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QS-WP/QP: CONTINUATION OF FIELD MONITORING OF HEAT PUMPS BY MEANS OF MEASUREMENTS, ANALYSIS OF LONG-TERM BEHAVIOUR AND CALCULATION OF EFFICIENCY FOR THE HEAT PUMP STATISTICS MODEL FOR THE PERIOD FROM 2008 TO 2011

Impressum

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Summary

The "Field measurements of small heat pumps" project has now been implemented consistently for 15 years. During this period more than 250 heat pumps have been studied and measured, and their technical status has been recorded. The measurements were directly recorded and documented by the owners of the heat pumps, who passed on the resulting data to us at regular intervals for evaluation. It is only thanks to this simple measurement procedure that it has been possible for us to collect and evaluate such a large volume of data in the course of the past 15 years.

The findings vary: from the point of view of efficiency, we would have expected a better result. While in the first few years up to 2000 we noted increases in efficiency, in the years thereafter there were no signs at all of a trend towards improved seasonal performance factor. But there are also some heat pumps that yielded good to very good results and met all the specified requirements.

Another analysis focused on annual operating hours. Here the degree of compliance with the criterion specified in the dimensioning guidelines of the Swiss Federal Office of Energy (SFOE) for the performance guarantee for household systems, and with SIA standard 384/6 for geothermal sensors, was examined. The operating hours of the studied heat pumps were as follows: air/water heat pumps, approximately 1'700 hours, and brine/water heat pumps, approximately 1'900 hours, i.e. in both cases close to the specified range of 2'000 to 2'300 hours per annum, with or without hot water production. In the case of brine/water heat pump systems it is essential that the figures regarding annual operating hours are accurate, otherwise concerns could arise relating to longer-term problems associated with cooled geothermal sensors.

The resulting analysis of faults produced a very positive picture. The average degree of availability is above 99.5 percent, which is extremely favourable in comparison with any other heat production system. This resulted in excellent performance figurers from the analyse of 61 heat pumps. For these small heat pumps the average servicing and maintenance costs are 21.60 Swiss francs p.a., and the average repair costs amount to 84.40 Swiss francs p.a. This results in an average outlay per heat pump of 106.00 Swiss francs p.a. On the basis of 1,000 operating hours, the costs for maintenance and repairs therefore amount to approximately 51.00 Swiss francs. This analysis of the 61 heat pumps is based on a total of 1.32 million operating hours.

From the findings obtained from this research it may be stated that the performance of small heat pumps is generally very good. The degree of efficiency is good, but there is still room for improvement, while the picture with respect to reliability and operating costs is very positive.

It is important to continue with this programme of field measurements of small heat pumps, since the studies need to be carried out during the next few years until the completion of the anticipated service life of these heat pumps (around 20 years). Confirmation still needs to be made that small heat pumps have a service life of 20 years or more without causing increasing problems and maintenance costs.

1 Objectives

The objectives of the project are based on the quality assurance strategy of the SFOE and FWS.[1] This project is being implemented in a niche that is characterised by a high level of importance. In order to secure additional confidence-building it is essential to collect and communicate data and findings at all levels concerning the long-term behaviour and servicing / maintenance costs of small heat pumps.

The necessity to carry out field studies in order to obtain significant and relevant findings that can be communicated for the purpose of confidence-building and to provide additional market information has also been acknowledged in other countries such as Germany and Austria, and more recently in England too. With the implementation of this project in Switzerland we are well in the lead, since no other project has recorded and analysed the results of up to 15 years of operation. The ongoing project is a follow-up to the field study that was initiated in 1995 within the scope of the FAWA project[2].

Thanks to our ongoing implementation of this project we are in the position to communicate the previously collected data and findings relating to ageing and availability in the form of long-term evaluations. Nowhere else in the world has a long-term study of this nature been carried out yielding such comprehensive results:

- Collection of data from the existing sample of 165 heat pumps.
- Addition of 10 new heat pumps each year for the purpose of determining the status of technology and making comparisons with older models.
- Data collection for the purpose of determining the annual working factor for inclusion in the overall energy statistics of the SFOE for the calculation of the effectively measured figures.
- Long-term monitoring of the ageing process: calculation of seasonal performance factor and comparison with previous results.
- System availability (analysis of faults): calculation and comparison of annual operating data with previous results.
- Recording of maintenance and repair costs for a statistically relevant sample of 61 heat pumps (from the overall sample of 165) for the purpose of obtaining key economic data. Until now there had been a lack of long-term findings that are of great value and are also sought after on the market.

2 Procedure and methodology

This project has been ongoing for 15 years, during which time a total of 250 heat pumps have been inspected and measured, and their status of technology has been recorded. In the course of the study, more than 40 percent of the heat pumps were eliminated for a variety of reasons. Each year, 10 new ones were added to the sample (Tables 1 to 3). In this way it was possible to identify any changes, including technological modifications or developments.

2.1 List of heat pumps in the study

Table 1: List of heat pumps added in 2008

No.	Short name	Segment	Bldg. type	Heat source	HW prep.	AWP	Beginning	Brand
1205	**SENDOR14**	New building	SFD	Outside air	yes	2.43	Okt 08	Alpha Innotec
1206	**STEHAU43**	New building	SFD	Geoth. sensor	yes	5.23	Nov 08	Weider
1207	**GOSFLO15**	New building	SFD	Geoth. sensor	yes	3.92	Nov 08	CTA
1208	**ZEIHOC20**	Renovation	SFD	Outside air	no	2.40	Dez 08	Six Madun
1209	**MÜHIMH00 ***	New building	SFD	Outside air	yes	2.88	Jan 09	Hoval
1210	**ABTMÜH06**	Renovation	SFD	Geoth. sensor	yes	3.79	Nov 08	ElcoTherm
1211	**RUSMUS11**	Renovation	SFD	Geoth. sensor	no	3.54	Nov 08	CTC-Giersch
1212	**HERBUR03**	New building	SFD	Outside air	no	3.33	Apr 09	Six Madun
1213	**INSBUR22**	New building	SFD	Geoth. sensor	yes	3.22	Okt 08	CTA
1214	**BRÜOBM00**	New building	SFD	Geoth. sensor	no	4.05	Feb 09	Waterkotte

[1] Swiss Association for the Promotion of Heat Pumps (FWS), Steinerstrasse 37, 3006 Bern - www.fws.ch

[2] FAWA field study of small heat pumps, an SFOE project - final report, 2004.

One heat pump (indicated by an asterisk) from the 2008 sample (Table 1) could not meet the specified requirements since the owner did not reliably record the measurement data. The other heat pumps continued to be actively processed. In the course of the past year we had personal contact (by e-mail or phone) with most of the owners who continue to record data. There were also one or two owners who did not want to continue recording data and thus had to be eliminated from the project.

Table 2: List of heat pumps added in 2009

No.	Short name	Segment	Bldg. type	Heat source	HW prep.	AWP	Beginning	Brand
1215	**WALLEI01**	Renovation	SFD	Outside air	no	3.30**	Feb 10	Hoval
1216	**ROSOBE08**	Renovation	SFD	Geoth. sensor	yes	3.56	Sep 09	Alpha Innotec
1217	**NIEHAM25**	Renovation	SFD	Outside air	yes	2.14	Nov 09	Vaillant
1218	**MURMÜH04**	Renovation	SFD	Outside air	yes	2.28	Okt 09	CTA
1219	**ETTBÜH28**	Renovation	SFD	Geoth. sensor	yes	4.37	Sep 09	Wieder
1220	**MUOGRO26**	New building	SFD	Outside air	yes	2.96	Dez 09	Siemens
1221	**OBEAMS09**	New building	SFD	Outside air	no	2.80	Dez 09	Oertli/Bartl
1222	**STGHÜT29**	New building	SFD	Outside air	yes	3.64	Feb 10	Viessmann
1223	**ERLALL11**	Renovation	SFD	Geoth. sensor	yes	4.49	Dez 09	Störi Mantel
1224	**BRUSAN02**	Renovation	SFD	Geoth. sensor	yes	3.83	Dez 09	Heliotherm

