Decentralized DHW Production from Exhaust air in the Bathroom Prewall

Florian Ruesch[1], Patrick Persdorf[1], Duglas Hunziker[2], Elias Büchel[3] and Michel Haller[1]

[1] SPF Institute for solar technology, HSR, Rapperswil (Switzerland)

[2] PV Laboratory, BFH, Burgdorf (Switzerland)

[3] IES institute for energy systems, NTB, Buchs (Switzerland)

Abstract

In urban multifamily houses, decentralized DHW systems using gas or electric boilers are still widely used. Their replacement with renewable energy sources is difficult and generally needs centralized DHW systems with a circulation system that ensures comfort and hygiene at the price of elevated heat losses. A consortium of three academic and one industry partner developed a decentralized DHW system, which uses the residual heat from the exhaust air of a controlled ventilation unit as energy source for a micro heat pump. The entire system, including ventilation unit, heat pump, and storage tank fits into the bathroom prewall and produces hot water for one apartment. This contribution gives an overview of the system and focusses on the development of the flat storage tank that fits into the prewall space of less than 30 cm width.

Keywords: Decentralized DHW, micro heat pump, flat DHW tank

1. Introduction

In Switzerland, there are still about half a million decentralized electric domestic hot water (DHW) boilers in operation, of which a large share will be replaced in the next decade. In most of the cases of multifamily buildings a central DHW installation with circulation system has to be installed, which can be complicated and expensive and needs to be coordinated with all inhabitants. Especially for the case of individually owned apartments, a possibility to replace old DHW systems with renewable energy sources is desirable, but difficult to achieve.

DHW circulation systems in multifamily houses are subject to heat losses of 20-65 % (rel. to the consumed energy) when correctly designed and installed (Vetsch et al. 2012) and even higher numbers have been found in field measurements (Citherlet et al. 2011). Large DHW circulation systems also provide an elevated risk of legionella contamination and need to be operated at high temperatures.

Various heat pump boiler systems using the surrounding air as heat source are available on the market. Since the operation of a heat bump boiler cools down the surrounding room, an installation in the apartment is often not possible or causes additional use of space heat energy in winter (Von Euw et al. 2014).

A consortium of three universities and an industry partner developed a decentralized DHW preparation system with a small heat pump that uses exhaust air of a controlled ventilation unit. The developed system provides a possibility to replace decentral DHW systems and include modern ventilation in existing apartments when renovating the bathroom. The flat construction fits behind a bathroom prewall and therefore is invisible for the user and does not use any additional space. It includes (Fig 1):

1. A modern controlled ventilation system with heat and humidity recovery for the entire apartment (max. capacity of 180 m^3/h).
2. A small heat pump designed especially for the purpose of using exhaust air of a single apartment ventilation unit. It provides a power of 0.3-0.5 kW_{th}, depending on the temperature conditions. A direct condenser is included in the storage volume.

doi:10.18086/eurosun2018.12.10 Available at http://proceedings.ises.org

3. A cuboid unpressurized storage tank with a water volume of 83 l and vacuum insulation. DHW is prepared with a stainless steel internal heat exchanger.
4. An electric flow through heater as a backup to ensure comfort also for long tappings.
5. A thermostatic tap for automatic compensation of temperature drops caused by the small volume of the storage tank.

