

DOMESTIC HOT WATER HEATING USING HEAT PUMPS

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Abstract: Five years ago, recommendations for designing domestic hot water heating systems using heat pumps were published in the STASCH project: Standardschaltungen für Kleinwärmepumpenanlagen ("Standard circuit diagrams for small-scale heat pump plant"). In the project on "Domestic hot water heating using heat pumps" the effectiveness of these recommendations was studied. Furthermore, optimum hydraulic circuits and control procedures were developed based on measurements on a test installation in Rorschacherberg (Canton of St. Gall). Using the recommendations prepared in the project, it should in future be possible to design domestic water heating installations for detached houses, apartment houses, school buildings, etc. – i.e. installations of any size – using commercial heat pumps, heat exchangers and storage tanks.

Key Words: *heat pump, domestic hot water, hot water temperature, legionella pneumophila*

1 INTRODUCTION

In the past, heat pump installations were often built to cover room heating alone, whilst domestic hot water continued to be prepared via electric heating tank. Unfortunately, this arrangement is not to be recommended. In fact, it is almost always possible to prepare the domestic hot water via the heat pump itself. For this reason, five years ago recommendations for the design of domestic hot water heating systems with heat pumps were issued through the STASCH project: Standardschaltungen für Kleinwärmepumpenanlagen ("Standard circuit diagrams for small-scale heat pump plant", STASCH 1 2002) and: Empfehlungen zur Auslegung der Warmwasserbereitung mit Wärmepumpen ("Recommendations for the Design of Domestic hot water heating systems with heat pumps", STASCH 2 2002). In the present project: Warmwasserbereitung mit Wärmepumpe ("Domestic hot water heating using heat pumps", Mayer et al. 2007) the effectiveness of these recommendations was studied, and additional recommendations made. With these, it should in future be possible to design domestic water heating installations for detached houses, apartment houses, school buildings, etc. – i.e. installations of any size – using commercial heat pumps, heat exchangers and storage tanks. In doing so, it is important for the installations to function efficiently and fault-free both in winter and in summer.



Figure 1: central heating room: heating tank (at left), hot water tank (at back) manufactured by CIPAG, two heat pumps (at right) manufactured by SATAG



Figure 2: hot water tank: the manhole cover gives an inkling of the size of the heat exchanger that was mounted later



Figure 3: hot water tank: external heat exchanger (at left) and internal heat exchanger (at right), that is only mounted provisionally

2 TEST INSTALLATION

For the purpose of the study, an installation in Rorschacherberg (Canton of St. Gall) was again chosen as the test installation (Fig. 1 to Fig. 3). The principal data of the installation are as follows:

- 2 heat pumps of type SATAG BWH113.1 with heat wells as ambient heat source
- working medium R407C, scroll compressor with intermediate steam injection
- maximum condenser temperature 65°C at 10 K temperature difference over the condenser
- heating capacity 2 x 16-18 kW
- electric hot-water tank CIPAG 1200 l.

3 RESULTS

Altogether, 3 hydraulic circuits were studied, or a total of 6 variants of these. The operating conditions and results of the studies on the above are summarized in Fig. 4. The specific heat exchange area required for dimensioning the heat exchanger is given in each case, [in m²/kW], and the temperature differences of the working fluid between the primary and secondary sides required for designing the flow rates quoted. The number given in the heat pump frame symbol indicates the seasonal performance factor over the entire charging phase (incl. ambient heat source pump and charging pump). The storage temperatures refer to conditions at the end of the charging cycle. Variant 6 (with storage temperature control) did not exist in reality, but was derived based on the results of variants 4 and 5.