Table 3: List of heat pumps added in 2010

No.	Short name	Segment	Bldg. type	Heat source	HW prep.	AWP	Beginning	Brand
1225	**SARBAH58**	Renovation	SFD	Outside air	yes	1.83	Apr 10	Krüeger
1226	**WITBET17**	New building	SFD	Eau	yes	5.23	Jun 10	CTA
1227	**RONAU10**	Renovation	SFD	Eau	yes	4.62	Apr 10	CTA
1228	**GRÜBÖS35**	Renovation	SFD	Outside air	yes	Nombre de mesures insuffisant	Okt 10	Striegatherm
1229	**GRAAMA23**	Renovation	SFD	Geoth. sensor	no		Sep 10	Kibernetik
1230	**MATALT28**	Renovation	SFD	Geoth. sensor	yes		Dez 10	Weider
1231	**WILALT20**	Renovation	SFD	Geoth. sensor	yes		Jan 10	AlphaInotec
1232	**GÜMRÜT08**	Renovation	SFD	Geoth. sensor	yes		Jun 11	CTA
1233	**AAROBE13**	Renovation	SFD	Outside air	yes		Jan 11	Stiebel Eltron
1234	**THABUE09**	Renovation	SFD	Outside air	no		Dez 10	Elco

In some cases the seasonal performance factor (**) were projected to 1 year. It is therefore possible that some minor changes may still be noted.

Table 4: Overall sample of heat pumps available for analysis

1st year of operation	Total no. of heat pumps in operation	BW-HP		AW-HP	WW-HP	Hot water preparation HP	No. Used in renovated buildings	No. Of years in operation
		with brine	with water					
1995	12	8		4		7	12	15
1996	8	5		2	1	5	4	14
1997	13	4		7	2	10	6	13
1998	10	6		4		6		12
1999	12	9		3		7	6	11
2000	9	5		3	1	4	4	10
2001	20	11		9		8	6	9
2002	21	10		11		16	6	8
2003	25	17	1	7		13	12	7
2004	1	1				1	1	6
2005	4	3		1		4	3	5
2006								4
2007								3
2008	10	6		4		6	3	2
2009	10	4		6		8	6	1
2010	10	4	2	4		10	8	
Total	165	93	3	65	4	105	77	

Note: No new heat pumps were added in 2006 and 2007. The continuation of this field study was only discussed and re-addressed by Hubacher Engineering and the SFOE in the course of 2000.

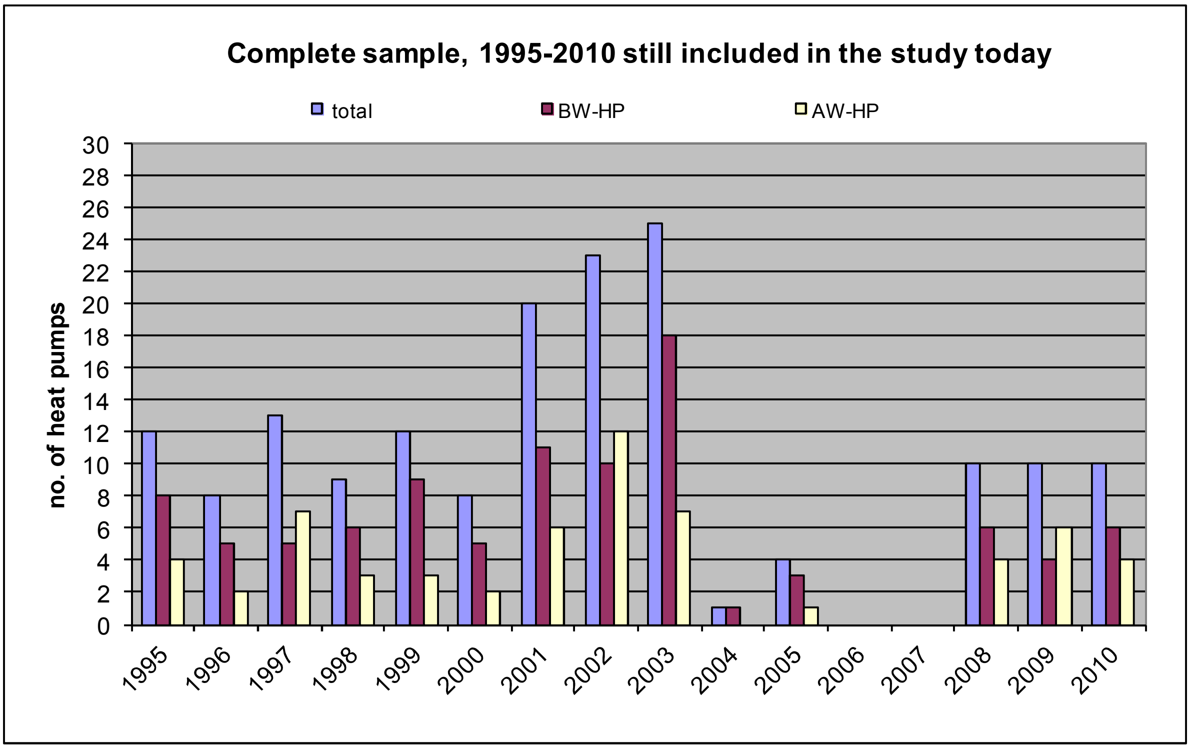

Figure 1: Sample that is still included in the study today

Water/water heat pumps are seldom used in small systems, and for this reason no such heat pumps with ground or surface water have been included in the sample since 2004 (Figure 1). Instead, for comparison purposes 4 systems with boreholes were included which are operated with water (without a brine component). To protect against freezing, deeper boreholes are required in order to reach down to higher source temperatures. Almost all these heat pumps have a considerably higher degree of efficiency.

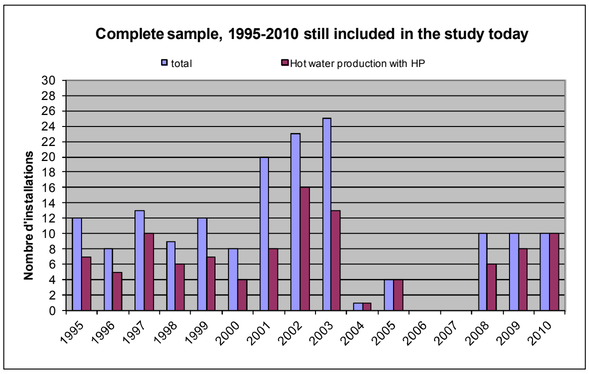

Figure 2: Heat pumps with hot water production

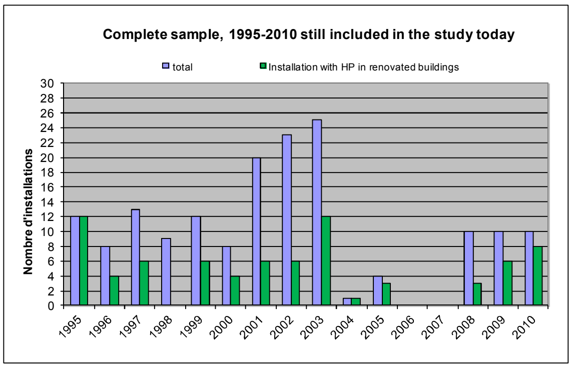

Figure 3: Heat pumps in renovated buildings

The evaluation of heat pumps that was carried out on the basis of the criteria already specified for the FAWA project is extremely complex. Attention was therefore paid to maintaining a balance between heat pumps with hot water production (Figure 2) and those used in new and renovated buildings (Figure 3). The various market participants (manufacturers, suppliers, installation companies) have a heavy workload and little spare time, and the interest in obtaining more comprehensive and better findings from installed systems has fallen sharply. But the quality of the heat pumps has not improved in the course of the past few years. In some cases, signs of wear and tear have been detected, which point to recurrences of earlier errors and omissions during the dimensioning and design stages.

2.2 Evaluation of heat pumps

In order to ensure that the calculations are statistically sound, a minimum number of heat pumps is required. The sample that is at our disposal today, including the 30 that were added to the project in 2008, 2009 and 2010 and those that have been eliminated, still comprises 165 heat pumps, divided into three categories: air/water, brine/water and water/water. The sample available for evaluating long-term studies relating to service and repairs comprises 61 heat pumps with ages ranging from 5 to more than 12 years.