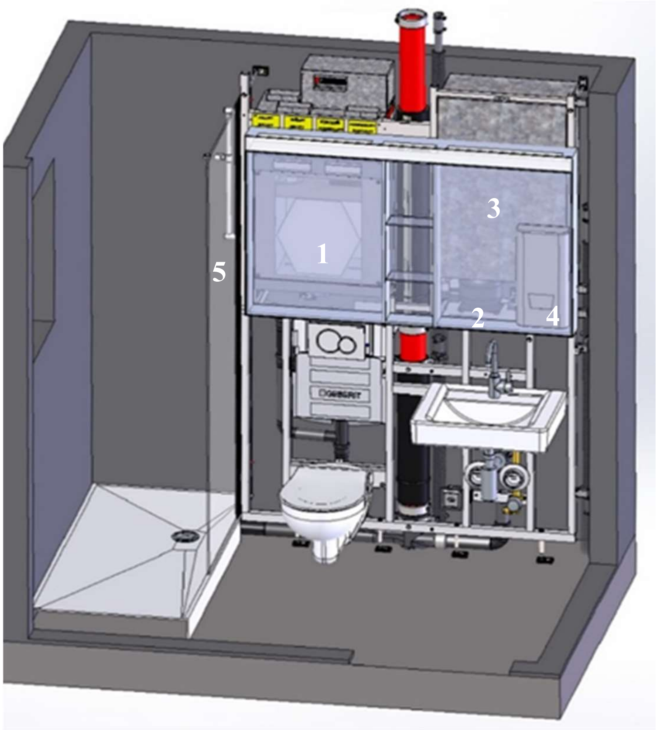

Figure 1: DHW system in the bathroom prewall.

The entire prewall (with the framing, the DHW system, the ventilation unit, all water and air piping and connections) is assembled in the factory and can be brought to the construction site in two parts. Therefore a high standardization and quality of the assembly can be achieved and the installation time is very short.

2. Storage Tank

The design of a storage tank that fits into the limited space behind a bathroom prewall with a spacing of only 30 cm, but at the same time exhibits low thermal losses, was challenging. This challenge was tackled with the following approaches:

2.1 Cuboid polypropylene container

The cuboid form of the storage tank was given by the limited available space in the bathroom prewall. The DHW pressure would create elevated forces onto the flat walls which cannot be compensated with a construction of reasonable wall thickness. Therefore, an unpressurized but closed construction was chosen in combination with a stainless steel internal heat exchanger. Due to this construction, there are little requirements on the tank vessel and a cost effective solution based on polymers was possible. Out of an analysis of different materials and construction techniques, a roto-molded polypropylene construction was selected to be the most cost effective solution for small to middle sized production series. FEM simulations were carried out to optimize the design for minimal dilatations within a lifetime of 30 years at a temperature of 60°. Even though there is only the static pressure of the tank height (< 1 m), three metal enforcements were needed to avoid dilatations greater than 2.5 mm. Due to the higher coefficient of thermal expansion of polypropylene in comparison to water, a negative pressure is expected when heating the storage tank, which can be compensated with a small volume of air in the upper part of the vessel. This construction allows to close the vessel without inducing pressure changes due to temperature variations.

1	Polypropylene vessel manufactured with rotomolding
2	Metal reinforcement
3	Vacuum insulation panel (VIP)
4	Metal cover to protect VIP during transport and installation.

Figure 2: Photo of the storage tank vessel with metal reinforcement and VIP insulation.

2.2 High performance vacuum insulation

The flat cuboid form of the vessel is not favorable in terms of heat losses, due to the high ratio of surface to volume. Therefore, a good insulation is of particular importance. Different combinations of vacuum insulation panels (VIP), aerogel insulation and conventional insulation were simulated in 2D FEM. Material properties of the VIP were taken from the manufacturer’s data sheet (“va-Q-vip” from the company va-Q-tec AG) and special attention was given to the joints of the VIP. Prototypes of the most promising solutions were constructed and heat losses were measured. As can be seen in Figure 3, the measured values of the overall heat loss coefficient was lower than the simulated ones for all tested configurations. This is due to a conservative value for the thermal conductivity in the data sheet (< 0.005 W/mK). The measurements show that the actual thermal conductivity, at least in an unaged state, is clearly lower than the declared limit. Furthermore, thermal bridges at the joints of the VIP (at the corners) can be minimized by the cuboid construction and don’t lead to additional losses in the real prototype compared to the idealized simulation.