4 RECOMMENDATIONS

4.1 Hot water temperatures

The principal measure taken to combat *legionella pneumophila*s (hereinafter called *legionellas*) is adherence to specific hot water temperatures. The recommendations of the Federal Office of Public Health contained in "Legionellen und Legionellose – Modul 12 Sanitäre Installationen" (*legionella pneumophila*s and legionellosis – Module 12 Sanitary Installations, FOPH 2006) may be summarized in two main requirements:

1. *It is recommended to raise the temperature of the domestic hot water daily to 60°C for a duration of one hour.*
2. *It should be ensured in practice that the hot water temperature at the point of use does not drop below 50°C.*

Requirement 1 can only be fulfilled using storage temperature control (variant 6). In the absence of storage temperature control (variants 1-5), auxiliary electrical heating is always required.

To fulfil requirement 2, both the hot water temperature and the hot water recirculation system are critical. If, for example, a temperature loss of 5 K is assumed, neither the variant with internal heat exchanger (variant 1) nor that with the greatest temperature difference over the heat exchanger (variant 4) would not be able to fulfil requirement 2.

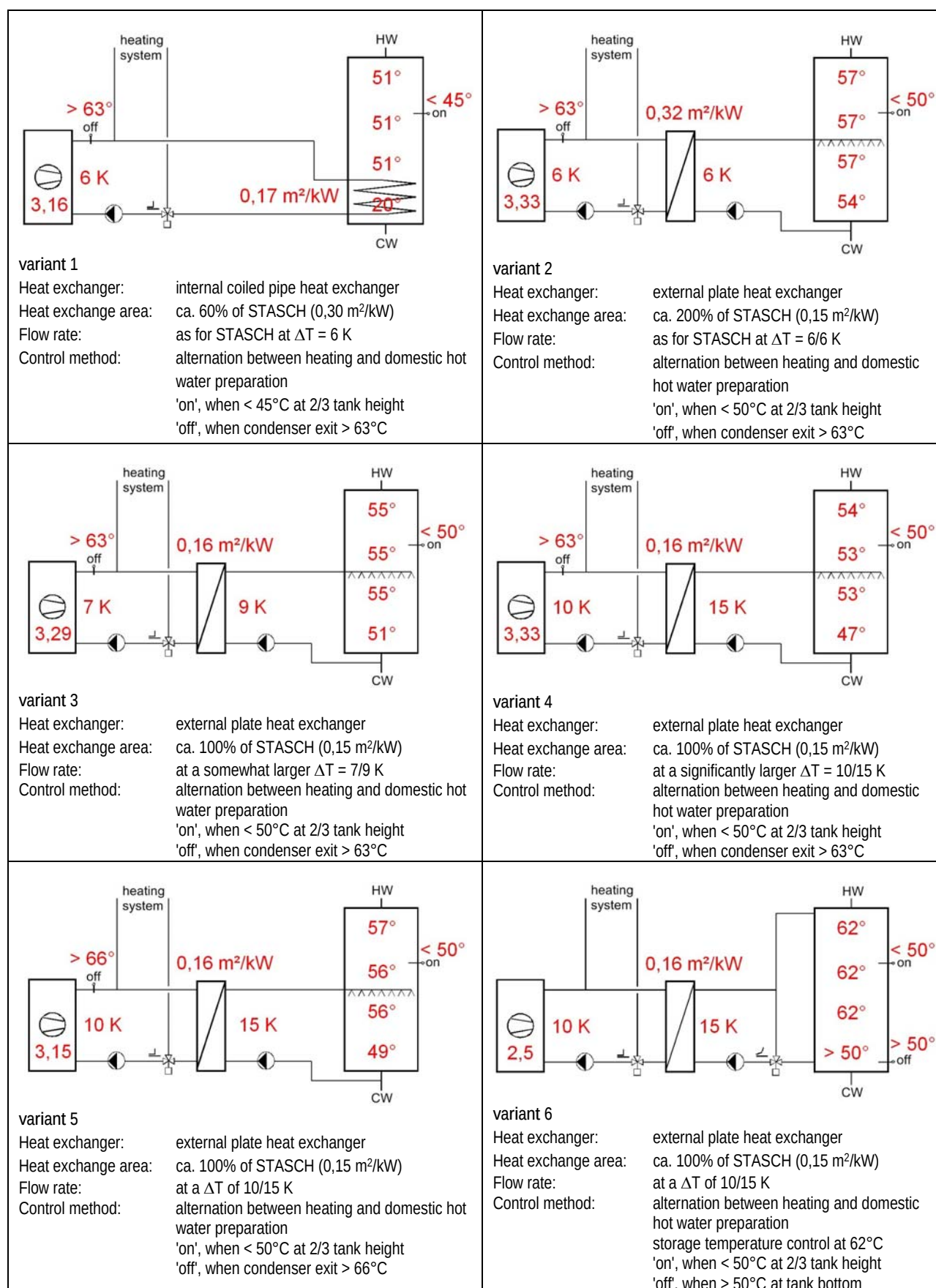


Figure 4: Operating conditions and results of the 6 variants studied
(also see the remarks in paragraph 3 of "Results")

4.2 Positioning of the storage tank connections and sensors

The configuration with the 'on' sensor at 2/3 of the tank height and a spray pipe for stratified charging at 1/2 of the tank height has proved to be satisfactory.

It is recommended to locate the secondary heat exchanger intake connection for variants 2-5 directly at the mains water connection, thus achieving the lowest possible condensation temperature, or in other words, the highest possible seasonal performance factor. The storage controller (variant 6) must not, however, be connected directly to the mains water, but must instead be connected separately as low as possible to a separate storage tank connection, since otherwise, this would lead to faulty operation of the storage controller each time hot water is drawn.

4.3 Dimensioning of the internal heat exchanger

