Investigation of the Influence of Instantaneous Water Heaters on the Efficiency of (Regenerative) Central Heating Systems in the Simulation Environment TRNSYS

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Abstract

The use of central instantaneous water heaters enables the use of buffer storage systems for domestic hot water provision. No hygiene requirements need to be observed for buffer storages, so a larger temperature stratification with lower temperatures at the bottom is permissible than for potable water storage tanks. This leads to energy benefits, as the efficiency of temperature-sensitive heat generators such as solar thermal and heat pump systems can be increased by lowering the mean storage temperature.

This study examines the influence of instantaneous water heaters on the efficiency of three different (partially) regenerative central heating systems. They are considered large-scale systems and must comply with the relevant regulations in Germany. The results are compared with a reference system with a focus on the CO_2 emissions during operation and the associated energy costs. For this purpose, a parameter variability study is conducted using the TRNSYS simulation environment. Instantaneous water heaters with different performance levels, the influence of a return flow distribution using various mechanisms at different actuating times and the influence of the tapping and circulation load were investigated. Furthermore, the storage setpoint temperature was minimized for each combination option.

Keywords: potable water hot, buffer storage, instantaneous water heater, efficiency, regenerative combi systems

Final energy consumption	FEC	Gas boiler	GB
Potable water hot	PWH	Instantaneous water heater	IWH
Potable water hot, circulation return	PWH-C	Electric instantaneous water heater	El.IWH
Potable water cold	PWC	Buffer storage	BS
Heat pump	HP	Apartment building	AB
Solar thermal	ST		

1. Introduction

Within the last 10 years, FEC per capita in Germany has fallen slightly and was around 28 MWh (100 GJ) in 2022. Just over half of this is accounted for by the heating sector. One focus is on space heating and PWH in the residential sector, which accounts for around a third of the total FEC. The FEC share for potable water heating has remained relatively constant at around 5 % over the last 10 years. The largest share of this, 4.47 % points, was accounted for by private households in 2022. In the same year, the share of renewable energies in total potable water heating was only 12.6 %. (AGEB 2023)

The energy modernization of existing buildings makes it possible to reduce the flow temperature level for heating. This is in contrast to the PWH supply. Hygienic requirements pose a challenge in particular for large systems, especially for temperature-sensitive heat generators such as HP and ST systems. Therefore, the focus of science is increasingly on efficient and hygienic potable water heating. (Pärisch et al. 2020a)

The use of central IWH enables the use of BS. With BS, no hygiene requirements need to be observed, allowing for a wider temperature range, including lower temperatures, compared to PWH storage. This leads to energy benefits, as the efficiency of temperature-sensitive heaters such as ST and HP can be increased by creating a cold preheating zone. (Pärisch et al. 2020b)

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In Germany, 53 % of homes are in apartment buildings (AB), which therefore account for a significant proportion of the FEC (Statistisches Bundesamt 2023). Therefore, more efficient PWH systems in AB are particularly relevant for the FEC in Germany.

In order to design the domestic hot water systems more efficiently, this study investigates the influence of technical properties of IWH on the efficiency of three different (renewable) central heating systems in AB. The heat centers each supply an AB with 8 residential units with PWH. They are therefore considered to be large systems for which hygiene regulations according to the generally acknowledged rules of technology must be observed. This means that a temperature of 60 °C must be maintained at the IWH outlet and the temperature of the circulating water (PWH-C) must not be less than 55 °C.

The results are compared with a reference system with a gas boiler (GB) and PWH storage. For this purpose, a parameter variation study is carried out in the TRNSYS simulation environment. A particular focus is placed on the potential savings in energy costs and CO_2-equivalent emissions. This study serves as a continuation of the earlier investigations by Pärisch et al., see (Pärisch et al. 2020b; Pärisch et al. 2020a; Keuler et al. 2022), in which the influence of other parameters and heat centers is investigated.

2. System models

This chapter presents the four systems examined. The most important TRNSYS types used and their key parameters are:

- Modulating GB: Type 204 (Glembin et al., eds. 2013) with 28.5 kW, water content 7.3 l and efficiency of 96.6 %;
- Modulating HP: Cascade of three Types 401 (Afjei and Wetter 1997) and interpolation with a typical thermal output of 20 kW;
- ST: Type 832v600 (Haller et al. 2012) with 32 m² and an inclination angle of 45° and inversion factor of 0.81 and coefficient of loss of lin. 3.757 and quadr. 0.0147, which represents a flat-plate collector;
- BS: Type 340 (Drück 2006) with energy efficiency labeling according to (EU-Verordnung Nr. 812/2013 2013) and (EU-Verordnung Nr. 814/2013 2014).