The evaluation of the 10 systems that were added each year in 2008, 2009 and 2010 was carried out on the basis of the criteria originally defined for the FAWA project:

a. **Thermal output**: the thermal output of heat pumps should not exceed 20 kW_{th}, since it is this group that dominates the market.
b. **Heat sources**: an approximately equal number of air/water and brine/water heat pumps.
c. **Production type**: series production, i.e. no customised or special models.
d. **Operating mode**: monovalent - by way of exception, bivalent with measurable second heat production process.
e. **Location**: geographically different locations.
f. **Objects**: the heat pumps should be installed in new and renovated buildings.
g. **Hot water**: systems with hot water production via the heat pump should be represented in line with their proportion of real installed systems.
h. **Ownership**: only privately-owned heat pumps - no public buildings.
i. **Quality label**: where possible, heat pumps should be used that have qualified for the quality label issued by the Swiss Association for the Promotion of Heat Pumps (FWS).
j. **Measuring instruments**: heat pumps should preferably already be equipped with electricity and thermal meters, otherwise it must be possible to retrofit them with such devices at low cost.
k. **Hydraulic integration**: As a rule, heat pumps should be designed for recognised standard switching, i.e. no complex or customised hydraulic switching.

2.3 Data collection

We continued to receive and verify measurement data, and rectified any minor problems such as the failure of measurement instruments and the occurrence of system faults.

The measurement instruments, notably the thermal meters made by NeoVac which are based on the principle of ultrasound, were randomly dismantled and inspected a total of 3 times in the course of earlier projects within the past 15 years. All results were within the defined tolerance ranges, which means that the quality of the measurements also met the basic requirements on system analysis in this respect.

The input of measurement data into the electronic system files and the corresponding evaluation were carried out on the basis of the received datasets. The individual heat pumps are only analysed and evaluated after all results have been placed at our disposal.

- Organisation of measurement data and control of received documentation, as well as input of the existing measurement data into the electronic files including analysis and evaluation.
- On-site inspections in order to rectify any faults or failures of measurement instruments.
- Preparation and distribution of information to owners, including an evaluation of their own heat pumps.
- Evaluation of measurement data and analysis of the entire sample, including preparation of the most useful and informative graphs.

Thermal, electricity and operating time meters are installed in each heat pump for calculating the seasonal performance factor, which are read and reported to us at appropriate intervals (weekly to monthly) by the owner. For the calculation of seasonal performance factor, secondary functions associated with the heat pumps are also taken into account, as are any storage losses that may occur.

However, secondary appliances such as heating group pumps, etc., which do not form an integral part of heat pump operation, are excluded.

For the purpose of determining the maintenance and energy costs it is necessary to interview each owner in person, since experience has shown that the mailing of questionnaires does not yield the desired result. Questioning the owner in person is also necessary so that any uncertainties and contradictions can be clarified on site. Maintenance and repair costs are recorded on the basis of available receipts, reports, invoices, etc.

It is not always easy to receive all measurement data punctually in order to carry out the contractually agreed analyses, including presentation of findings (status report, support group meeting, annual report). Periodical contact is required in order to ensure that owners do not forget to take readings and thus to prevent the occurrence of any significant gaps in recorded data.

In order to further motivate owners and keep them on board, in 2010 a thank you letter was sent to them, together with a small gift. This action was greatly appreciated, especially since some owners have been supplying data more or less regularly for more than 10 years.

2.4 Heat pump statistics

Since the first field analyses were conducted and seasonal performance factor were calculated (FAWA and subsequent projects), in the statistics for all heat pumps the figures have been determined on the basis of these studies instead of previous average seasonal performance factor, i.e. the results are incorporated in the renewable energy segment of Switzerland's overall energy statistics.

3 Analysis and findings

In order to ensure that the results can be compared with the findings from the previous FAWA project, the same dimensions and criteria were applied. Thus in data analysis it is now only annual working factor 2 (Figure 4) that is determined and compared.

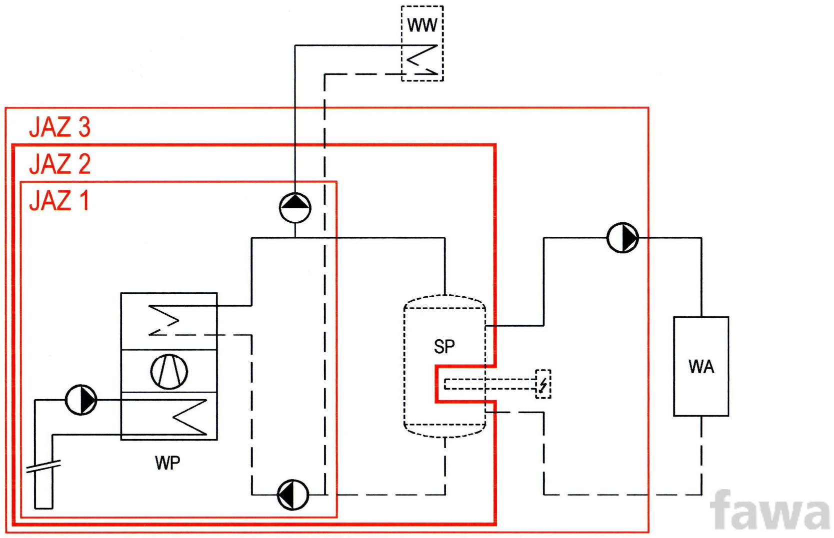

Figure 4: System limits for evaluation, SPF 1, 2 and 3.

Here, for evaluation and comparison purposes the limit for SPF 2 was applied, which takes any occurring storage losses into account. For systems without storage, the electricity consumption of the circulation pump on the output side in accordance with pressure loss via the condenser is taken into account.

The difference between standardised SPF2 (nSPF2) and SPF2 is that nSPF2 is climate standardised. This involves a relatively simple procedure in which the regression curve is assessed for the calculated working factors in heating mode at an outside temperature of 3° C. In this way, all heat pumps can be compared with one another, regardless of the height above sea level at which they are located. A detailed description of this procedure was included in the FAWA project report.

The data analysis over a period of more than 15 years has shown, however, that the current sample (90 percent of which is located in Switzerland's central lowlands), is relatively insensitive to this standardisation. A comparison between nSPF2 and SPF2 confirms that this is also the case in the most recent evaluations.

There are some heat pumps for which the datasets for the first year of operation are incomplete or could not be adopted for evaluation purposes due to other problems. In such cases, if evaluation was not possible for the first year of operation, the second year was taken as reference.

3.1 Analysis of seasonal performance factor

The seasonal performance factor of the 165 heat pumps evaluated in this sample are divided into two main groups (brine/water and air/water). Here, the years of operation and the progress during the year are adopted into the evaluation and depiction.

3.1.1 Comparison by years of operation

We are now entering an interesting phase in which we will be able to see whether our expectations in terms of longer-term ageing are correct. Since the past three years could not be evaluated fully because of the number of analysed heat pumps, in order to obtain a reliable evaluation it will be necessary to carry out a further-reaching field study at least over the next 3 years.

Changes versus the first year of operation can barely be ascertained until the 11th year of operation. Minor deviations are more likely to be attributable to the accuracy of calculations and/or measurements. The past 3 years should be viewed with caution, since to date only a few heat pumps have been studied that have been in operation for 12 years or longer. In addition there is the fact that, unlike more recent heat pumps, most of these older models have reciprocating compressors, for which we would expect more pronounced ageing as the result of greater wear and tear on the piston seals.

The limit of annual working factor nSPF2 encompasses not only the heat pump, but also the heat loss for storage facilities (if installed). The amount of purchased energy for the storage charging pump, or in the case of heat pumps without storage, the proportion of pump energy that is required for mass flow via the capacitor of the heat pump, and the overall energy requirement on the source side (energy required for pumps or ventilators) also have to be included in the energy balance for nSPF2.