The water heater in the test installation consisted of the largest possible coiled pipe heat exchanger. As opposed to the recommendation made by STASCH, this had only slightly over one-half the heat exchange area (0.17 instead of the 0.30 m²/kW recommended by STASCH). With this, assuming a maximum condenser temperature of 63/57°C, the tank could be charged to 51°C. In comparison to the variants with external heat exchanger having 54-62°C, this is relatively modest.

Furthermore, the coiled pipe heat exchanger, which was situated relatively high in the tank, led to a situation whereby the tank could not be fully charged, and the lowest temperature sensor remained cold (20°C). As against this, the lowest temperature sensor in the variants with external heat exchanger still reached 47-54°C.

The data does not permit a conclusive assessment to be made of the internal heat exchanger. Measurements have, however, shown that the internal heat exchanger

- should not be designed smaller than the 0.3 m²/kW recommended by STASCH
- should in addition be located as low as possible.

This may be achieved, for example, using special hot water tanks for detached houses. With these, it is possible to employ a relatively low-powered heat pump and a relatively large heat exchange area, a specific heat exchange area of ≥ 0.30 m²/kW may be achieved. Particularly compact designs and those with low-lying heat exchangers also favour complete charging of the hot water tank. Frequently, provision is made for the installation of supplementary solar collectors.

4.4 Dimensioning of the external heat exchanger

The test installation had been operated with temperature differences over the heat exchanger of up to 10 K on the primary side and 15 K on the secondary side. Here, no stratification of the storage temperature was discernable, as might be expected from theoretical considerations of stratified charging. Instead, the storage temperature rose more-or-less continuously (Fig. 5). Here, the term "ramp charging" would really be more appropriate. The effect of this would be that random fluctuations in the prior charging procedure hardly have any influence, and that even larger temperature spans do not normally lead to problems.

In conclusion, the dimensioning of the heat exchange area and the control strategy adopted in STASCH are perfectly satisfactory as follows:

- heat exchange area 0.15 m²/kW
- switch 'on' via a sensor in the tank and switch 'off' via the condenser exit temperature.

It is in fact worthwhile to provide an even larger heat exchange area. Using a heat exchange area of twice the value used in STASCH. It even proved possible to charge the tank to a storage temperature 2-4 K higher still.

