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DEVELOPMENT OF A TEST PROCEDURE FOR EXTERNAL DOMESTIC HOT WATER MODULES

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Abstract

The market of DHWM is growing fast, but the absence of a standardized testing procedure makes comparison of the products and quality assessment difficult. Therefore a project is being carried out at SPF aiming at the definition of a test procedure for DHWM. In the first phase a suitable test rig has been set up and six commercially available modules where tested extensively to determine the most important parameters and testing conditions necessary for evaluating the quality of a domestic hot water module. In this paper, an overview over the results of the first testing phase is given, focussing on three main performance indicators: power, comfort and efficiency.

1. Introduction

Providing domestic hot Water (DHW) by using external heat exchangers is a technology which has become more and more important, especially on the German market. The unit composed of an external heat exchanger, a circulation pump and a control mechanism is called “domestic hot water module” (DHWM). This technology decouples the DHW from the stored water and by this avoids hygienic constraints caused by the used materials or associated with legionella. The large heat exchange capacities of flat plate heat exchangers offer a potential for energy savings due to an improved stratification in the storage tank in case of low return temperatures [1].

Despite of the growing importance of DHWM technology there is no standardized test procedure or performance assurance. Commonly used definitions for working points for the declaration of the main characteristic parameters are missing. For this reason different manufacturers indicate important parameters as the nominal (maximum) tapping rate at different conditions. Thus, a comparison of the products available is difficult. Comparisons of DHWM already published are limited to the energetic comparison of different control strategies based on component simulations without losses [1] or to the comparison of manufacturer data [2].

With the goal of defining a standardized test procedure for DHWM a test rig has been designed and set up at SPF and six commercially available modules where tested extensively.

2. Experimental

An experimental set-up able to provide tapping rates up to 50 l/min was designed and installed. A schematic overview of the test set-up is given in Figure 1. The use of a hot storage tank on the *primary side* (the side associated with the storage tank or the heat source) and a cold storage tank on the *secondary side* (the side associated with the DHW or the heat sink) allows controlling both input temperatures with a precision of less than ± 1K. Custom made sensors (PT100) with reduced tip diameters (T_{66} < 1s) were used in order to resolve rapid temperature changes measured every second. Temperature sensors were placed directly at the module connections in order to exclude effects from the subsequent tapping system. The combination of slow ball valves and fast magnetic valves allows the emulation of tapping procedures with almost instantaneous changes in the flow rate. Adjusting the same tapping rate profiles for all tests was achieved with a precision of less than ± 1 l/min. The secondary flow rate is measured by an electromagnetic flowmeter (Krohne opiflux DN 10) which provides good precision over a wide range of flow rates. Not to disturb the performance of the DHWM, no flowmeter was added to the primary side.

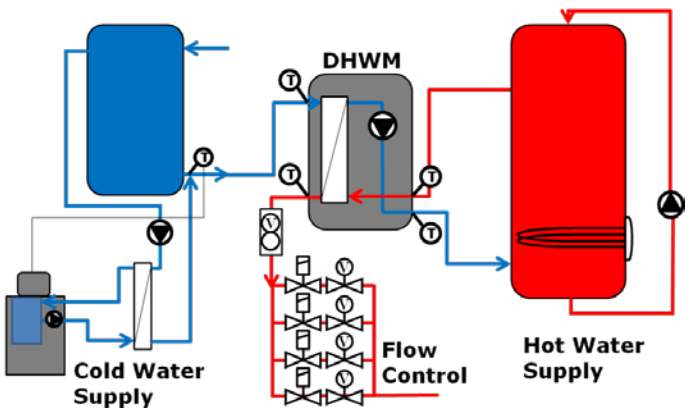

Figure 1 Schematic overview of the experimental setup for testing DHWM. A cold water tank in combination with a temperature control unit provides cold water at a defined temperature on the secondary side. On the primary side hot water is provided by another tank with an electrical heater of 32kW. The secondary flow is controlled with a set of slow ball valves in combination with fast magnetic valves and an electromagnetic flow meter.

