Furthermore, the seasonal storage, the utility storage and the solar panels were simulated during several days with and without heating load and validated based on real measured data. The point balance after the first year of operation (without optimisations) shows that the calculated potential is far from being reached. For the calculated annual heating demand of 10'800 kWh [3] and the DHW demand of 3'400kWh [4], 3'730kWh of electricity were consumed, corresponding to a SPF of 3.8. Generally, after the drying phase of its concrete structure, the heating consumption of the building diminishes, and a higher SPF (with optimisations SPF > 8) can be expected. Simulations of the building are mainly realised by the use of CARNOT Blockset and the design of experiments for the optimisation of the control-system with ModeFrontier.* The system shall be optimized during 2011 and 2012.

3.6 Field Tests and Methods to Calculate COP's and SPF's

Although huge work was invested worldwide in the area of definitions of COP's and SPF's and although an international standard would be very welcome, the discussions are still going on. Also Switzerland is interested to be able to compare test rig results with field test results, also if different boundary conditions have been used in different investigations. The recalculation from one dataset into another dataset is not so easily done. To reach this aim, also Switzerland joined the IEA HPP Annex 39 'A common method for testing and rating of residential HP and AC annual/seasonal performance' and supports two projects.

One project, dealing with the efficiency of combined systems with heat pumps, started in January 2011 and no special report is available yet. The other project has to be recognized as being one part of a series with long tradition in field testing activities in Switzerland. The project 'Long-term behavior and performances of residential heat pumps in dwellings' [Rognon F. and Hubacher P., 2011] monitors 151 selected heat pump installations with a thermal capacity < 25 kW where 100 have an age of > 10 years. The project characterizes SPF, reliability and costs over the whole lifetime and compares the results from heat pumps installed in Switzerland with results in other countries. To be able to do that, also calculation methods of SPF have to be discussed and will be compared with field test results of different field test measurement campaigns from different countries.

4 OUTLOOK

The Swiss Federal Office of Energy constantly tries to improve the efficiency and reliability of heat pumps and refrigeration equipment. The main goal is to support research projects which are expected to produce results for practical application. On the technical side, the Carnot-efficiency should be brought to levels near 0.7 and the integration of the heat pump in the building has to be further improved in order to lower the heating temperature. All kinds of measures to increase the heat source temperature should be evaluated and auxiliary systems such as short or long-time heat or cold storage have to be investigated and included in the heating or HVAC system.
Research activities in the field of heat pumps are ongoing in Switzerland although the budget situation is slightly worse than in previous years. The research results of the projects are of good quality and several presentations of projects which have been supported by the Swiss Federal Office of Energy are presented during this conference.

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