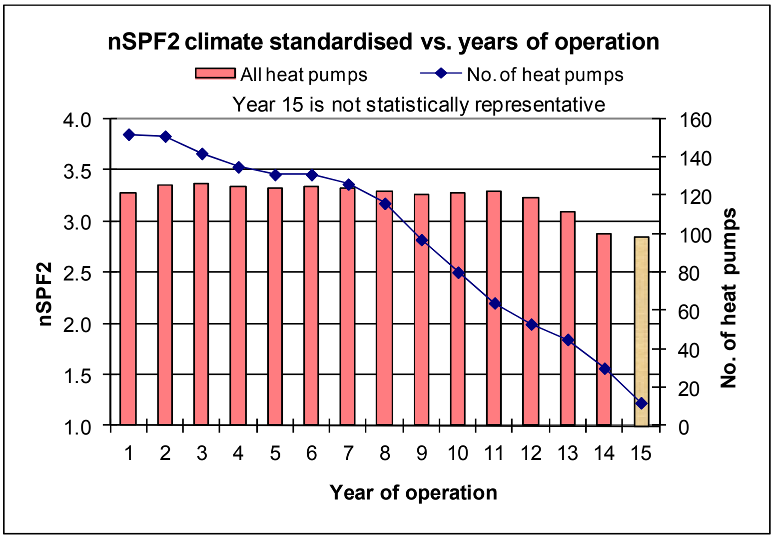

Figure 5: Time series of the development of absolute seasonal performance factor ($nSPF2_{abs}$) by number of years of operation

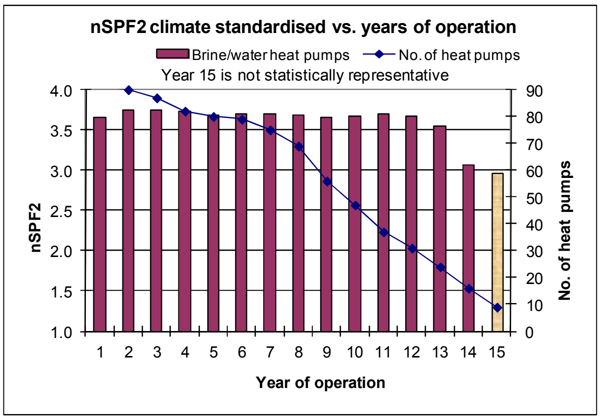

Figure 6: Time series for brine/water heat pumps

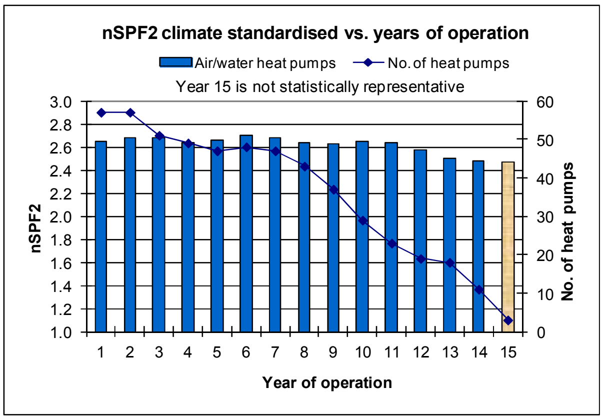

Figure 7: Time series for air/water heat pumps

As already noted at the beginning of this chapter, the standardisation of nSPF2 is a simple procedure. The graph with all systems with non-standardised SPF2 has been included here for comparison purposes.

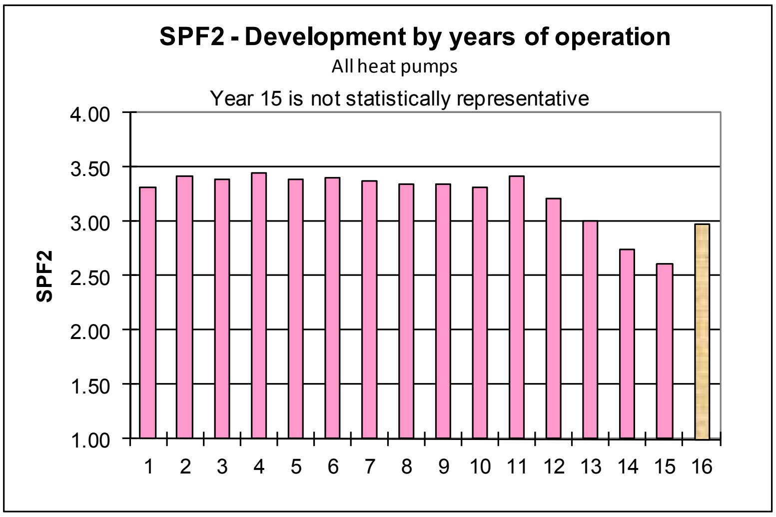

Figure 8: Time series of the development of absolute seasonal performance factor ($SPF2_{abs}$) by number of years of operation

The averages in the two compared graphs (Figures 5 and 8) are very similar. Over a 15-year period, the average nSPF2 is 3.23, compared with 3.25 for the non-standardised SPF2. As already noted, this is attributable to the fact that most of the heat pumps are located in Switzerland's central lowlands at an altitude of between 400 and 500 metres above sea level.

3.1.2 Comparison by calendar year

The development of nSPF2 by calendar year corresponds to the data and findings that have already been communicated for the previous FAWA analysis. After a period (from 1995 to 2000) during which better SPF figures were recorded, with effect from the 2000/2001 heating period the figures stagnated and have remained at around the same level until today. The reason for this is not immediately apparent, but since there have not been any major advances in technology in this sector and sales figures have constantly increased, it would seem that the industry faces other problems such as a shortage of specialised personnel, insufficient training, etc., which will have to be addressed.

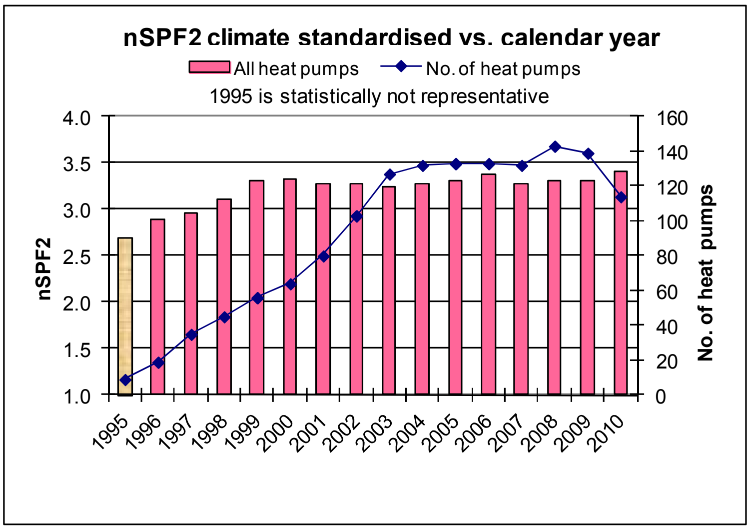

Figure 9: Time series of the development of absolute seasonal performance factor ($nSPF2_{abs}$), adjusted for climate factors, by calendar year

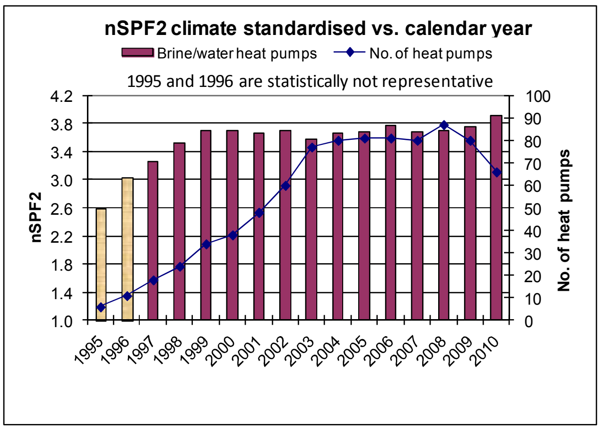

Figure 10: Time series for brine/water heat pumps

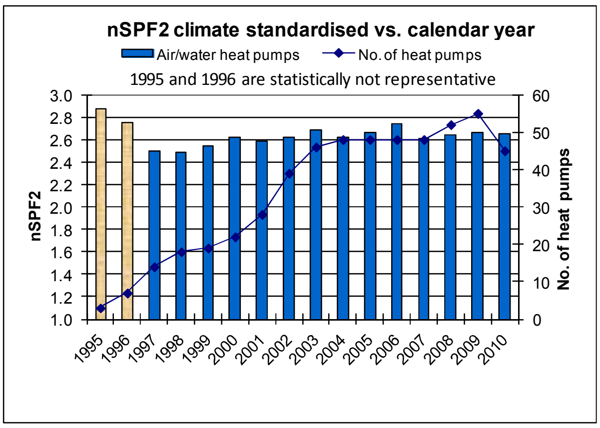

Figure 11: Time series for air/water heat pumps

In table 5 below, the 4 water/water heat pumps (WW) have been included, for both comparison and information purposes. Since there are only 4, the figures cannot be regarded as representative, but they are probably accurate since in many small water/water heat pumps the heat source is not very efficient. This is attributable to the open geodetic delivery head, and to the fact that these small groundwater systems are also frequently over-dimensioned. There are no groundwater pumps that are sufficiently small.

