HEAT PUMP HEATING SYSTEMS FOR LOW-ENERGY HOUSES IN SWITZERLAND FIELD MEASUREMENTS AND TECHNICAL HANDBOOK

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Low energy houses with an annual end energy heat demand below 160 MJ/m^{2}a (45 kWh/m^{2}a) have several special features, such as a tight building envelope, low supply temperatures for heat distribution, high solar gains and a high ratio for sanitary hot water. The objective of the project was to develop an efficient low-cost heat pump system, where building and heat generation system have been taken into consideration.

In field tests over 2 years it could be proven that a simple hydronic scheme works for low-temperature floor heating systems with supply temperatures up to 30°C very well. The heat pump can be connected directly to the circulation system without heat storage, mixing valves or thermostatic regulators.

A handbook containing the design fundamentals for heat pump heating of residential buildings conforming to the Swiss MINERGY standard has been completed. Main findings are

Two key values describe annual efficiency of heat production and complete system, i.e. heat production efficiency (SPF_{prod}) and system efficiency (SPF_{sys})
There are non-negligible differences between SPF_{prod} / SPF_{sys}, e.g. the
ground source heat pump for heating and tap water achieved SPF of 4.8/4.1 and
the air water heat pump for heating 3.0/2.7

Furthermore new control strategies have been tested, to cover the heat demand. Energy based models have been applied instead of using the return temperature for a two-point control. The new strategies worked well, even no information of a temperature sensor in a reference room has been used.

INTRODUCTION

Low-energy dwellings with an annual heat demand of less than 160 MJ/m^{2}a will be state of the art by the year 2010 according the energy development predicted by the Swiss Association of Engineers and Architects (SIA). The end energy demand for heating defined in the Swiss MINERGY standard already fulfills these requirements, even with a weighting factor of «2» for electricity. Thereby the heat demand of these dwellings is about one half of the existing ones. Hence hot water heating reaches a share of 30-50% of the total heat demand. Also large window areas with south direction have a stronger impact on building dynamics than in conventional dwellings. To achieve the objective of a high comfort in a cost efficient and environmentally acceptable manner, a project was carried out on contract to the Swiss Federal Office of Energy, where heat generation, distribution and dwelling have been treated as a complete system (Fig. 1). Furthermore, new requirements for heating systems are established, primarily for the heat production with heat pumps. Comparisons with other, conventional heating systems are carried out for the environmental impact and economical feasibility analysis.