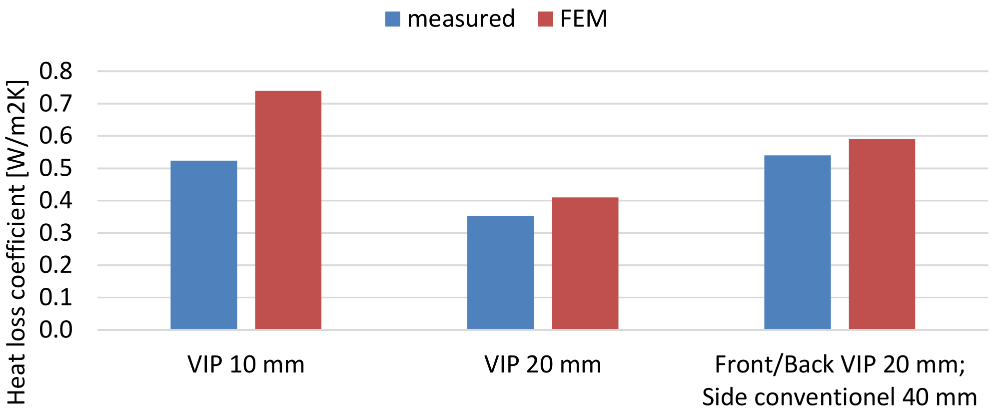

Figure 3: Measured heat loss coefficients vs. the predictions from FEM simulations.

2.3 Connections only at the bottom

In order to avoid heat losses and to simplify the construction of the tank all connections are integrated in a metal flange fixed to the bottom of the tank. This includes DHW heat exchanger, heat pump condenser and valves for filling and drain. The heat pump condenser consists of copper piping directly welded to the heat pump cycle. Conventional insulation is used at the bottom, which can be fitted around the connections.

3. Other components

More details on the development of the heat pump, including detailed performance measurement in the laboratory, is given by Büchel et al. 2016 and is therefore not explained in detail in this paper. Available standard products were used for the controlled ventilation (Zehnder, ComfoAir 180) unit and the electrical flow through backup heater (CLAGE, CEX ELECTRONIC MPS).

4. Simulation

Simulations were carried out with the simulation tool Polysun (Brönner et al. 2011) in order to characterize energy efficiency, the need of the electric backup heater and the possible direct consumption of PV electricity. The simulations were focused on the DHW system and the effect of the controlled ventilation was not considered.

- As there is no heat pump model with internal storage condenser available, an external heat pump was used. This heat pump was parametrized with measured data given by Büchel et al. 2016. A set point of 60°C was used for the heat pump control.
- Tapping profiles for 1-5 persons (62 l/p @ 40°C) were generated with the DHWcalc tool from Jordan & Vajen, 2003 and applied to different storage configurations. Special profiles with one second time steps during tapping were used to force the program to use small simulation time steps during these periods and to fit simulation parameters to measured data.
- Only cylindrical storage tanks can be implemented in the software. Therefore, insulation parameters were fit in order to match measured heat losses in four heights of the tank.
- Also the parameters of the internal heat exchangers were fit in order to match measured data rather than using the design geometries.
- Air flows and controlled ventilation units cannot be simulated in detail in the software polysun. As the heat pump only uses exhaust air it does not affect the operation of the unit and the simplified model with a constant recovery efficiency coefficient that is included in the building model can be used. On the other hand, the effect of the ventilation unit has to be considered when parametrizing the heat pump.

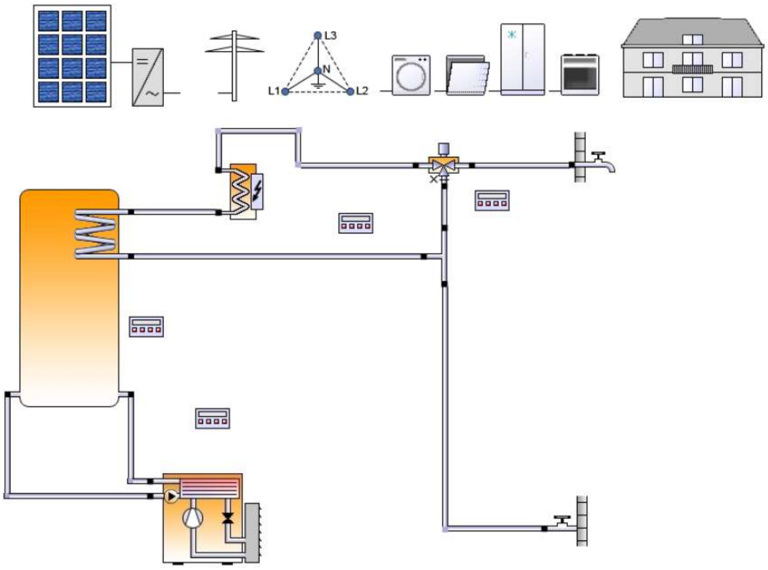

Figure 4: Simulation scheme in the software Polysun.