Table 5: nSPF2 figures by operation year for each heat source

HS	Operation year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AW	nSPF2	2.60	2.67	2.69	2.66	2.68	2.73	2.67	2.65	2.61	2.62	2.67	2.63	2.47	2.56	2.59	3.25
	No.	49	48	46	45	44	45	41	35	26	21	16	16	12	5	1	1
BW	nSPF2	3.61	3.73	3.69	3.69	3.67	3.69	3.68	3.64	3.75	3.70	3.71	3.54	3.25	2.80	2.47	
	No.	85	86	80	78	79	77	71	54	46	36	30	22	17	11	6	
WW	nSPF2	3.56	3.71	3.74	3.63	3.53	3.48	3.51	3.37	3.50	3.21	2.89	2.94	2.95	2.50		
	No.	4	4	4	4	4	4	4	4	4	4	3	3	3	1		

The graphs by calendar year (Figure 9-11) illustrate the analysis by number of years of operation, since we can clearly see that the heat pumps dating from the early years (1995 to 1999) indicate increasing efficiency each year - a development that was also noted in the FAWA report.

3.2 Analysis of operating hours

Operating hours play a major role, especially with regard to brine/water heat pumps. Dimensioning criteria for heat source systems with boreholes are based on a specified maximum of 2'000 operating hours without hot water production, and 2'300 hours with hot water production. The general criteria for dimensioning heat pumps are cited in the SFOE brochure, "Performance Guarantee for Household Systems". For borehole systems, the criteria are also specified in SIA Standard 384/6 (2010).

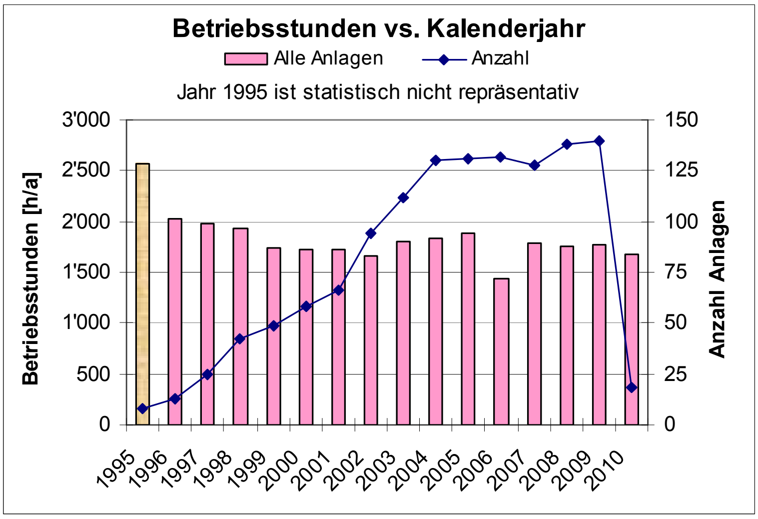

Figure 12: Time series of operating hours by calendar year

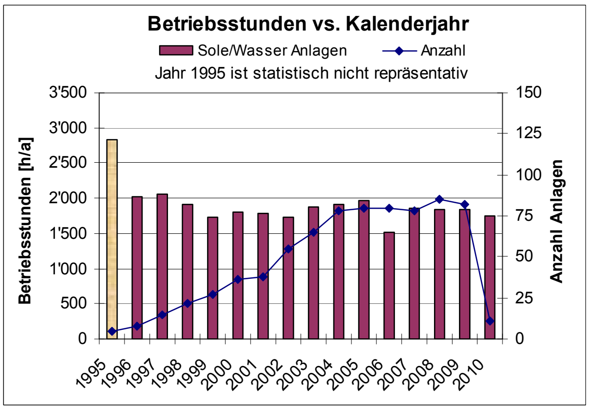

Figure 13: Time series for brine/water heat pumps

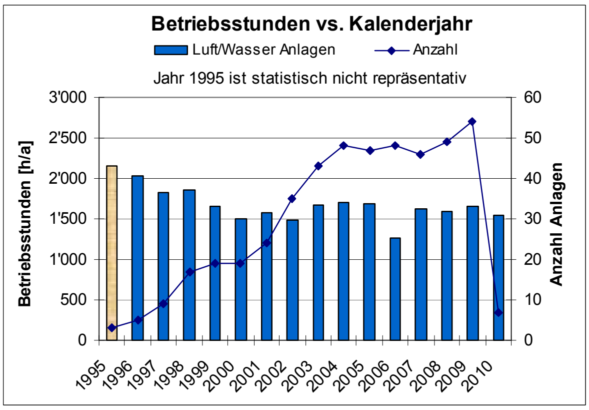

Figure 14: Time series for air/water heat pumps

Table 6: Operating hours, phase 1 by operating hours per annum for each type of heat source

Heat source	Calendar year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AW-HP outside air	Hours of Operation Phase 1	2154	2025	1835	1866	1664	1496	1580	1481	1669	1700	1694	1263	1631	1592	1653	1548
	No. of heat pumps	3	5	9	17	19	19	24	35	43	48	47	48	46	49	54	7
BW-HP Geoth. sen.	Hours of Operation Phase 1	2824	2018	2061	1918	1726	1810	1778	1728	1867	1885	1950	1501	1829	1813	1835	1748
	No. of heat pumps	5	8	15	22	27	36	38	55	65	79	81	81	79	86	83	12
WW-HP Water	Hours of Operation Phase 1			2190	2489	2394	2021	2163	2165	2216	2188	2182	1794	2323	2248	2065	
	No. of heat pumps			1	3	3	3	4	4	4	4	4	4	4	4	4	

We can clearly see from Figure 12 that the dimensioning criteria have been complied with. The figures are around 2'000 operating hours per annum. In the case of brine/water heat pumps (Figure 13) it is essential that the figures regarding annual operating hours are accurate, otherwise concerns could arise relating to longer-term problems associated with cooled boreholes.

For air/water heat pumps (Figure 14) the number of operating hours is not as important. From the analysed figures we can deduce that the dimensioning recommendations of the SFOE have been adhered to.

Table 7: Operating hours, phase 2 by operating hours per annum for each type of heat source

Heat source	Calendar year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AW HP Outside air	Hours of Operation Phase 2		67	256	898	472	515	511	565	855	1139	831	1018	392	639	
	No. of heat pumps		2	2	2	2	4	4	4	5	5	5	5	5	6	
BW HP Geoth. sen.	Hours of Operation Phase 2	702	266	47	329	847	1158	795	1009	947	1157	819	1079	1148	1637	
	No. of heat pumps	1	2	2	3	3	3	3	3	3	3	3	3	3	3	
WW HP Water	Hours of Operation Phase 2		369	763	868	703	1342	1370	1424	1440	1502	1088	1404	1373	1239	
	No. of heat pumps		1	1	1	1	2	2	2	2	2	2	2	2	2	

The evaluation of phase 2 is not particularly relevant, since the analysed sample only encompassed 5 air/water, 3 brine/water and 2 water/water heat pumps.

3.3 Analysis of heat production

The average heat production from heat pumps in the analysed sample was approximately 19'000 kWh p.a. (brine/water) and 15'100 kWh p.a. (air/water). With the average figure for brine/water heat pumps the excess level from 1995 had a slight influence (+ 3 percent).