The investigations in this study are carried out in TRNSYS 18 (version 18.04.0001) for an AB with 8 residential units. Annual simulations with a time resolution of 5 s are carried out. To reduce the simulation time, the dynamic coupling of the system technology with the building is dispensed with and only the PWH load profile is used. We consider this to be justified when using a separate heat storage for potable water heating with a PWH priority circuit of the heat generator. An ambient temperature is required for the individual components, which is set to 15 °C for all components in the boiler room. The storage connection positions are specified from 0 to 1 as a relative height. The 4 systems shown in Figure 1 are described below.

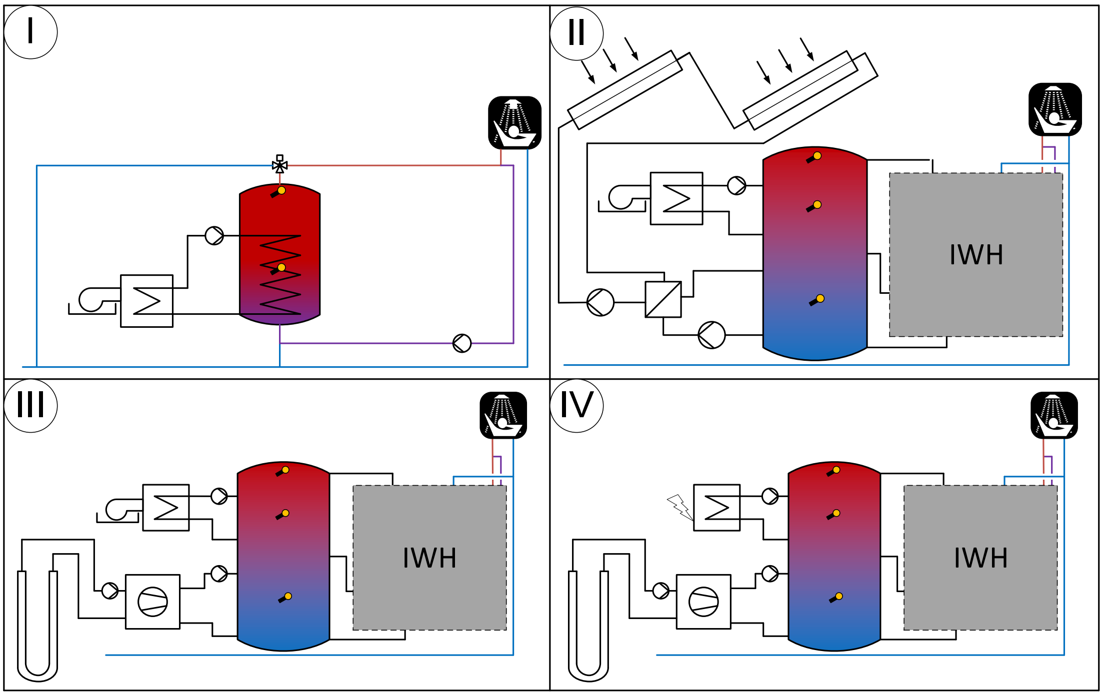

Figure 1: Hydraulic plans of the four systems: I Reference system; II Solar thermal & gas boiler system; III Heat pump & gas boiler system; IV Heat pump & electrical instantaneous water heater.

Description System 1: Gas boiler with PWH storage

In the reference system, heat is generated by a gas condensing boiler, which heats a PWH storage monovalently. A PWH storage supplies the AB with PWH. The PWH outlet is at a height of 1, whereas PWC and the PWH-circulation (PWH-C) enter the storage from below, i.e. at a relative height of 0. Due to the size of the system, a circulation pipe must be installed. This is connected to the PWC pipe just before the storage inlet. The GB transfers the energy to the potable water via an immersed pipe heat exchanger with an inlet height of 0.55 and an outlet at 0.05. This means that the storage has four connections. They are equipped with heat siphons to minimize losses. As a result, the storage has an average UA value of 2.25 W/K with a volume of 600 l. A thermostatic control unit with a temperature sensor is used to control the GB. This is positioned centrally between the flow and return of the GB. It is switched on at a temperature below 65 °C and switched off at over 70 °C.