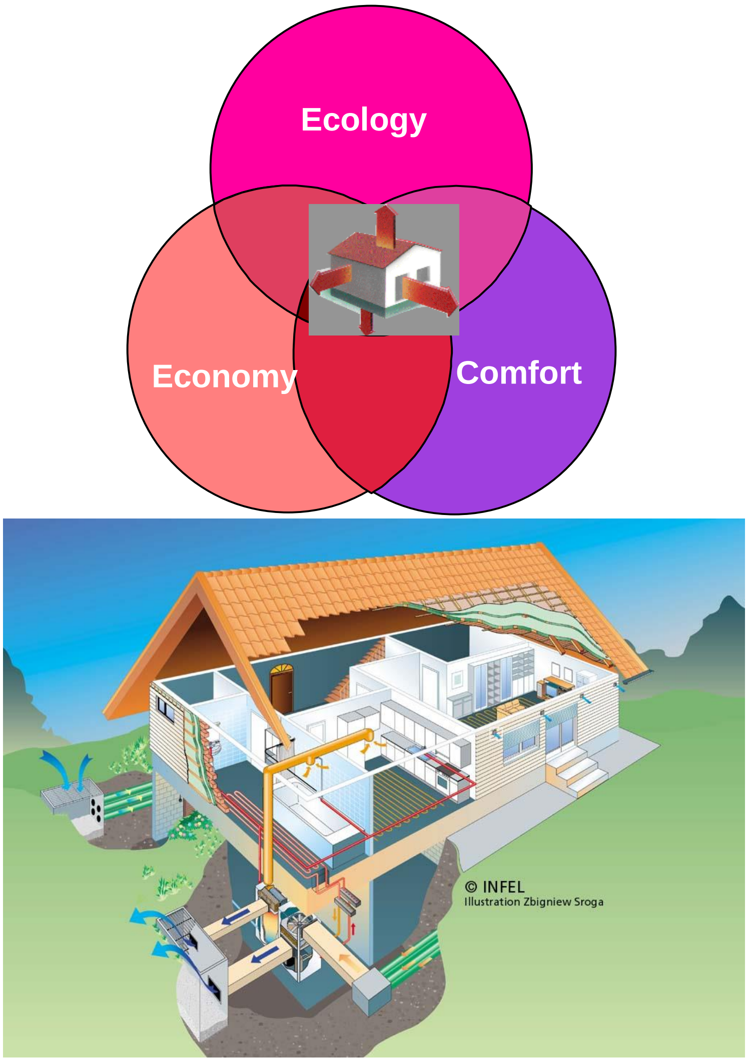

Fig. 1: Complete system view of «dwelling and heating system» (left), low-energy residential dwelling according Swiss Minergy standard (right)

The project «Low-Cost Low-Temperature Heating System» carried out under contract of the Swiss Federal Office of Energy is divided in the following four phases:

I. 1/96-12/96: Feasibility study, problem analysis and preparation of a pilot plant [NTH1 96]
II. 4/97-12/98 Ecological and economic comparison, system optimization and intelligent control [NTH2 98]
III. 7/98-3/00 Measurements on three pilot plants, fundamentals for a design handbook [NTH3 00]
IV. 9/98-7/00
   a) Technical Design handbook for low-energy and passive dwellings [NTH4a 00]
   b) Marketing handbook [NTH4b 00]

See also website under http://www.waermepumpe.ch/fe/projekte/nth

PILOT PLANTS

Three pilot plants have been selected in the project „Cost efficient Heat Pump Heating Systems for Low-Energy Houses in Switzerland“ to verify the simulation findings in the field. Two of them are presented in this paper. The following criteria had been applied for the selection:

- New built residential home achieving the design requirements of the Swiss MINERGY standard (end energy demand of 45kWh/m^{2}a for heating and tap water, where electricity is multiplied by «2»)
- The building is based upon a cost efficient prefabricated dwelling
- A low temperature distribution system is feasible

The objective of the project was the achievement of a high comfort in a cost efficient manner and a high system efficiency. The choice of prefabricated system dwellings for the pilot plants ensures a good dissemination and a broad market introduction.

Measurement results «Grafstal»