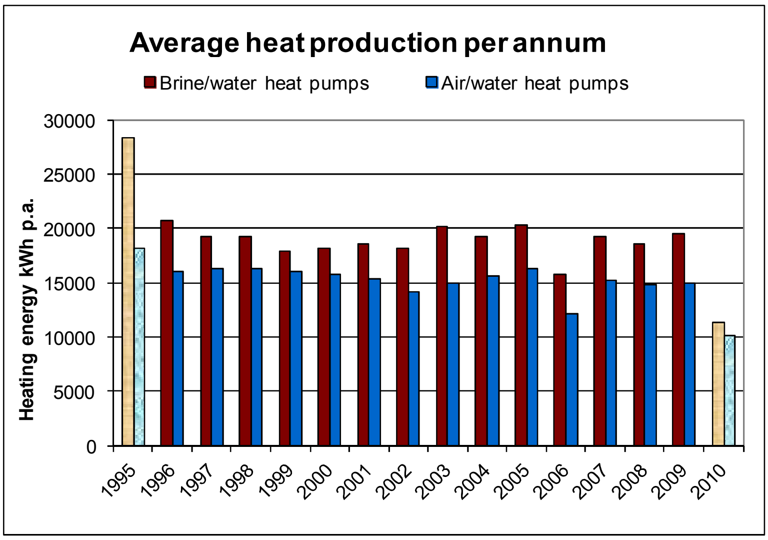

Figure 15: Time series of average heat production by calendar year

In 1995 it was only possible to analyse 5 heat pumps, and 1 of these had an extremely high proportion of heat production of > 43'000 kWh p.a.

The statistics for 2010 are not yet definitive, since some results are still missing

3.4 Analysis of electricity consumption

The average electricity production of heat pumps in the analysed sample (165 heat pumps) was approximately 6'000 kWh p.a. (brine/water) and approximately 5'600 kWh p.a. (air/water). The fact that the average electricity consumption of brine/water heat pumps is higher is attributable to the higher level of heat production (cf. Figure 15). The excess level of electricity consumption of brine/water heat pumps in 1995 influences the average figure by approximately + 6 percent.

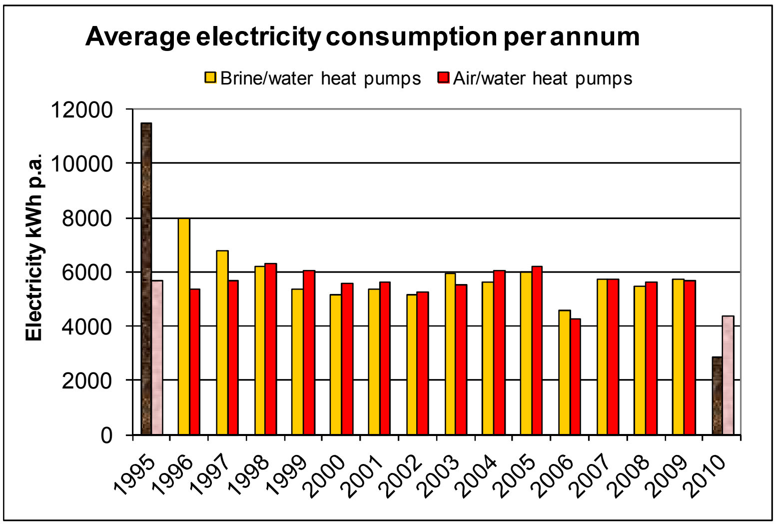

Figure 16: Time series of average electricity consumption by calendar year

1995 is not representative, since it was only possible to analyse 5 heat pumps. Furthermore, with one of these the level of electricity consumption was extremely high (> 17'000 kWh p.a.)

The statistics for 2010 are not yet definitive, since some results are still missing

3.5 Influence of refrigerant on efficiency

The influence of refrigerants on the efficiency of heat pumps was also studied. For comparison purposes, a number of systems with R22 were included in the analysis, as was the environment-friendly coolant, propane (R290).

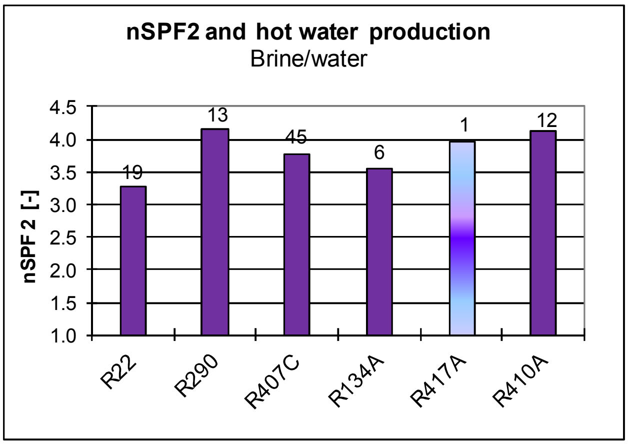

Figure 17: Influence of refrigerants on the efficiency of brine/water heat pumps

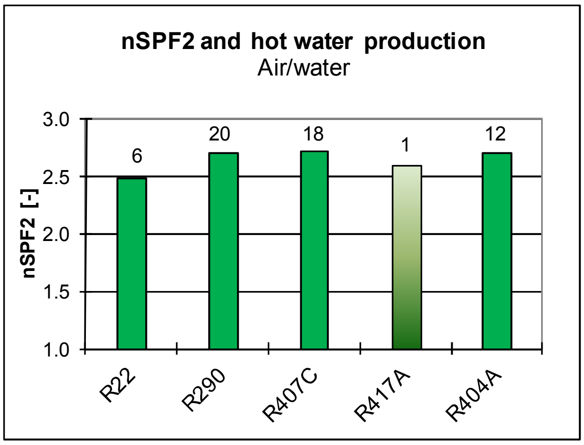

Figure 18: Influence of refrigerants on the efficiency of air/water heat pumps

We can see that, in both groups, the results with R22, which is no longer used and no longer permitted, are significantly more negative.

With brine/water heat pumps, the best results were achieved with R290 and R410A, as expected. It was only possible to study the influence of R417A on one heat pump. With air/water heat pumps there were no notable variations between the refrigerants, with the exception of R22.

This analysis clearly shows that, in heat pumps, efficiency is influenced to a considerably greater extent by various other factors, e.g. temperature lift (source and heating temperatures), dimensioning, hydraulic integration.

3.6 Influence of altitude above sea level (air/water heat pumps)

The question has often been asked concerning the height above sea level at which air/water heat pumps can be operated with sufficient efficiency. We were able to answer this question reasonably satisfactorily. In the sample, only around 10 air/water heat pumps are operated at an altitude exceeding 600 metres above sea level.

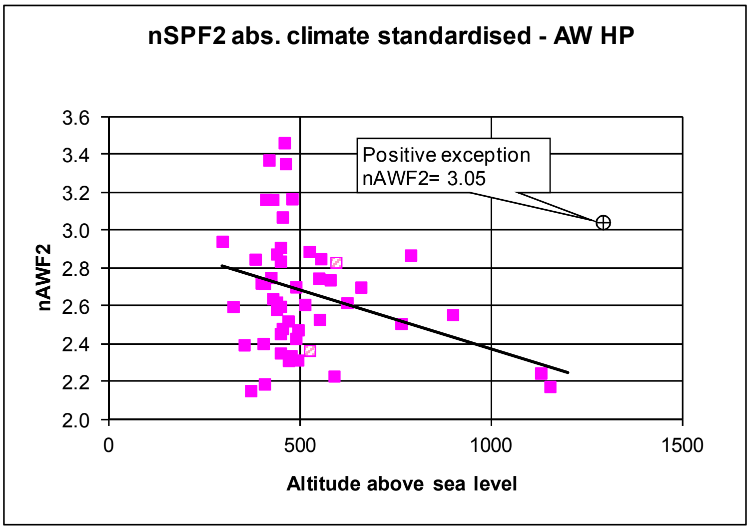

Figure 19: Altitude above sea level of air/water heat pumps

The fact that it would also be possible to achieve good results with heat pumps operated at higher altitudes despite the lower mean outside air temperature is demonstrated by the existence of a heat pump that is in operation at 1,200 metres above sea level and has a very good annual working factor of 3.05.

3.7 System availability (analysis of faults)

System availability of heat pumps has been analysed since the FAWA study, and the results have always been (and remain) very positive. The results for brine/water and air/water heat pumps also only differ very slightly.