Six different commercially available modules, designed for the use in single family houses or small apartment blocks, were tested extensively and evaluated.

3. Performance indicator: Power

3.1. Maximum secondary flow rate

The maximum secondary flow rate is an important function variable for the performance of a DHWM. A correct and comparable measurement of this quantity can serve as a basis for the choice of a suitable DWHM for a given application. The maximum secondary flow rate depends on the two inlet temperatures and on the set point of the DHW temperature. The procedure of setting the DHW temperature setpoint turned out to be crucial for a comparable measurement of the maximum flow rate, especially for modules with hydromechanic temperature control: Therefore, the DHWM is operated at the nominal flow rate declared by the manufacturer (at the corresponding conditions) and then the DHW set point is adjusted until the secondary outlet temperature reaches 45°C (or 60°C) independent of the value indicated at the DHWM control.

The *maximum secondary flow rate* was defined as the flow rate at which the secondary outlet temperature drops below 42°C (for a DHW set point of 45°C and a primary inlet temperature of 10°C). For a DHW set point of 60°C a drop of the secondary outlet temperature below 57°C was the limiting condition. A consecutive increase of the secondary flow rate until the outlet temperature drops below 42°C or 57°C followed by a linear interpolation allows the exact determination of the *maximum secondary flow rate*. During the linear interpolation also small deviations from the desired inlet temperatures can be corrected mathematically. Figure 2 illustrates an example of such a measurement with a primary inlet temperature of 50°C and a secondary inlet temperature of 15°C. After interpolation and mathematical correction a *maximum secondary flow rate* of 20.7 l/min was determined from this example. Similar measurements were carried out at different DHW temperature set points and different primary inlet temperatures resulting in the plot shown in Figure 3 (maximum secondary flow rate as a function of the primary inlet temperature).

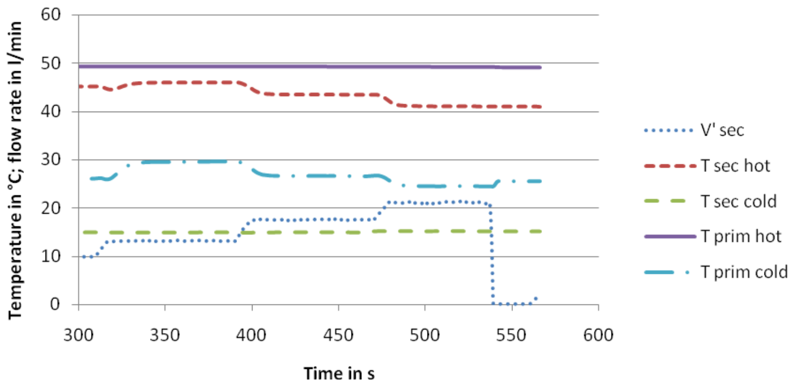

Figure 2 Example for a measurement of the maximum flow rate. The DHW temperature is set to 45°C, the primary inlet temperature to 50 °C and the secondary inlet to 15°C,. Then the flow rate is increased until the secondary hot temperature drops below 42°C.

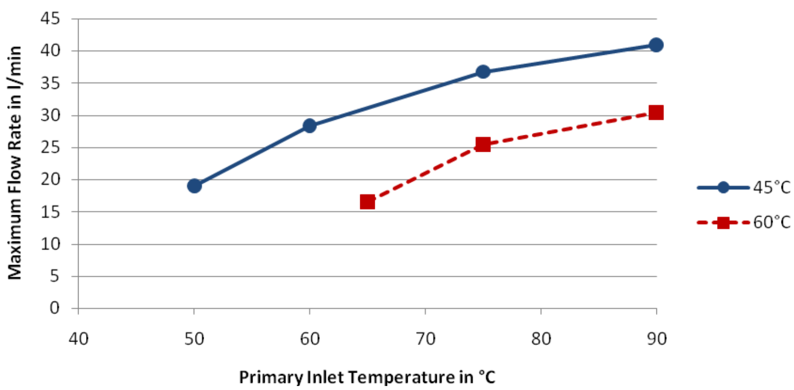

Figure 3 Example of measured maximum flow rates for two DHW temperature set points (45°C and 60°C) as a function of the primary inlet temperature.