5. Results of the simulations

5.1 Internal heat exchanger

The size/surface of the internal storage heat exchanger affects the output temperature especially for longer tapping, which exceed the volume of the DHW stored inside the heat exchanger. High output temperatures are desired in order to keep the consumption of the additional electrical heater connected in series low. However, the consumption of the electrical backup heater also depends on the variable temperature/state of the storage tank and the tapping profile, which cannot be evaluated by a single measurement.

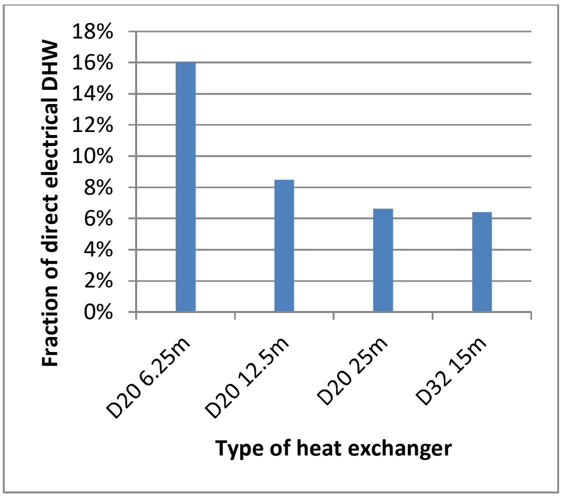

Figure 5: Annual fraction of direct electrical DHW heating with different internal heat exchangers.

Figure 5 shows the influence of different tested internal heat exchangers on the annual consumption of the electric backup heater during dynamic operation with a stochastic tapping profile for three persons (186 l/day @ 40 °C). A duplication of the length of the internal heat exchanger from 6.25 m to 12.5 m cuts the use of the direct electricity use to half. The effect of a further duplication to 25 m is much less pronounced. In terms of a compromise between cost and efficiency a length of 12.5 m was used for the system prototype.

5.2 System performance

The main interest of the simulation was to gain knowledge about the performace of the system in different Situations. The most important parameter, is the amount of DHW consumption. Therefore, stochastic tapping profiles for one to five persons (62 l/person @ 40°C) were used for the simulations. Figure 6 shows the electricity consumption of the heat pump as well as the direct electrical heater and the seasonal performance factor (SPF) of the heat pump and the entire system for different numbers of users. The electrical energy consumed by the heat pump increases nearly linearly from one to three persons. For more persons the possible runtime of the heat pump limits its contribution as it runs nearly continuously (> 8000 h/a) for five persons. This is compensated by a strong increase of the direct electricity consumption for more than three users. An increased DHW consumption leads to lower mean storage temperatures and therefore to less storage losses and increased SPF of the heat pump. A combination of all effects leads to the highest system performance (SPF 1.9) with 3-4 users.