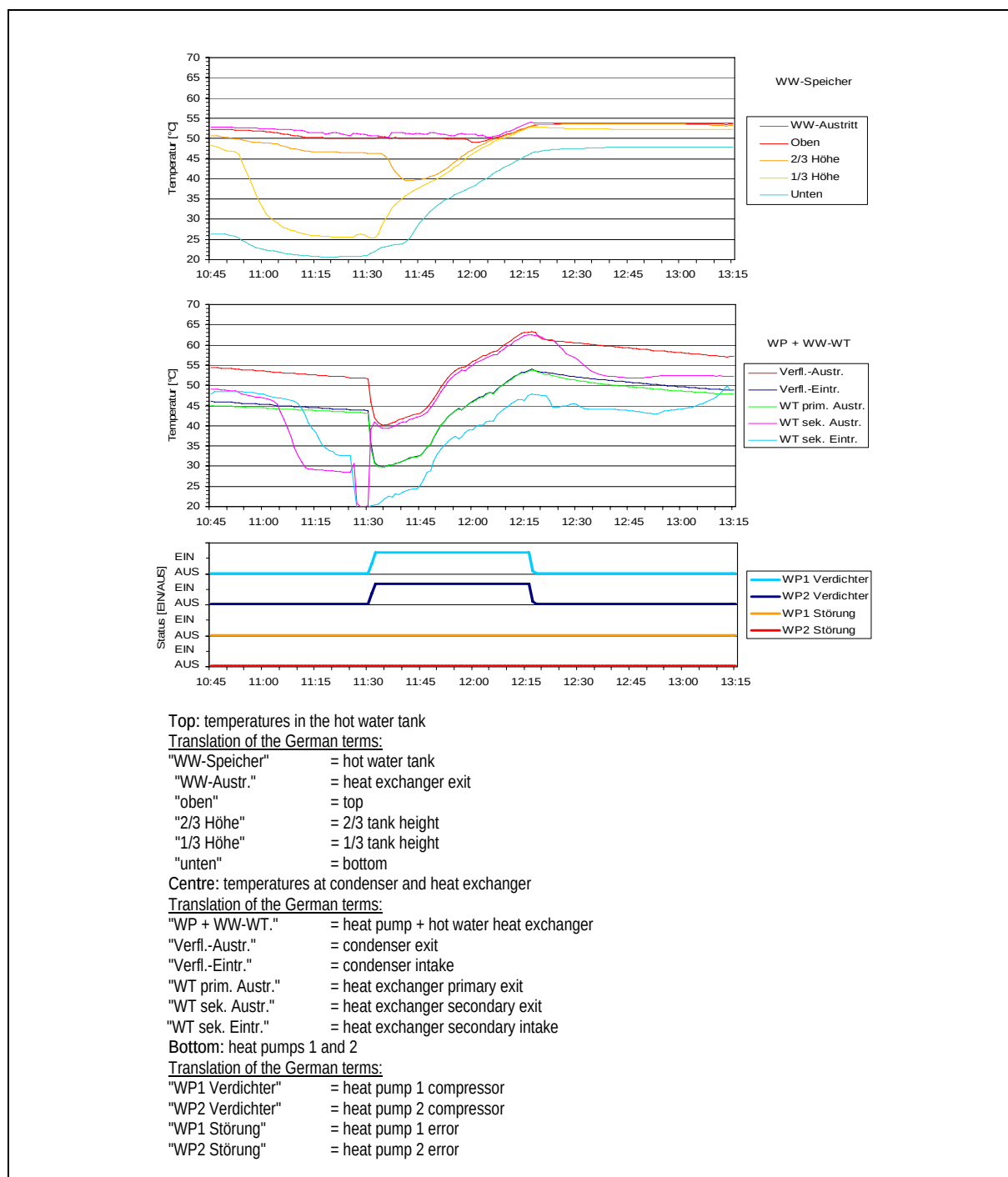


Figure 5: Typical charging procedure for variant 4 (see Fig. 4)

4.5 Storage temperature control

With hot water temperatures of over 60°C, enabling the requirements of the Federal Office of Public Health (FOPH 2006) for the avoidance of problems with legionellas in domestic hot water to be met, may only be achieved with storage temperature control. Even though variant 6 did not exist in reality, the measurements showed that a set value of 62°C is achievable. However, in this case, the seasonal performance factor would be significantly lower than

without storage temperature control (around 2.5 instead of 3.3). Here, the electricity consumption would be 1/4 to 1/3 greater than without storage temperature control.