3.2. Minimal secondary flow rate

Small tapping rates turned out to be critical operating conditions, especially when the primary inlet temperature is high. Problems with the regulation of very small primary flow rates result in fluctuations of the secondary outlet temperature which are treated in the following section. The criterion defining a *minimal secondary flow rate* within the performance section was chosen independent of any comfort requests. Therefore, the *minimal secondary flow rate* is defined as the smallest flow rate at which warm water is provided, i.e. the minimal flow rate at which the primary circulation pump is switched on. For all tested DHWM this condition was fulfilled already for flow rates smaller than 2 l/min. In most cases, the *minimal secondary flow rate* was even below 1l/min.

4. Performance indicator: Comfort

4.1. Temperature oscillations

Oscillations of the secondary outlet temperature are the most important comfort deficiencies for DHWM. Six modules were tested at different conditions to identify critical conditions. Several tapping situations were tested with two different DHW set points and for variable primary inlet temperatures:

- DHW set point: 45°C, 60°C
- Primary inlet : 50°C, 60°C, 75°C, 90°C
- Tapping profile: constant flow rates (3l/min, 5l/min, 7l/min, 10l/min, 20l/min, 30 l/min)
- instantaneous change in tapping rate (± 10 l/min, ± 20 l/min)
- short disturbance (+5 l/min during 5s)

In Figure 4 the behaviour of one of the tested modules is shown for small tapping rates in the range of 3..10 l/min and a primary inlet temperature of 90°C. Three different phenomena can be observed:

- Continuous oscillations of the secondary outlet temperature at a tapping rate of 3 l/min.
- Over-/undershoots of the secondary outlet temperature at the start of each draw off.
- Deviations of the secondary outlet temperature from the appointed 45°C for small tapping rates (see also section 4.3.).

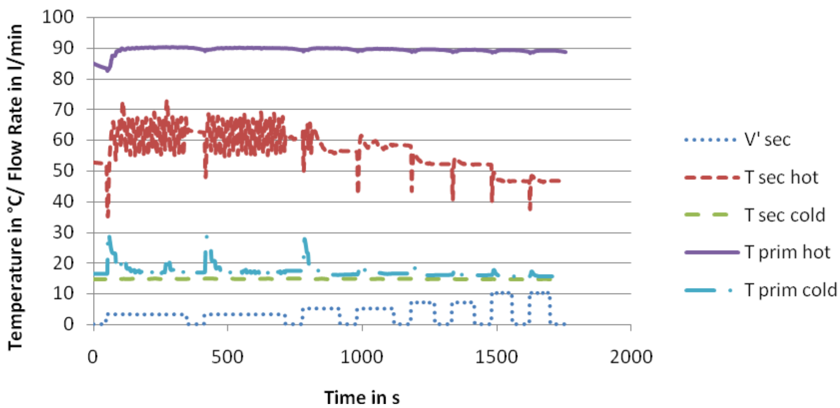

Figure 4 Example of a measurement with small flow rates where three different phenomena are visible: 1. At the flow rate of 3 l/min the temperature of the provided tap water (Tsec hot) oscillates, 2. This temperature decreases with an increasing flow rate. 3. Over-/undershoots occur at the beginning of each draw off.

Continuous oscillations at constant tapping rates are the most important comfort problems observed, especially when occurring at tapping rates typical for taking a shower. Not all of the tested DHWM were able to reach a constant secondary output temperature for all tested constant flow rates and temperatures. In most cases the regulation of the primary pump to very small flow rates was limited. For this reason small secondary flow rates in combination with elevated primary input temperatures often resulted in control problems causing temperature oscillations. Most of the time these oscillations where limited to flow rates below 3..5 l/min, but in some cases continuous oscillations ($\Delta T > \pm 5°C$) were observed for flow rates up to 7 l/min.