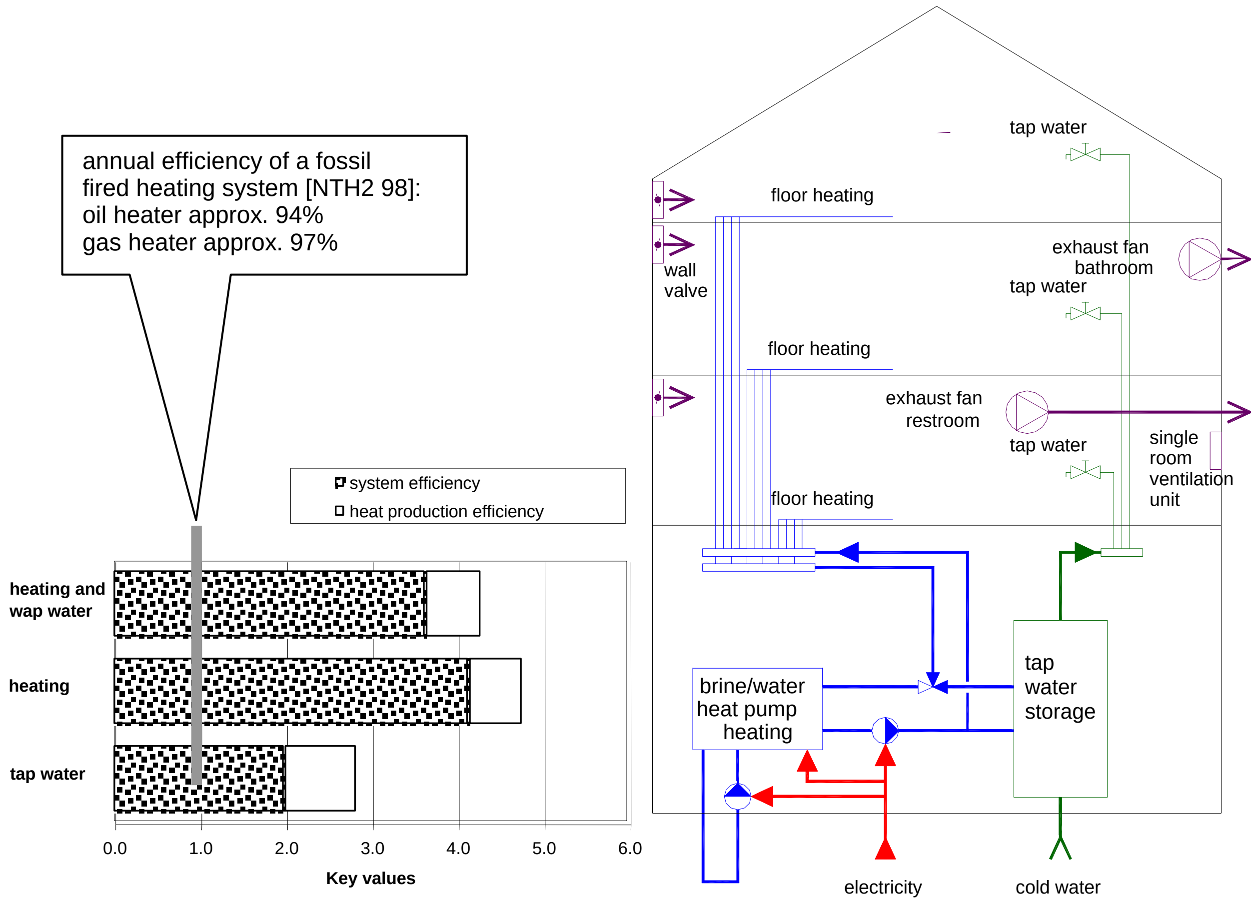

Fig. 2: Key values of the pilot plant «Grafstal» (left) and hydraulic circuit (right)

Energy Balance «Grafstal»

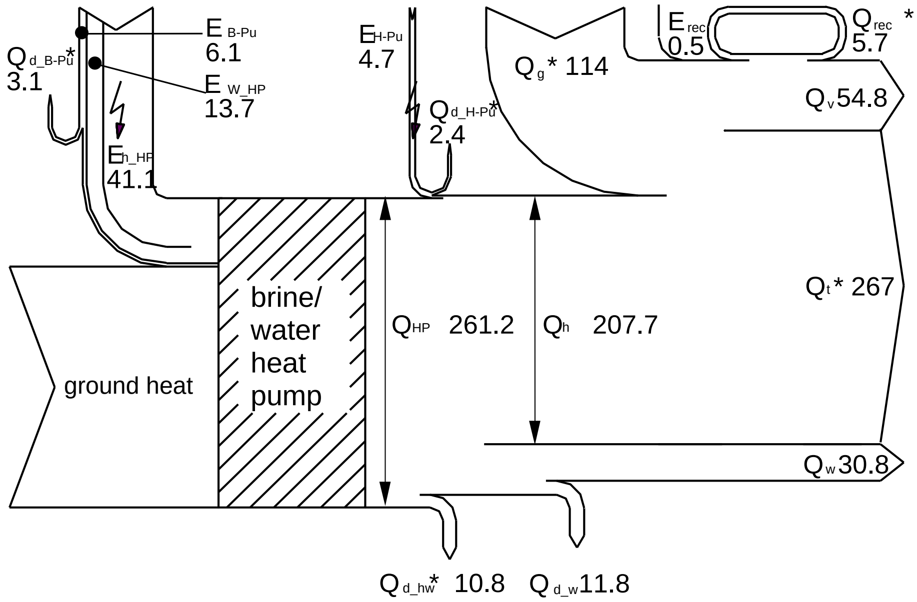

Fig. 3: Energy flow diagram „Grafstal“ for the period May 1999 until April 2000, values in MJ/m^{2}a, average inside room temperature 22.2°C, energy relevant area 174 m^2, *=calculated

Measurement results «Schötz»