Description of system 2: Solar thermal & gas boiler

In the second system, a ST and a GB are used as heat generators (ST&GB-system). They bivalent parallel heat a BS with 1600 l. The BS supplies the IWH with heating water. If required, this heats the potable water for the AB. The flow of the IWH is located at the top at a relative height of 1. During hot water draw-off, the cold heating water is fed in at the bottom. In circulation operation, it can be fed in at a relative height of 0.55. The BS has a volume of 1600 l and a total of seven connections. All of them are equipped with heat siphons to avoid pipe-internal circulation losses. The BS therefore has an average UA value of 4.1 W/K. The flow of the GB is at a height of 0.8, the return at 0.6. The GB is controlled by means of thermostatic regulation with a temperature sensor. This is positioned in the middle between the flow and return. The GB is switched off at 5 K above the set temperature (part of the parameter variation). In addition, there is a protective control which stops the GB and the ST as soon as the temperature sensor at the top of the BS registers over 95 °C. The flow of the ST is at a height of 0.5, the return flow at 0.03. As suggested in (Mercker and Arnold 2017), an area of 4 m² is used for each apartment. This results in a total area of 32 m². The heat is transferred via an external heat exchanger with a UA value of 100 W/K per m² collector area (VDI 2014). It is also controlled via a centrally positioned temperature sensor between the flow and return. If the collector temperature is 15 K higher than the lower BS area, the primary pump is started. It is stopped when the temperature falls below 5 K. The secondary pump starts as soon as the temperature in the flow of the primary side of the heat exchanger exceeds the BS temperature by 7 K and stops at a difference of less than 3 K. The pumps operate at 640 l/h in the low-flow range. As soon as the maximum BS temperature of 95 °C is reached, only the secondary pump is switched off. To protect the system components, the primary pump is switched off at collector temperatures above 130 °C.

Description of systems 3 and 4: Heat pump & gas boiler as well as heat pump & electric instantaneous water heater

The third system uses a HP and a GB as the heat generators (HP&GB-system), the fourth system uses a HP and an electric instantaneous water heater (El.IWH) (HP&El.IWH-system). As both systems are very similar, they are described in one chapter. They provide bivalent parallel heating for a BS with 1600 l. The storage connections of the IWH, as well as the number of connections and size, and the resulting UA value, are the same as for the ST&GB system. However, the heat generators are connected differently to the BS. The flow of the heat pump is at a height of 0.5, the return flow is at a height of 0.15. The flow of the El.IWH or GB is at a height of 0.8, the return flow at 0.6. The HP has a geothermal probe available as a heat sourcec. The control works by means of a thermostatic control with one temperature sensor each, which is positioned centrally between the respective flow and return. The heat pump is switched on at 55 °C and switched off at 60 °C so that the maximum heat pump temperature of 62 °C is not exceeded. The upper heat generator is switched off at 5 K above its set temperature, which is part of an optimization. The output of the GB and the El.IWH is 28.5 kW.

Location

The building location is the city of Zurich and represents a moderate, central European climate (Heimrath and Haller 2007). The weather data is provided by Meteonorm 8. The radiation data is based on the climate period from 1996 to 2015, the other parameters are based on the years 2000 to 2019. The PWC inlet temperature is calculated according to Task 32 (Heimrath and Haller 2007) using Eq.

$$\vartheta_{\mathrm{CW}} = \vartheta_{\mathrm{CW,Av}} + \mathrm{d}\vartheta_{\mathrm{CW,AMP}} \cdot SIN\left(360 \cdot \frac{TIME + 24 \cdot \left(273.75 - \mathrm{d}t_{\mathrm{CW,Shift}}\right)}{8760}\right). \qquad \text{(eq. 1)}$$

The following applies to Zurich: the average temperature $\vartheta_{\mathrm{CW,Av}}\ [°\mathrm{C}] = 9.7$, the maximum amplitude $\mathrm{d}T_{\mathrm{CW,AMP}}\ [°\mathrm{C}] = 6.3$, and the shift $\mathrm{d}t_{\mathrm{CW,Shift}}\ [\mathrm{d}] = 60$. The time *TIME* is given in h and corresponds to the hour of the year. BHE is from an internal ISFH pre-simulation and is imported into this simulation in order to shorten the calculation time.