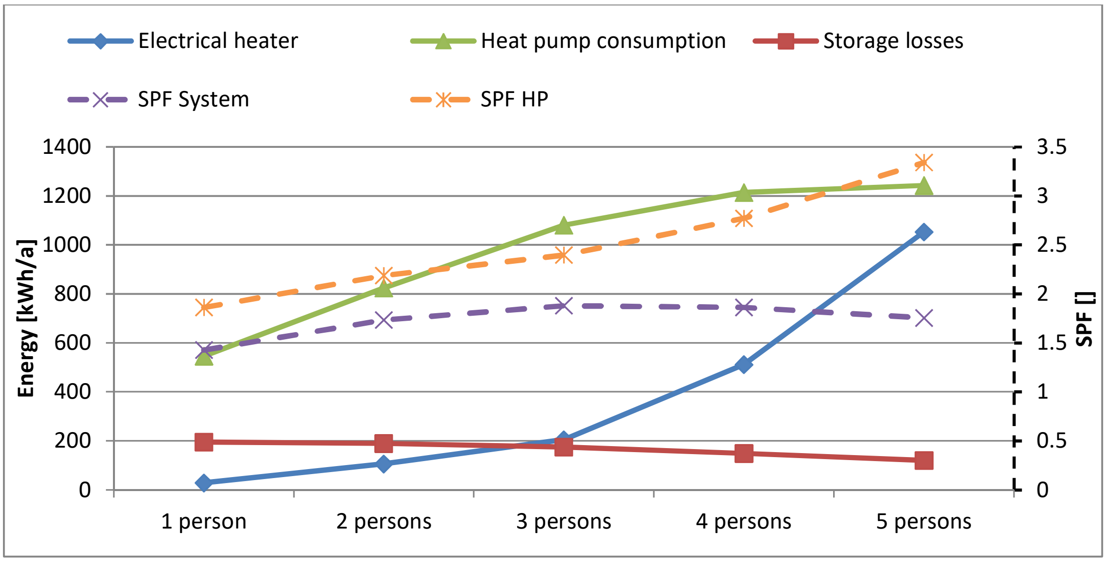

Figure 6: SPF and energy consumption of selected components for varying number of users.

The small size and therefore long runtimes of the heat pump limit the flexibility with respect to control and maximization of PV self-consumption. Simulations with different control strategies were carried out, but didn't result in great differences. However, as the heat pump generally runs during daytime, the system is suitable for the combination with PV-installations.

6. Prototype testing

A prototype of the system was constructed and installed in the lab. Different tapping profiles were automatically induced by a timer clock; two or three draw-offs of 100 l/d and a tapping profile similar to the EU tapping profile M (370 l/d, some small tapping were accumulated because the timer only handled 15 tapping per day). The different tapping profiles were run over various days, but with some interruptions and during different seasons. No systematic test was run was performed for an entire year.

In Figure 7, the temperature evolution in the tank and the tapping rates of the profile (similar to EU M) are given for an exemplary day. The fraction of direct electrical heater and the daily performance factor (DPF) of the heat pump is given in Figure 7 for all day operated with this profile (Sept. – Nov.). A clear dependence of the mean ambient temperature can be identified for the fraction of the direct electrical heater. On the other hand, there is no clear tendency for the DPF. This is due to the fact, that lower ambient temperatures result in lower output power of the heat pump and therefore in lower mean storage temperatures. The efficiency loss from cold ambient temperatures is therefore compensated by the efficiency gain caused by lower storage temperatures. This effect is especially pronounced when a lot of DHW is used (370 l with this profile).

During the entire testing, which includes various profiles irregularly distributed over more than a year, a heat pump SPF of 2.8 and a system SPF of 2.0 was measured (temperature set point 60°C).