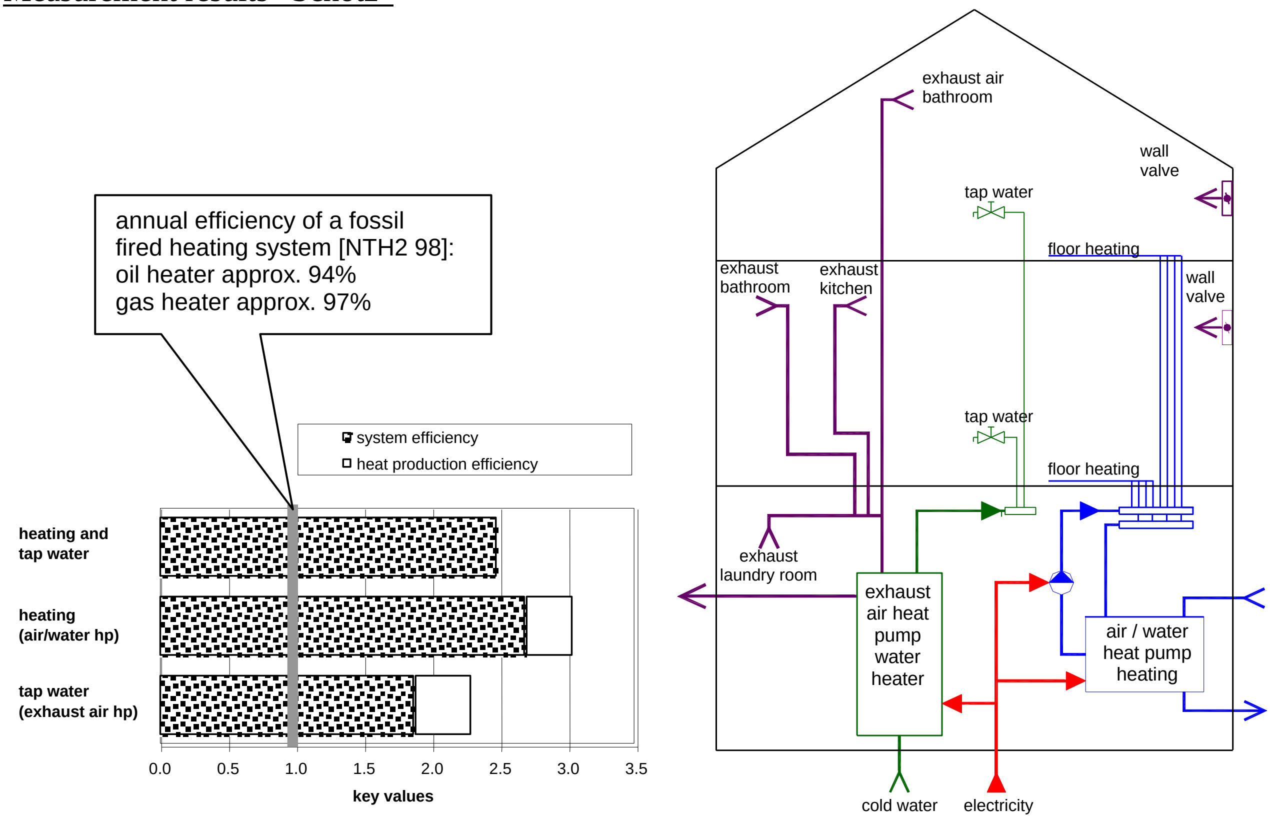

Fig. 4: Key values of the pilot plant «Schötz» (left) and hydraulic circuit (right)

Energy Balance «Schötz»