Temperature variations caused by sudden changes in the tapping rate do not have the same relevance for the user as continuous oscillations. However, in most of the cases over- and/or undershoots with different extent have been observed (example in Figure 5 a&b). Some DHWM generated high overshoots reaching more than 70°C (before finally reaching the set point of 45°C) in the case of a primary inlet temperature of 90°C and for instantaneous decreases in the secondary flow rate. The influence of such overshoots on the comfort at the extraction point or even the danger of skin burns depends also on the effect of the piping attached. This effect has been studied separately and will be published in a subsequent paper.

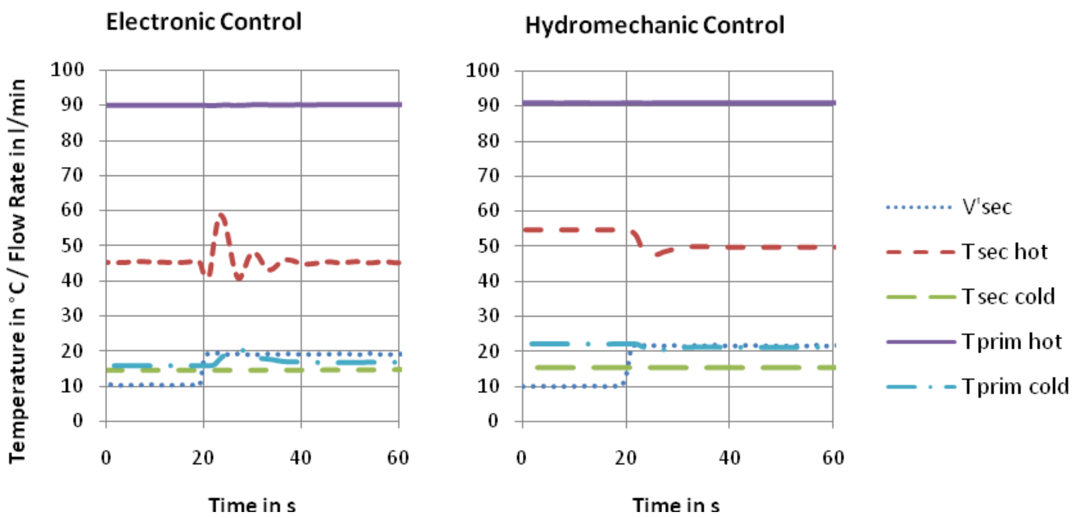

Figure 5 a&b The reaction of two different examples of DHWM to a stepwise increase of the secondary flow rate from 10 l/min to 20 l/min. The electronically controlled DHWM illustrated reacts with over and undershoots, but exactly readjusts to the same constant secondary outlet temperature (left). The hydromechanically controlled DHWM readjusts to a constant secondary outlet temperature almost immediately, but with a different temperature than before (right).

4.2. Time until constant tapping temperature

Time delays for providing DHW at the desired temperature can also be caused by the additional thermal mass or a slow adaption of the controller. In [3] a latency of only 7s resp. 9s at the extraction point is allowed to reach the first resp. second comfort level. Additional latencies caused by the DHWM can easily exceed these numbers. The reactions of two different DHWM to the start of a constant draw off are shown in Figure 6 a&b.