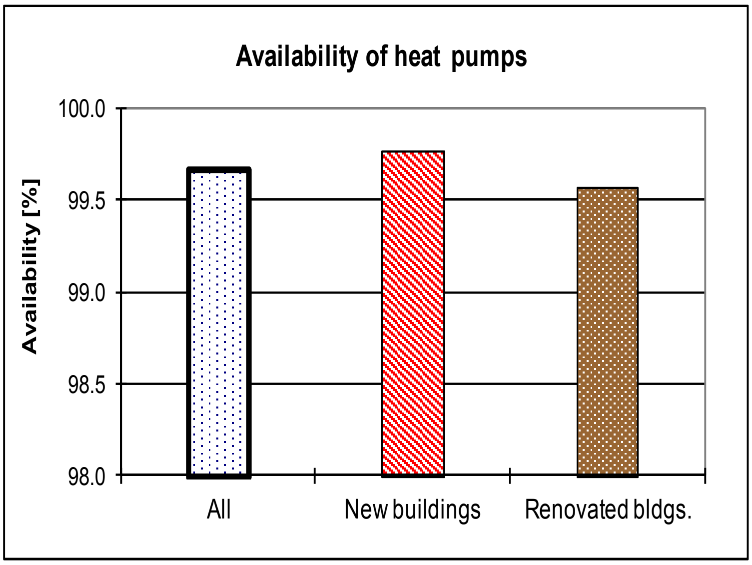

Figure 20: Degree of availability of all heat pumps, and of those in new and renovated buildings

The table below contains additional data concerning the various groups.

Table 8: System availability by group

Faut	All	New buildings	Renovated bldgs.	A/W	B/W	monovalent	bivalent	without storage	with storage
Run time [hrs]	2'257'079	1'139'108	1'117'971	759'978	1'339'321	2'122'269	128'034	868'400	1'388'679
Fauts [hrs]	7'416	2'655	4'761	5'308	1'705	6'966	450	3'962	3'454
Availability [-]	99.673	99.767	99.576	99.306	99.873	99.673	99.650	99.546	99.752

According to the definition of availability, a fault is deemed to occur and is duly recorded if the heat pump can no longer be operated because it is unable to produce any heat. It is interesting to note that in all groups the availability is well above 99 percent, including air/water heat pumps. The figures for renovated buildings are also very good (approximately 0.2 percent difference).

4 Maintenance and repairs

The costs of maintenance and repairs are recorded and evaluated in two separate categories as follows:

Maintenance	This category (which includes service) incorporates the costs of inspection and (if necessary) adjustment of the settings of a heat pump and its control mechanisms. It also encompasses the replacement of parts (including replenishment of refrigerant, replacement of filters, cleaning, etc.), if this is specified in advance as an integral part of the manufacturer's maintenance concept. Service agreements also belong in this category.
Repairs	This category encompasses the replacement of components of the heat pump that are no longer functioning correctly or have entirely ceased to function.

4.1 Maintenance of heat pumps

The overall operating costs of a heat pump are influenced not only by energy costs, but also by the costs of maintenance and repairs. Heat pumps are significantly more expensive than conventional oil or gas systems, and this means that, for owners, the maintenance costs are a major factor. Furthermore, the amount that has to be budgeted for maintenance is also an important factor for carrying out viability studies, which are of great importance in terms of assessment of heat pumps and can also be directly applied for image advertising.

These analyses were initiated in an earlier SFOE project[3] involving a sample of 50 heat pumps. There are now 61 in this sample, and we have integrated this analysis into the present study since it is also of great importance that verified statistics concerning costs are available and can be communicated accordingly.

For the purpose of determining the maintenance and energy costs, each owner has to be questioned in person. The use of questionnaires has proved to be unsuitable, and for this reason it is necessary to question owners by phone or on site in order to clarify any existing uncertainties and contradictions. Maintenance and repair costs are recorded on the basis of service reports, invoices, etc.

The composition of the analysed sample was as follows:
Heat sources (31 geothermal energy sensors, 3 earth-to-air heat exchangers, 1 energy pile, 22 air, 4 water), heating and hot water production, 46 , and 15 for heating purposes only.

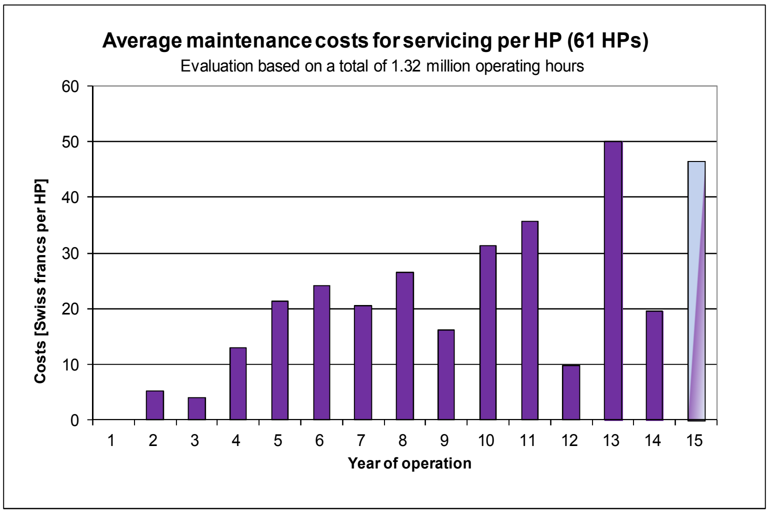

Figure 21: Average maintenance costs (service and maintenance) during the years of operation of heat pumps

As we can see, some costs are also incurred during the guarantee period (normally 2 years) - these concern costs that are not covered by warranty, e.g. resulting from operating errors

The average maintenance costs (service and maintenance) for heat pumps are 21.60 Swiss francs p.a., i.e. are extremely low. The fact that there are almost no costs in the first 2 years is attributable to the guarantee period and a relatively high degree of goodwill. The slightly increasing costs are attributable to more frequent servicing procedures for control purposes and for repairing minor faults.

[3] SFOE research project no. 100,454

4.2 Heat pump repairs

Repair costs vary according to type of fault. The years in which higher costs are incurred reflect major repairs such as compressor damage, heat exchanger failure, and in one case fire damage (in a propane system, caused by an electrical fault). The other costs reflect normal repairs, e.g. to the expansion valve, flow monitor, control mechanism, etc., as well as other external influences such as blockage of the hydraulic system, mixing valves and circulation pumps. The average level of all repair costs is 84.40 Swiss francs p.a. per heat pump. These low costs represent a good result and have a positive influence on the calculation of the operating costs for a heat pump.

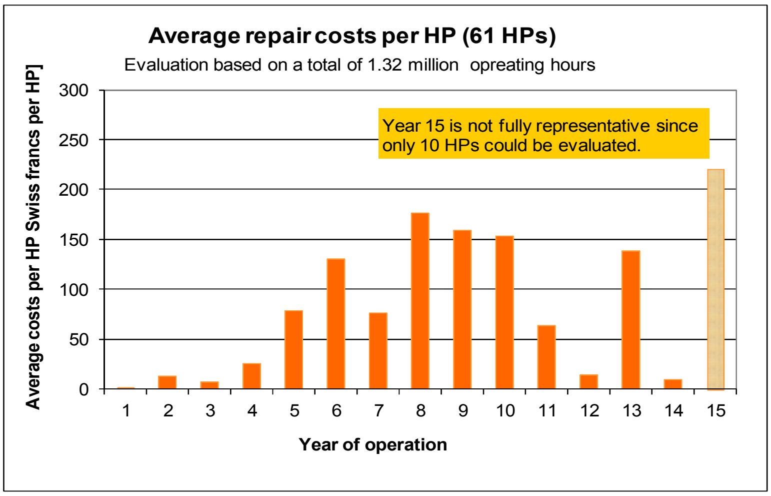

Figure 22: Average repair costs calculated throughout the years of operation of a total of 61 heat pumps

During the 15 analysed years of operation, the repair costs for the 61 heat pumps varied considerably. We were unable to ascertain that the frequency of repairs also increased in line with age, and these positive findings are a reflection of the high quality of small heat pumps.