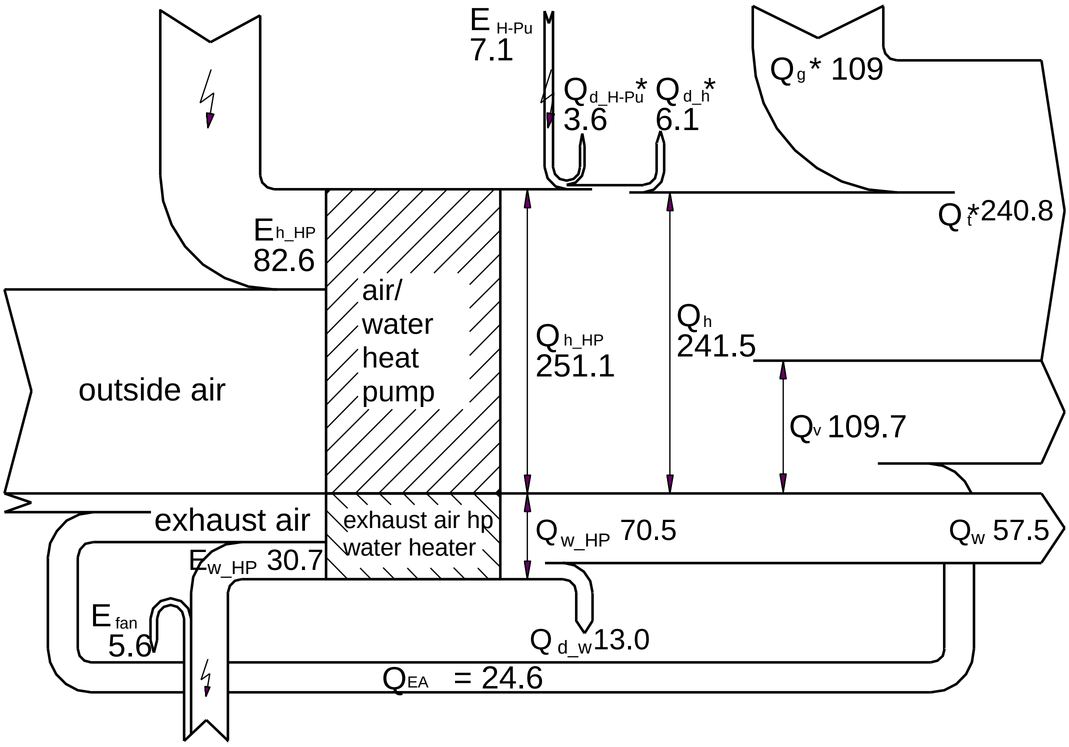

Fig. 5: Energy flow diagram „Schötz" for the period May 1999 until April 2000, values in MJ/m^{2}a, average inside room temperature 23.0°C, energy relevant area 155 m^2, *=calculated

TECHNICAL DESIGN HANDBOOK

Key values and system boundaries

In the design handbook the following system boundaries are being used.

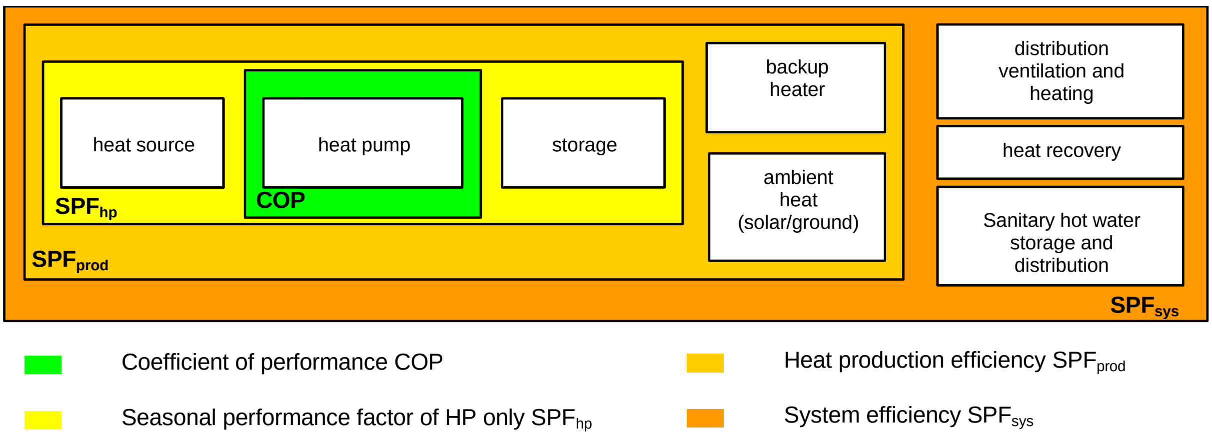

Fig. 6: System boundaries for COP and SPF (from [RAVEL 96], modified)

Key values are used to evaluate the efficiency of varous heating systems with heat pump and heat recovery. The most important are shown in the following paragraphs. To assess the complete heating system a new key value called system efficiency SPF_{sys} has been introduced.