3. Object of investigation: instantaneous water heaters

The IWH heats the PWC to PWH with a plate heat exchanger in the flow. To provide the thermal energy, BS are used, which are heated directly by one or more heat generators. (Albers, ed. 2021)

The most important features of IWH in terms of energy efficiency are according to (Pärisch et al. 2020b):

1. The necessary excess temperature of the heating water compared to the desired PWH temperature.
2. The cooling of the return flow compared to the PWC temperature.
3. The changeover time of the return valve, or two pump solutions, for switching between circulation and tap operation so that temperature stratification can be maintained.

The UA value of the IWH was determined empirically in the lab of ISFH according to (Pärisch et al. 2020b) based on the quality of the heat exchanger and the mass flow rate according to

$$UA = f_{\vartheta} \cdot \left(-3 \frac{\mathrm{W/K}}{(\mathrm{l/min})^2} \cdot \dot{V}^2_{\mathrm{secondary}} + 295 \frac{\mathrm{W/K}}{(\mathrm{l/min})} \cdot \dot{V}_{\mathrm{secondary}}\right) \cdot f \qquad \text{(eq. 2)}$$

with

$$f_{\vartheta} = \left(1{,}0395 - 0{,}008 \cdot \left(\vartheta_{\mathrm{P,in}} - 60\ °\mathrm{C}\right)\right). \qquad \text{(eq. 3)}$$

The definition of the temperature correction factor f_ϑ (see eq. 3) is limited to primary inlet temperatures $\vartheta_{\mathrm{P,in}}$ between 60 and 90 °C. The specific heat transfer coefficient (*UA*) is obtained in W/K where the secondary side flow rate $\dot{V}_{\mathrm{secondary}}$ is in l/min. Various high-performance heat exchangers and station concepts (see Figure 2) are simulated by varying the factor f. The factor is varied in the range from 1.0 to 2.5. A factor range of 1.0 to 1.5 stands for a standard IWHs according to Concept I, which is more than sufficiently efficient for the above-mentioned tapping profile in AB. The factor range from 1.5 to 2.0 represents large modules for AB in accordance with Concept II or III with a circulation module in parallel. A factor of 2.5 stands for particularly powerful heat exchangers or Concept IV, in which two heat exchangers are connected in series.

The changeover time of the primary returns between the lower and middle storage area is examined with modeling from 5 to 130 s, as well as without. The shortest changeover time of 5 s, which is the simulation time-step, is possible either with two pumps on the primary side or with fast-switching valves.

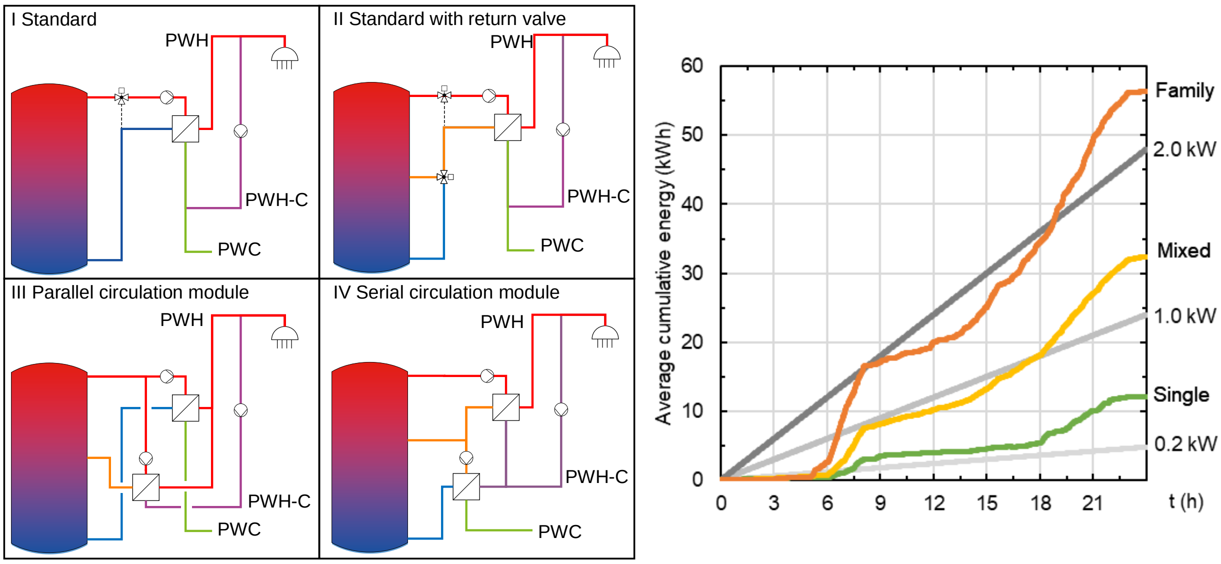

Figure 2: Left: Comparison of four different instantaneous water heaters according to (Pärisch et al. 2020b); Right: Average daily tapping and circulation demand (chapter 4).