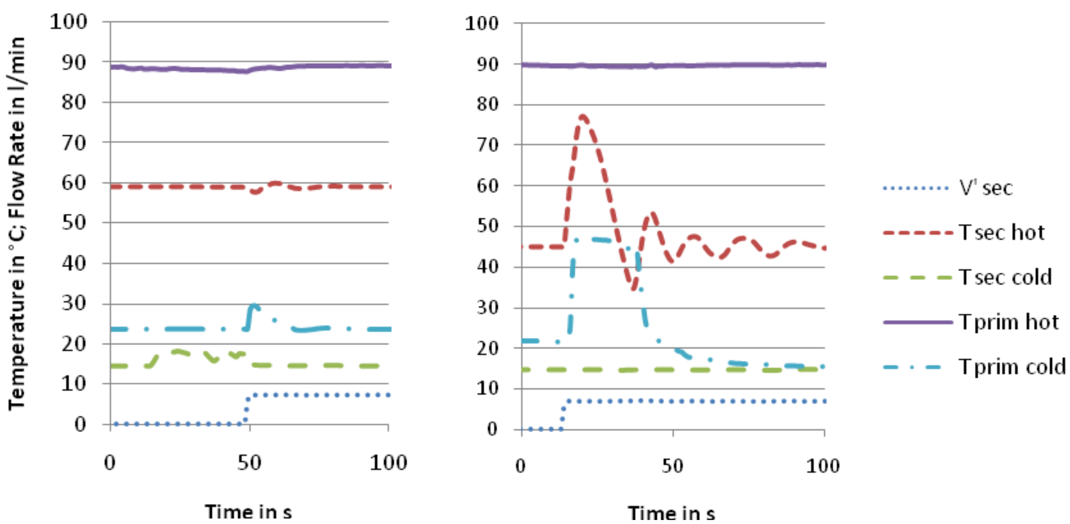

Figure 6 a&b The reaction of two different examples of DHWM to a stepwise increase of the secondary flow rate to about 10 l/min. The first one nearly instantaneously reaches a constant temperature and the other one shows a long-lasting regulation characteristic with over- and undershoots.

The first module instantaneously reaches a nearly constant temperature, the second one needs 30s to reach a tolerance band of ± 5°C or 61s for a tolerance band of ± 2°C. In the exemplified cases the modules were already warm because of previous draw offs which are not displayed.

4.3. Variation of tapping temperature

Most of the modules with an electronically controlled variable flow primary circulation pump are able to generate a DHW temperature independent of the secondary flow rate and the primary hot water temperature. However, most hydro-mechanically controlled modules and some electronically controlled modules generate a secondary DHW temperature which is variable for different flow rates or different primary hot water temperatures. As a practical consequence of this effect, the tapping temperature changes when an additional water plug is opened or closed obligating the user to readjust the setting of the temperature mixing device. In Figure 7 the measured secondary output temperatures of a hydro-mechanically controlled Module is given for one temperature set point, different secondary flow rates and different primary inlet temperatures.

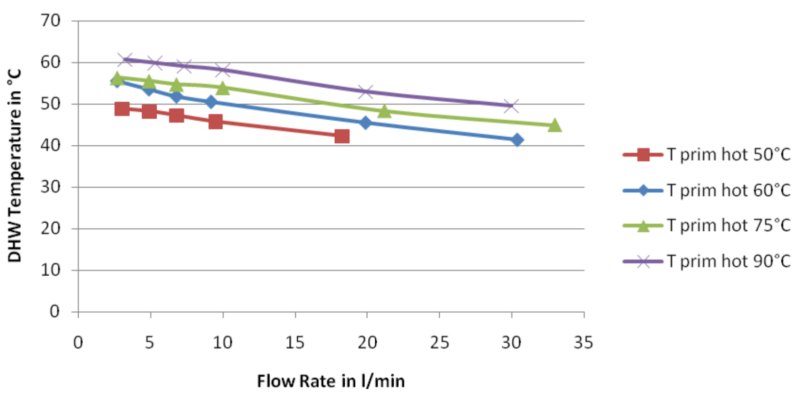

Figure 7 Variation of the secondary outlet (DHW) temperature as a function of the secondary flow rate and for different primary inlet temperatures. The values are mean temperatures measured during constant tapping rates and after reaching a fluctuation free operation with a secondary inlet temperature of 15°C.

5. Performance indicator: Efficiency

5.1. Electricity consumption

The electricity consumption was measured for different conditions such as standby, part load or full load. These measurements have been weighted based on realistic load profiles generated by the tool DHWcalc [4] with the standard probability distributions. The standby consumptions are in the range of 13..32 kWh/y, see Table 1. All tested electronically regulated DHWM were based on a regulation of the pump power for secondary outlet temperature regulation. This strategy results in reduced electricity consumption for partial load and in significantly lower yearly energy consumption during draw off. Especially for the DHWM with high-efficiency DC-pumps the electricity consumption during operation is very low in comparison to the standby consumption. The hydro-mechanically controlled DHWM had the lowest standby consumption in the test (1.5W or 13 kWh/y), but the highest consumption during draw off because of a regulation strategy that runs the primary circulation pump at full power for all draw off rates. However, the electrical energy consumption of all tested modules has to be put into perspective to the energy needed for heating the DHW, which is in the range of 3000 kWh for the 200 l/day draw off or 6000 kWh for the 400 l/day draw off.