Coefficient of Performance (COP)

The *COP* is intended to evaluate the efficiency of a heat pump at certain operation points.

$$COP = \frac{\dot{Q}_{HP,hw}}{P_{HP} + P_{HP,aux}},$$

(Eq. 1)

with the heating capacity $\dot{Q}_{HP,hw}$ for space and if applicable tap water heating, the power consumption of the compressor P_{HP} and the extra power $P_{HP,aux}$ to overcome the pressure drop in the evaporator and condenser, for defrosting and controls of the heat pump.

Heat Production Efficiency (SPF_{prod})

The heat production efficiency SPF_{prod} evaluates the efficiency of the heat production over a year. It corresponds to the annual efficiency of a fossil fired heater. Thus no circulating pumps for the heat distribution and no standby losses of the water heater are included.

$$SPF_{prod,hw} = \frac{Q_{HP,hw} - Q_S}{E_{HP} + E_{HP,aux}} \quad \text{(for monovalent heat pump heating systems)}$$

(Eq. 2)

with the heat produced by the heat pump over a year $Q_{HP,hw}$, the heat loss of the storage Q_S, the annual electricity consumption of the compressor E_{HP} and the electricity consumption of the auxiliaries required for heat production $E_{HP,aux}$ (circulating pumps evaporator and condensor, fan, defrost device, carter heater, control).

System Efficiency (SPF_{sys})

The system efficiency enables the energetic assessment of the complete system. It considers all energies required for heating, ventilation and tap water production. Standby losses of the storage and distribution losses are subtracted from the usable energy, presumed they are in the unheated area. The system efficiency SPF_{sys} describes, how efficiently the usable energy (e.g. space heat from the radiator, hot water from the faucet, etc.) has been produced.

$$SPF_{sys,hw} = \frac{Q_{use,hw}}{E_{total}} = \frac{Q_{HP,hw} + Q_{z,hw} + Q_{rec} - Q_S - Q_{d,h} - Q_{d,w} - Q_{d,v}}{E_{HP} + E_{HP,aux} + E_{z,h} + E_{z,w} + E_v}$$

(Eq. 3)

The system efficiency $SPF_{sys,hw}$ is ususally estimated as a single value for space heating and tap water heating by dividing the usable heat $Q_{use,hw}$ with the total electricity consumption E_{total}. It is calculated with the heat produced by the heat pump $Q_{HP,hw}$, the additional heat of the backup heaters (e.g. electric resistance heaters or a solar collector) for space heating and tap water $Q_{z,hw}$ and the heat recovered by the ventilation heat recovery Q_{rec} minus the storage losses Q_S, the distribution losses for heating $Q_{d,h}$ and the standby and distribution losses for tap water $Q_{d,w}$ and ventilation $Q_{d,v}$. It can also be estimated as $SPF_{sys,h}$ and $SPF_{sys,w}$, if the circuits are completely separated.

STANDARD HYDRAULIC CIRCUITS

After completion of the project „Cost efficient Heat Pump Heating Systems for Low-Energy Houses“ by the end of 2000 a new project called “standard hydraulic circuits for small-scale heat pump plant” (STASCH) has been launched by the beginning of 2001. In the first phase of the project small-scale heat pump plants were evaluated from both practicability and error tolerance [1] standpoints. The project was also carried out on contract to the Swiss Federal Office of Energy. The project benefited from experience gained in field trials (FAWA), publications on previous standard circuits (RAVEL, SWKI, FWS) and quality assurance projects. The investigations concerned circuit variants for a range of heat sources and hot water heating systems for new building (supply temperature 35-45°C) and renovation (supply temperature 60°C). In the second phase of the project, circuits that proved viable in the field and offer sizeable implementation potential will be simulated using MATLAB/SIMULINK and the CAR-NOT Blockset. They are then compared and evaluated, and their number finally minimized. Assessment criteria are: comfort, overall annual efficiency, investment required, annual costs and fault tolerance.