4. Parameter variation

The parameter variations of the systems with IWH are listed in Table 1. There are 216 different possible parameter combinations per system. Including temperature minimization this results in 4536 possibilities. By using a binary search algorithm, however, significantly less simulation time is required to find the lowest setpoint temperature for each of the 216 different possible combinations.

Table 1: Parameter variation table of the (partially) regenerative systems.

UA factor *f* (IWH)	1.0, 1.5, 2.0, 2.5
Changeover time return valve (s)	5, 20, 65, 100, 130, without
Circulation load (kW)	0.2, 1.0, 2.0
Tapping profile	Family, Single, Mixed
Setpoint temperature (°C)	55, 56, …, 75

The aim is to find a minimum BS temperature for the respective variation case at which the PWH temperature never falls below 60 °C at the outlet of the IWH. The hard criterion makes it possible to compare the variants, as they all have the same level of comfort. This is achieved by varying the setpoint temperature, which is examined between 55 and 75 °C in 1 K steps. Setpoint temperature means that as soon as the temperature at the sensor falls below this temperature, the heater is switched on. In all cases, the heaters are operated with a hysteresis, i.e. the heaters are switched off again at a certain excess temperature. This is always the case at 5 K above the set temperature.

The variation of the circulation load is intended to cover different network topologies and insulation standards. The load of 0.2 kW stands for short insulated lines, 1 kW for long insulated lines and 2 kW for long uninsulated lines.

Unlike with the old studies, this study uses high-resolution 5 s tapping profiles according to (Distelhoff et al. 2022). These high-resolution tapping profiles are necessary to correctly map the IWH with changeover of the return valve. Furthermore, three tapping profile are created for the parameter variation. A low (only young singles (Single)), a medium (mixed house occupants (Mixed)) and a high consumption (only families with two children (Family)) are considered in order to cover the "normal case" and two "extreme" scenarios. Simultaneities were avoided by shifting the profiles by one week each when using identical tapping profiles. The average daily tapping and circulation requirements are shown in Figure 2. The maximum peak loads at the tapping point with 45 °C are 22.8 l/min for singles, 33.6 l/min for mixed households and 37.2 l/min for families.

The parameter variations of the reference system are listed in Table 2. The aim is to find a minimum storage volume for the 9 reference cases at which the PWH temperature does not fall below 60 °C at the outlet of the PWH storage. The results range from 200 l for the lowest to 800 l for the highest load.

Table 2: Parameter variation table of the reference system.

Circulation load (kW)	0.2, 1.0, 2.0
Tapping profile	Family, Single, Mixed
Storage volume (l)	200, 300, …, 1000

5. Evaluation

The key assessment parameters in this evaluation are the CO_2-equivalent emission and energy cost savings compared to the corresponding reference system. Firstly, the absolute values of the reference system and the systems with simple IWH (UA factor of 1 and without return valve) are compared with each other. Then the potential savings of the (regenerative) systems with IWH variation compared to the reference system are analyzed.

Various assumptions regarding energy costs and CO_2 equivalents are necessary for this comparison. Considering the upstream chain emissions, the values for Germany are shown in Table 3. However, these only represent a snapshot for Germany and are subject to fluctuations and trends. For Germany, the Climate Protection Act stipulates, that emissions in the electricity sector will fall from 257 Mt of CO_2 equivalents in 2022 to 108 Mt of CO_2 equivalents by 2030 (Agora Energiewende 2024). With a forecast electricity consumption of 658 TWh (Kemmler et al. 2021), this results in CO_2-equivalent emissions of 164 g/kWh without upstream chain emissions. If the upstream chain emissions for electricity are neglected, the ratio electricity/gas is already 0.71 in 2030 instead of 2.17 in 2022 and even heating directly with electricity emits fewer CO_2 equivalents than heating with gas.

Table 3: Energy costs and CO_2 equivalents for electricity and natural gas for Germany in 2022.