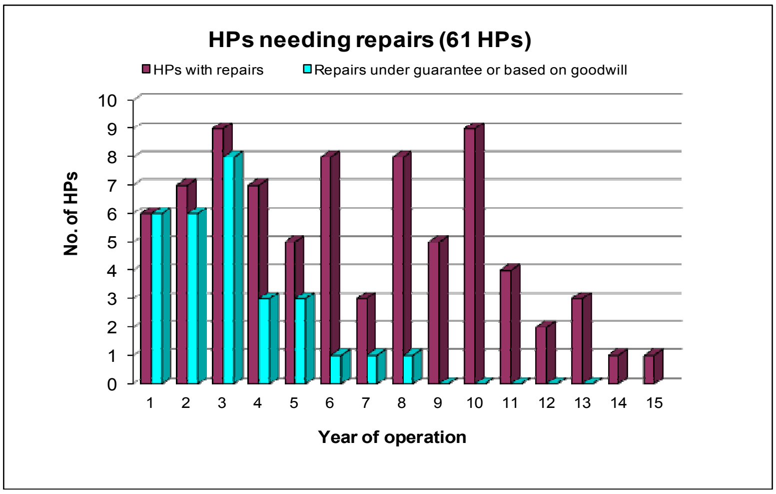

Figure 23: Number of heat pumps in need of repairs in relation to years of operation

Figure 23 shows the number of systems that required minor and major repairs during the corresponding number of years of operation. Here we can clearly see that, in the first 3 years, most of the repairs were carried out under guarantee or on the basis of goodwill.

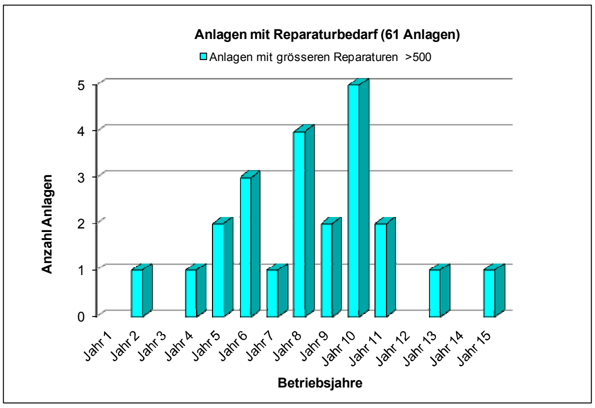

Figure 24: Heat pumps with repair costs > 500.00 Swiss francs

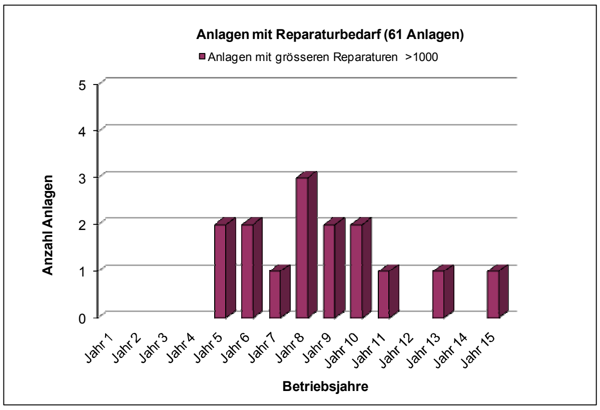

Figure 25: Heat pumps with repair costs > 1,000.00 Swiss francs

As we can see from Figures 24 and 25, only very few heat pumps required major repairs. Despite these positive figures, major repairs cannot be entirely ruled out, of course.

4.3 Total maintenance and repair costs

On average, the total costs for maintenance and repairs of the 61 heat pumps during the 15 analysed years of operation amount to 106.00 Swiss francs p.a. These are very low figures, which point to the high quality of small heat pumps. Nonetheless, this does not mean that no repairs were required. The analysed costs include 5 compressors, fire damage and icing damage on the evaporator.

Table 7 below shows details concerning the average maintenance costs. If we calculate these maintenance costs per operating hour, the figures are 1.065 cents per hour for maintenance and 4.045 cents per hour for repairs. This analysis of the 61 heat pumps is based on a total of 1.32 million operating hours.

Table 9: Maintenance costs for heat pumps

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average
No. Of HPs	33	61	61	61	61	61	60	58	55	52	51	42	36	21	10	
Maintenance	0.00	5.10	4.03	13.02	21.67	24.11	20.60	26.59	16.22	31.30	35.61	9.71	50.09	19.47	46.56	21.60
Repairs	0.02	13.56	7.40	26.00	78.26	130.76	76.00	176.51	159.10	153.43	63.17	13.73	138.76	9.52	220.40	84.40
Total costs	0.02	18.65	11.43	39.01	99.92	154.87	96.60	203.10	175.32	184.72	98.78	23.45	188.85	29.00	266.96	106.00

The final year of operation (year 15) is not yet representative, since in the sample only 10 systems with 15 years of operation could be evaluated.

5 Co-operation at the national level

Two support group meetings were held each year with Richard Phillips and Gerold Truniger from the SFOE, and Professor Max Ehrbar (as expert).

The contacts with the Swiss Association for the Promotion of Heat Pumps (FWS) are a favourable platform for conveniently passing on findings in a focussed manner, which flow directly into educational material.

The various topics are subsequently disseminated via all available FWS channels, as well as in the form of lectures and workgroup activities, and directly through training courses (certified FWS partners).

6 Co-operation at the international level

The head of the project was able to hold a presentation concerning this project at the International Heat Pumps Symposium at the TWK in Karlsruhe, Germany (Professor Reichelt) on 29 October 2009, and at the 2011 Vorarlberg Heat Pumps Conference.

No further official international contacts were scheduled. Contacts are maintained with the project groups in Germany and Austria, and reports and publications are compared with one another.

As the result of far-sighted planning within the SFOE, Switzerland had already approved the initial project concerning field studies on small heat pumps (FAWA study [1] and follow-up projects QS-WP/QP [2]) in 1995, in terms of experience and findings we are well in the lead.

7 Conclusions

The evaluations demonstrate a high level of continuity. There are very few inconsistencies and the quality of the results is high. In addition, the cost analyses for maintenance and repairs yield good results, and these can also additionally support the positive development of heat pump sales since the figures relating to maintenance costs (service and maintenance) are also very favourable.

It is very important to continue these studies on small heat pumps. The findings relating to efficiency and maintenance costs throughout the entire service life of these systems are of great interest, and heat pumps are currently in a stage of development that is especially noteworthy. It is only now that we are in a position to obtain reliable information concerning the entire service life of heat pumps which is of interest to the market and potential buyers.

Hubacher Engineering wishes to express its thanks to the Swiss Federal Office of Energy. Within the scope of this SFOE project the company has been able to carry out valuable studies for the benefit of the industry. These field studies call for comprehensive experience and a constant commitment which has been actively supported through the cooperation of owners who have recorded data on a periodical basis. We also wish to thank these owners, some of whom have been consistently providing data for the past 15 years.

8 References

[1] **FAWA-Schlussbericht BFE: Feldanalysen von Wärmepumpenanlagen FAWA, 1996 - 2003** Schlussbericht April 2004, Autoren: P. Hubacher, M. Erb, M. Ehrbar.

(SFOE final report on the field analyses of heat pumps (FAWA), 1996-2003. P. Hubacher, M. Erb and M. Ehrbar, April 2004.)

[2] **QS-WP/QP: Qualitätssicherung von Klein-Wärmepumpen mittels Norm- und Feldmessungen**, Teilprojekt Langzeitverhalten 2007-2008, Schlussbericht 2008, Autoren: P. Hubacher, Experte M. Ehrbar.

(QS-WP/QP: Quality assurance of small heat pumps by means of standardised and field measurements. Long-term behaviour sub-project, 2007-2008. P. Hubacher, M. Ehrbar. Final report, 2008.)

[3] **Verbesserung der Jahresarbeitszahl durch witterungsgeführten Ladekreis**; Schlussbericht 2008; Autoren P. Hubacher, M. Ehrbar.

(Improvement of seasonal performance factor through a climate-based charging cycle. P. Hubacher, M. Ehrbar. Final report, 2008.)

Engelburg, Spring 2012

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