Standard Systems

From discussions held in workshops on the question, it was evident that the most frequent systems are those seven illustrated in Fig. 7.:

Standard system 1:	without storage tank, heating only
Standard system 2:	without storage tank, with heating and hot water
Standard system 3:	with series storage tank, heating only
Standard system 4:	with series storage tank, with heating and hot water
Standard system 5:	with parallel storage tank, heating only
Standard system 6:	with parallel storage tank, with heating and hot water
Standard system 7:	with combination storage tank and solar collectors, with heating and hot water

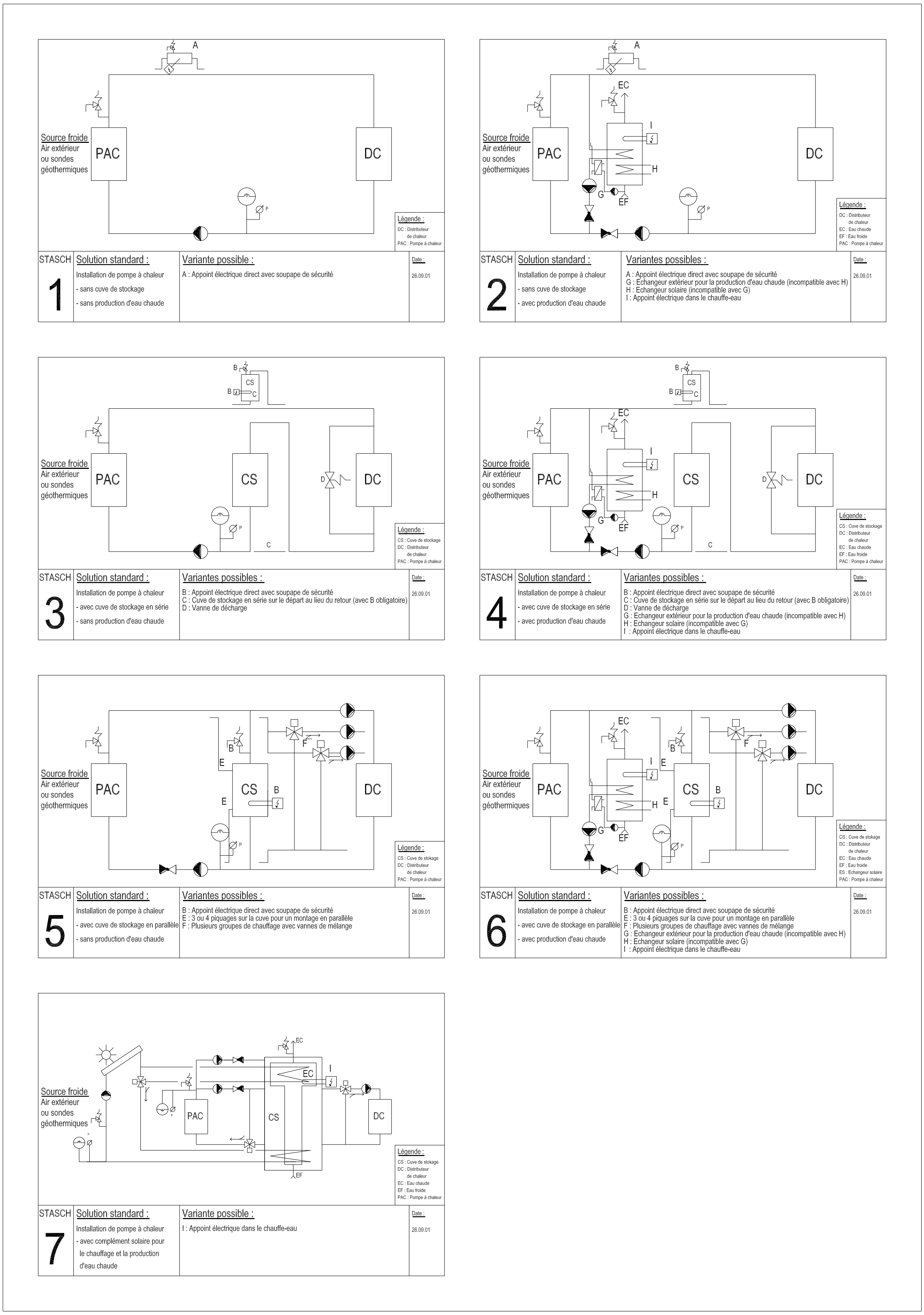

Fig. 7: Standard systems
Legend: PAC=Heat Pump; EC=Sanitary Hot Water; DC=Heat Emission System; CS=Buffer Storage

Two steps towards a viable standard system

The Swiss Heat Pump Test Center (WPZ) in Winterthur-Töss has established clarity with regard to practicable heat pump designs. The task of STASCH will be to establish similar clarity on the plant side.