	Electricity	**Natural gas**	**Ratio**
Costs (€/kWh)	0.28 (Spiegel 2023)	0.0838 (Icha and Lauf 2023)	3.34
CO_2 equivalents (g/kWh)	498 (Statistische Bundesamt 2023)	230 (DVGW 2020)	2.17

The calculation of the CO_2 equivalent savings compared to the reference system with the same circulation load and tapping profile is carried out according to:

$$f_{\mathrm{save,CO_2}} = 1 - \frac{m_{\mathrm{CO_2}}}{m_{\mathrm{CO_2,Ref}}}. \qquad \text{(eq. 4)}$$

Equivalently, the energy cost savings are calculated according to:

$$f_{\mathrm{save,K}} = 1 - \frac{K}{K_{\mathrm{Ref}}}. \qquad \text{(eq. 5)}$$

The different ratio of emission factors and energy prices leads to a different weighting of the savings. The results based on costs and CO_2 equivalents can therefore also be applied to other assumptions. For example, a natural gas price of 13 ct/kWh leads to a ratio of 2.15 and the expected cost savings can be seen from the CO_2 equivalent savings.

In the calculations, only the heat pumps are considered, but not the pumps and control systems. However, these values are generally less than 1 % compared to the amount of heat transferred and it is assumed that they are the same in all systems.

Other parameters are important for the assessment: According to (VDI 2014), the solar fraction f_{sol} and the solar utilization factor η_{sol} are used to evaluate the ST&GB system. The solar fraction can also be transferred to the heat pump. The solar utilization factor is defined as the ratio of the amount of energy fed into the storage tank by the solar thermal system (system yield) Q_{sol} to the solar radiation energy H_{c}, which hits the collector surface A_{KF} within a year, to:

$$\eta_{\mathrm{sol}} = \frac{Q_{\mathrm{sol}}}{A_{\mathrm{KF}} \cdot H_{\mathrm{c}}}. \qquad \text{(eq. 6)}$$

To determine the solar fraction f_{sol}, the quotient of the annual solar system yield Q_{sol} and the sum of Q_{sol} and the system yield of the gas boiler Q_{boiler} is calculated as follows

$$f_{\mathrm{sol}} = \frac{Q_{\mathrm{sol}}}{Q_{\mathrm{sol}} + Q_{\mathrm{boiler}}}. \qquad \text{(eq. 7)}$$

According to (VDI 2019), the seasonal performance factor SPF_{HP} of the heat pump is determined from the ratio between the amount of heat generated Q_{use} and the electricity used for this W_{drive} within a whole year, to

$$SPF_{\mathrm{HP}} = \frac{Q_{\mathrm{use}}}{W_{\mathrm{drive}}}. \qquad \text{(eq. 8)}$$

According to (Baehr and Kabelac 2016), the GB utilization factor ω_{boiler} is calculated as follows

$$\omega_{\mathrm{boiler}} = \frac{|Q_{\mathrm{n}}|}{m_{\mathrm{fuel}}^{\mathrm{to}} H_{\mathrm{s}}}. \qquad \text{(eq. 9)}$$

$|Q_{\mathrm{n}}|$ is the usable heat supplied by the fuel input $m_{\mathrm{fuel}}^{\mathrm{to}}$ and the calorific value H_{s}.

To limit the scope, however, only isolated values are given.

Comparison of the systems

First of all, the results contain certain outliers. This has to do with the search for the lowest possible storage tank setpoint temperature. Due to unfavorable operating states, there is not one minimum storage setpoint temperature but sometimes several. Unfortunately, the use of the binary search means that the lowest minimum is not always found. This worked better with the ST&GB system than with the HP&GB and HP&EL.IWH system, as the temperatures there are often higher than the set temperature due to the solar thermal system.

For an initial overview, the 2022 CO_2 equivalents and the energy costs of the four systems above the circulation load and the tapping profile can be compared in Figure 3. To avoid giving the impression that the current installation of a heat pump with direct electric heating has even higher emissions over its lifetime than the reference system, the CO_2-equivalent emissions for the year 2030 are shown in the discussion in Figure 7. The next chapters will deal in detail with the savings that can be made by increasing the performance of the plate heat exchanger and the influence of the return flow distribution.