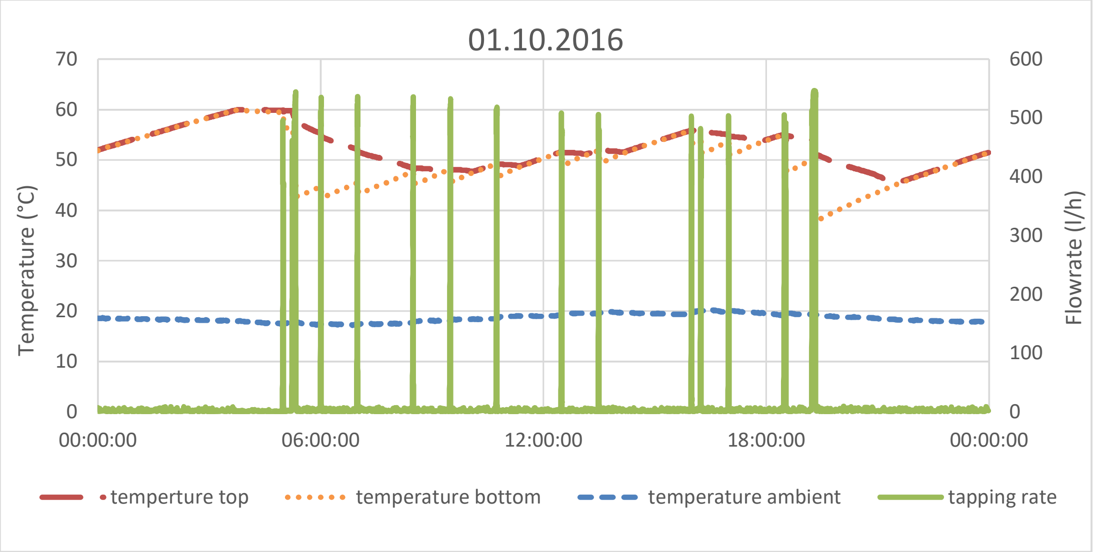

Figure 7: Temperature development at an exemplary day for a tapping profile similar to EU M.

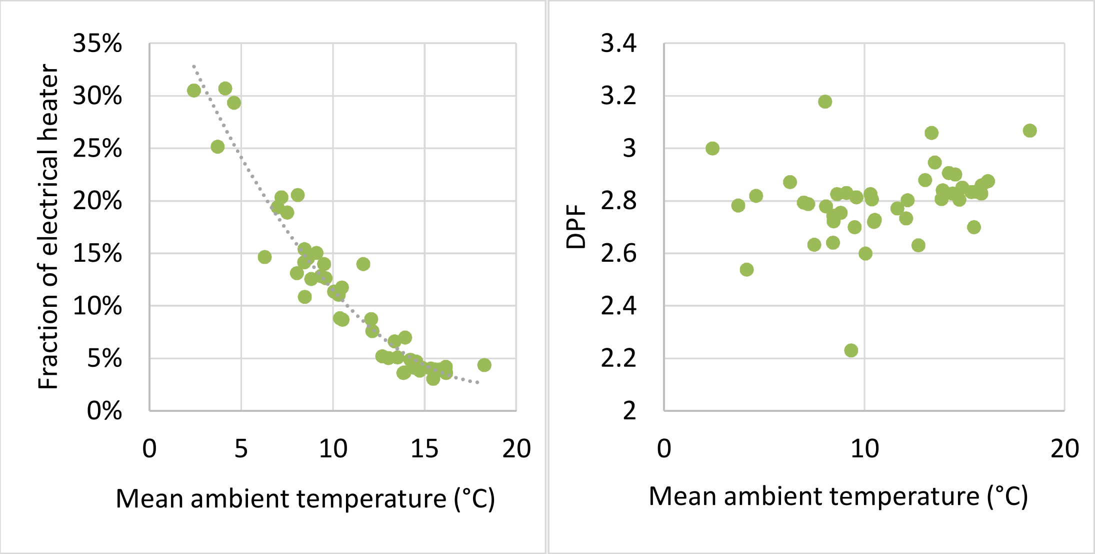

Figure 8: Fraction of the needed heat from the electrical heater (left) and corresponding DPF for all tested days with the profile EU M as a function of the mean ambient temperature.

7. Discussion and Conclusion

- High performance VIP is well suited for the insulation of small cuboid storage tanks. In the contrary to initial concerns, the effect of thermal bridges at joints was low and good performance could be achieved despite the unfavorable surface/volume ratio. Manufacturer data on the heat conductivity were undermatched with the actual prototype set up and measured un-aged.
- A final test of the storage tank with an intermediate VIP thickness of 15 mm according to CDR (EU) No 812/2013 resulted in a heat loss coefficient of 0.78 W/K and an energy label “B” just at the limit to “A”. The storage tank will be placed in the small space in the bathroom prewall, which will be heated up by thermal losses of the storage and the heat pump. This effect is expected to lower thermal losses in practice.
- The simulated system SPF of 1.9 (three persons) corresponds well to the measured value of 2.0, even though the values are not directly comparable because of interruptions and different tapping profiles in the measurements.