Table 1 Comparison of estimated yearly electricity consumption for different tested DHWM. The electricity demand for standby is compared to the electricity consumption of the pump for two different tapping profiles (single family: 200l/day, two families: 400l/day).

Module	Standby	Draw off (200 l/day)	Draw off (400 l/day)
Microelectronic control, High efficiency pump	20 kWh/y	1.6 kWh/y	3.0 kWh/y
Microelectronic control, Standard pump, elevated standby	32 kWh/y	4.8 kWh/y	9.4 kWh/y
Hydromechanic control, Standard pump	13 kWh/y	20 kWh/y	38 kWh/y

5.2. Heat losses

The additional thermal mass and surface of a DHWM causes additional heat losses during operation and mainly after a tapping procedure. The thermal mass has been investigated by heating the module completely to 60°C by switching on the primary side pump and blocking the flow on the secondary side for 15 min. Then, the primary flow was blocked and the module was flushed on the secondary side by water with ambient temperature until no temperature difference between in- and outlet could be detected. Thermal masses in the range from 11..22 kJ/K were measured for the tested modules of different sizes and nominal flowrates between 25..40 l/min. By similar measurements, but with different interruptions between the heating and the flushing process, also the heat loss coefficients were measured. A heat loss coefficient of 1.0 ±0.2 W/K was measured which was similar for all modules. For these measurements the connections and the piping on the secondary side were not insulated as in reality DHW pipes without circulation are rarely insulated. Additional yearly heat losses in the order of magnitude of 100 kWh were estimated based on the tapping profiles described in 5.1. and an estimated surrounding temperature of 20 °C. However, these heat losses depend strongly on the chosen parameters as the surrounding temperature, the temperature in the storage tank, the insulation of the connected piping and the tapping profile.

6. Conclusion and outlook

A test rig for the investigation of DHWM has been designed and successively tested. A set of six commercially available modules were extensively tested with the goal of identifying the most important parameters and critical operation conditions for a test procedure. A criterion for measuring the maximum secondary flow rates has been defined and tested as well as a number of comfort aspects. In a next step the test rig will be extended and improved, followed by a new testing series aimed to directly compare the tested modules to each other.

Temperature oscillations were mainly observed for small tapping rates and high inlet temperatures in the range of 90°C. Important differences between the tested modules were observed, ranging from modules showing practically no oscillations at constant tapping rates to modules with significant oscillation up to constant tapping rates of 7 l/min. Also large overshoots at the start of a draw off procedure or caused by instantaneous changes in the tapping rate have been observed for some DHWM. These transient oscillations could last more than one minute before reaching constant temperature in the worst cases. All sorts of temperature oscillations are influenced by the following taping system before reaching the extraction point. This effect was studied separately and will be communicated in future publications.

The electrical energy consumption was measured for different loads and extrapolated to yearly numbers based on realistic load profiles. For single family households the power consumption of the pump ranges from less than one per mill (speed-controlled high efficiency pump) to about two thirds of a percent (standard pump without power regulation) of the energy needed for heating the DHW. Yearly standby electricity consumptions are in the range of 10..30 kWh which is - depending on the DHW consumption - up to one percent of the energy needed for heating the DHW and can exceed the pump power consumption by more than a factor of ten. Based on measurements of the thermal mass and the heat loss coefficient yearly heat losses from the DHWM where estimated in the order of magnitude of 100 kWh. These losses depend strongly on the chosen parameters as the surrounding temperature, the isolation of the connected piping etc., but are considerably more important than the electric energy consumption. The influence of different parameters as control strategy, heat loss, efficiency of heat exchange and time to reach constant output temperature to the yearly energy consumption of an entire DHW system will be studied based on TRNSYS simulation in the next step of this project.

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