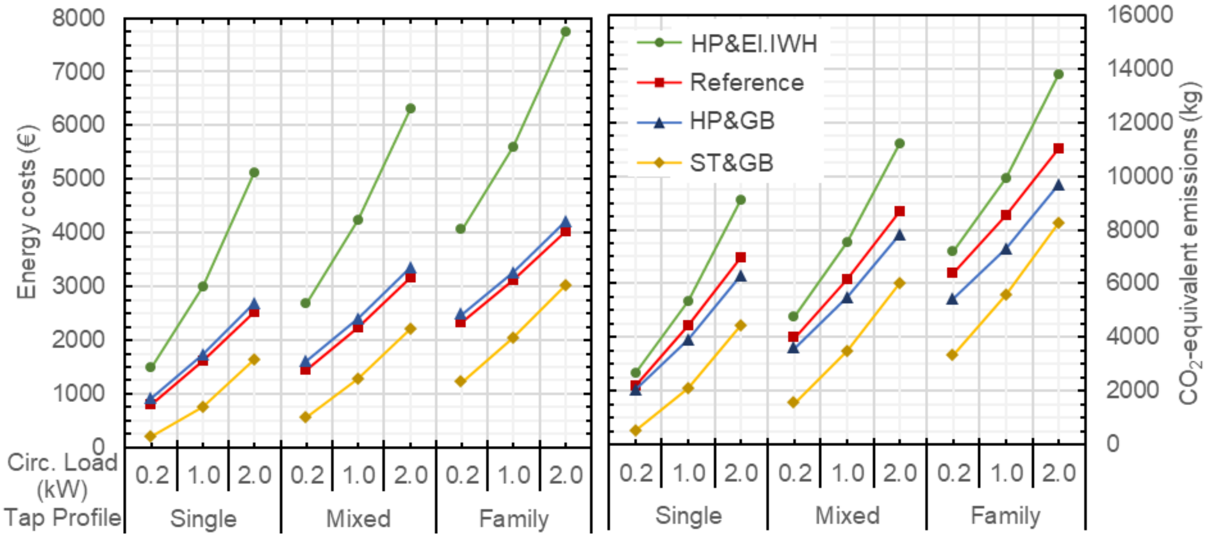

Figure 3: Comparison of the 2022 energy costs (left) and the 2022 CO_2-equivalent emissions (right) of the four systems over the circulation load and the tapping profile (with UA factor of 1 and without return valve).

The ST&GB system always has the lowest costs and emissions, as the radiation energy is free of emissions and costs. With low tapping profile and low circulation load, they can reach almost zero. However, the solar utilization rate then reaches its minimum at 18 %.

The emissions of the HP&GB system are slightly lower than those of the reference system, whereas the energy costs are slightly higher. This behaviour can be explained by the relationship between the energy costs and emissions of gas and electricity. In this system, the actual efficiency of the GB is between 0.7 and 0.8. Assuming an efficiency of 0.75, the ratio between gas and electricity is 2.5 for energy costs and 1.6 for emissions. The HP has an SPF of between 2.8 and 3.3, which means that emissions and energy costs are lower.

In the HP&El.IWH system, the El.IWH takes over the part of the gas boiler and operates with a significantly higher efficiency of 0.98. However, this cannot compensate for the approximately twice as high emissions and approximately three times higher energy costs of the electricity. As a result, the emissions are higher than with the reference system and the energy costs are significantly higher.

Solar thermal & gas boiler system

Figure 4 shows the potential savings of the ST&GB system with IWH variation in terms of CO_2 equivalents and energy costs compared to the respective reference system. With this system, it is possible to show all variations clearly in one diagram, as the results of the individual variations are identical in terms of savings in energy costs and CO_2 equivalents. They are therefore summarized below and described as savings.

A higher UA factor always has a positive effect on the savings. It can increase the savings by up to 8 % points. This influence is to be expected, as the temperatures in the storage tank are lowered with a higher UA value and the ST system can therefore provide a higher proportion of the heat generation. The influence is greater the larger the hot water demand and the smaller the circulation load.

In general, the lower the specific demand of the solar collector (kWh/m²) (Family→Single, circulation load = 2.0→circulation load = 0.2), the higher the savings from the solar thermal system. With higher circulation load, the return valve can be assessed as consistently positive. It can increase the savings by up to 8 % points. The shorter the changeover time and the higher the tapping profile, the higher the savings. This behaviour is to be expected, as temperature stratification is possible due to the return valve and is improved by a fast changeover time. This allows a cold zone to form in the lower part of the BS, which improves the temperature level for the ST system.

However, with circulation load of 0.2 kW and especially with low UA values and large tapping profile, the savings are reduced with slow return valve. This is due to the significantly poorer efficiency of the GB, which becomes worse as soon as a return valve is used. This effect is compensated for at high circulation load by increasing the solar utilization factor. However, at low circulation load, the solar utilization factor stagnates over the changeover time. In addition, the storage losses tend to stagnate over the tapping profile for circulation load of 0.2 kW, whereas they can fall by over 300 kWh (1.08 GJ) from without return valve to short changeover time for high circulation load.