4.6 Hot water recirculation pump

The worst enemy of a stratified tank is the hot water recirculation pump. This unavoidably disrupts the stratification, and sooner or later leads to complete mixing of the storage water. Concerning this, two recommendations are made:

- Always consider whether a hot water recirculation pump can be dispensed with (always design smaller installations having separate extraction points)
- Hot water recirculation systems using recirculation pumps should be optimised (i.e. minimized recirculation losses, minimised daily recirculation flow quantity, optimised recirculation connection).

4.7 Limit governor of the heat pump

To ensure fault-free operation, the settings of the limit governor must be carefully chosen in consultation with the heat pump manufacturer, and it must be ensured that these settings are not altered despite instructions to this effect.

4.8 Auxiliary electrical heating

With auxiliary electrical heating in the form of heating elements in the tank, a distinction must be made between elements intended solely for raising the hot water temperature and those to raise the temperature for the purpose of combating legionellas. In the first case, it will suffice to reheat the upper third of the tank with a minimum of energy expenditure (heating element at 2/3 tank height), and in the second case, the entire useful content of the tank must be heated daily to at least 60°C for a duration of one hour as specified in (FOPH 2006) (with the heating element as low as possible in the tank). These two forms of auxiliary electrical heating can also be combined.

4.9 Low-pressure fluctuation

With direct alternation between hot water and heating operation, possible low-pressure fluctuation must be taken into account.

The storage controller should not be connected directly to the mains supply, but be connected as low as possible to a separate tank connection. By this means, the likelihood of disturbance from low-pressure fluctuations caused by a sudden drop in the condenser input temperature can be avoided.

4.10 Heat pumps with maximum condenser exit temperature of 55°C

All of the present studies were performed using heat pumps designed for a maximum condenser exit temperature of 65°C (working fluid R407C, scroll compressor with intermediate steam injection). Comparable results would have been obtained using heat pumps with R134a working fluid. The most frequently adopted heat pumps with a maximum exit temperature of 55°C would, however, have led to lower (estimated) hot water temperatures of 41 to 52°C.

Using heat pumps with a maximum condenser exit temperature of 55°C, and with stratified charging, an auxiliary electric heater is always necessary. In the absence of auxiliary electrical heating, hot water temperatures of above 50°C can only be achieved using storage temperature control.

5 FUTURE PERSPECTIVES

In the absence of auxiliary electrical heating, hot water temperatures above 60°C can only be achieved using heat pumps designed for a maximum condenser exit temperature of 65°C in combination with storage temperature control, in this way enabling the requirements of the Federal Office of Public Health (FOPH 2006) on the avoidance of problems with legionellas in domestic hot water to be met (see Section 4.5 "Storage temperature control"). On the basis of the analyses in the present project, the charging procedure to avoid legionellas should be performed using storage temperature control as described in the project "Warmwasserbereitung mit Wärmepumpe und sekundärseitiger Laderegelung" (Domestic hot water heating using heat pumps and storage temperature control, Gabathuler et al. 2007-2009). By this means, in normal operation it should be possible to achieve hot water temperatures around 55°C with a satisfactory seasonal performance factor (using stratified charging), and in anti-legionella charging operation hot water temperatures of above 60°C should be achievable using storage temperature control with the heat pump alone – i.e. without auxiliary electrical heating.

6 LITERATURE

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