This mainly involves provision of the following three planning tools:

1. Standard applications Classification of possible applications
2. Standard systems Hydraulic circuit + control system + layout
3. Selection matrix Which standard system is best suited to what standard application?

This results in a logical procedure in two steps as follows:

Step 1 Choice of standard system using the selection matrix

Step 2 Layout of the chosen standard system (each standard system having its own separate design data sheet)

It is recommended that the planner/plumber should adopt these two steps in designing each new heat pump installation. They will be further detailed in the following based on current experience. Substantial changes and additions must however be expected in the ultimate version.

Selection matrix

The selection matrix based on Fig. 7 is shown in Table 1.

Additional comments:

for parallel storage tank, the '😐' symbol is shown, since a series storage tank (having only a single pump) would be more suitable for standard system 7, no such comparison is possible, since this is the only system that permits the use of solar energy for heating and hot water (here, it may well be better to deploy solar energy for hot water alone)

Table 1: Selection matrix to combine a standard system with the corresponding application

Standard applications ↓				Standard systems →						
				Without heating tank		Heating tank in series (in the return)		Heating tank in parallel		Heating tank with integrated hot water tank
				without hot water storage tank	with hot water storage tank	without hot water storage tank	with hot water storage tank	without hot water storage tank	with hot water storage tank	
				1	**2**	**3**	**4**	**5**	**6**	**7**
O	K	N	**1**	☺	–	☹	–	☹	–	–
		T	**2**	⦸	–	☺	–	😐	–	–
	V	N	**3**	⦸	–	☺*	–	😐	–	–
		T	**4**	⦸	–	☺*	–	😐	–	–
	E	N	**5**	⦸	–	⦸	–	☺**	–	–
		T	**6**	⦸	–	⦸	–	☺**	–	–
W	K	N	**7**	–	☺	–	☹	–	☹	–
		T	**8**	–	⦸	–	☺	–	😐	–
	V	N	**9**	–	⦸	–	☺	–	😐	–
		T	**10**	–	⦸	–	☺	–	😐	–
	E	N	**11**	–	⦸	–	⦸	–	☺**	–
		T	**12**	–	⦸	–	⦸	–	☺**	–
S	K	N	**13**	–	–	–	–	–	–	☺
		T	**14**	–	–	–	–	–	–	☺
	V	N	**15**	–	–	–	–	–	–	☺
		T	**16**	–	–	–	–	–	–	☺
	E	N	**17**	–	–	–	–	–	–	☺
		T	**18**	–	–	–	–	–	–	☺

What is the hot water system?
O hot water *not* via heat pump
W hot water via heat pump (solar backup for hot water possible)
S hot water via heat pump with solar backup for heating and hot water
Is the flow rate essentially constant, and/or is hydraulic separation necessary, i.e. does the system have:
K a single controlled heating branch, percentage of thermostatic regulators < 25% (effectively constant flow rate)
V a single controlled heating branch, percentage of thermostatic regulators ≥ 25% (effectively variable flow rate)
E several controlled heating branches (irrespective of number of thermostatic regulators)
How high is the inertia of the radiator system?
N wet-laid floor heating system, with (a few) or without any additional radiators
T dry-laid floor heating system, OR wet laid floor heating system with a significant proportion of radiators or radiators only
Recommendations (based on current experience):
☺ system recommended
😐 system recommended under certain conditions
☹ system not recommended
⃠ system banned
– inappropriate combination
* version with spill valve
** version with mixing valve for several heating branches

CONCLUSIONS

Simulation work and measurements of three pilot plants resulted in a technical design handbook describing
a) fundamentals including key values and definitions for heat production and overall system efficiency,
b) findings of the field measurements with detailed energy flow diagrams yielding high seasonal performance factors of 4.8 for space heating and tap water (ground source) and 3.0 for heating with an air source heat pump and a
c) step by step design procedure for energetically efficient and economically feasible heat pump heating systems.
Furthermore standardized hydraulic circuits typically used in Switzerland are presented. A selection matrix combines the hydraulic circuit with the corresponding application.

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