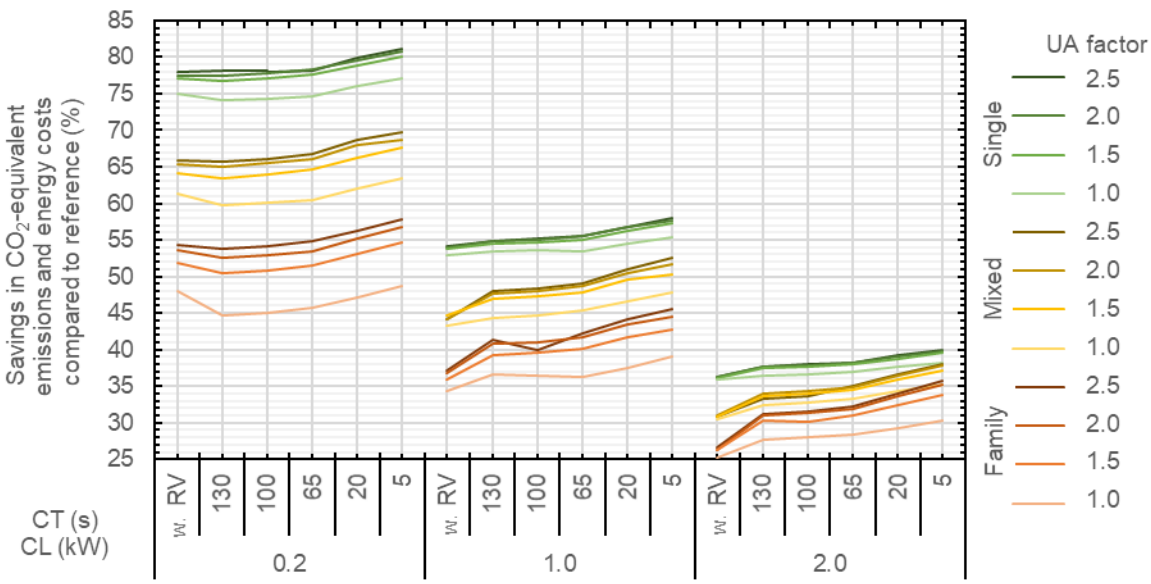

Figure 4: Illustration of the savings in CO_2-equivalent emissions and energy costs of the solar thermal & gas boiler system compared to the reference system via the changeover time (CT) of the return valve and the circulation load (CL) (w. RV: without return valve).

Heat pump & gas boiler system

Figure 5 shows the potential savings of the HP&GB system with IWH variation in terms of CO_2 equivalents and energy costs compared to the corresponding reference system.

The tapping profile has almost no influence on the CO_2 savings. For a better overview, only the tapping profile Family is therefore shown. With a low tapping profile and high circulation load, however, the savings from a higher UA factor are significantly smaller.

A higher UA factor always has a positive effect on the savings. It can increase the savings by up to 10 % points. The smaller the circulation load, the greater the impact. This influence is to be expected, as the temperatures in the BS are lowered with a higher UA value and the heat pump can therefore provide a higher proportion of the heat generation. In extreme cases, its share can be increased by up to 30 % points.

A return valve can minimize the savings with fast switching and low circulation load. If it switches slowly, however, it reduces the savings by up to 2.5 % points. Two effects work against each other here: The share of HP drops significantly with the introduction of a return valve (up to 25 % points), but then stagnates as the changeover time decreases. The SPF of the HP, on the other hand, increases continuously (by up to 0.25), while the degree of utilization of the GB first increases (by around 0.01) and then stagnates.

When analysing the energy cost savings, the savings of the tapping profile Mixed are not shown for reasons of clarity, as they lie between those of the two others. A higher UA factor always has a positive effect on the savings. It can increase the savings by up to 8 % points. The smaller the circulation load, the greater the influence. This influence is to be expected, as the temperatures in the BS are lowered with a higher UA value and the HP can therefore provide a higher proportion of the heat generation. A return valve usually increases the savings by a few % points. The impact of the effect is different here than with CO_2 savings, as the difference in costs between the heat generators is minimal and the efficiency benefits are more important here. The efficiency of both heat generators increases with a return valve and the lower the changeover time, the better the efficiency of the HP.

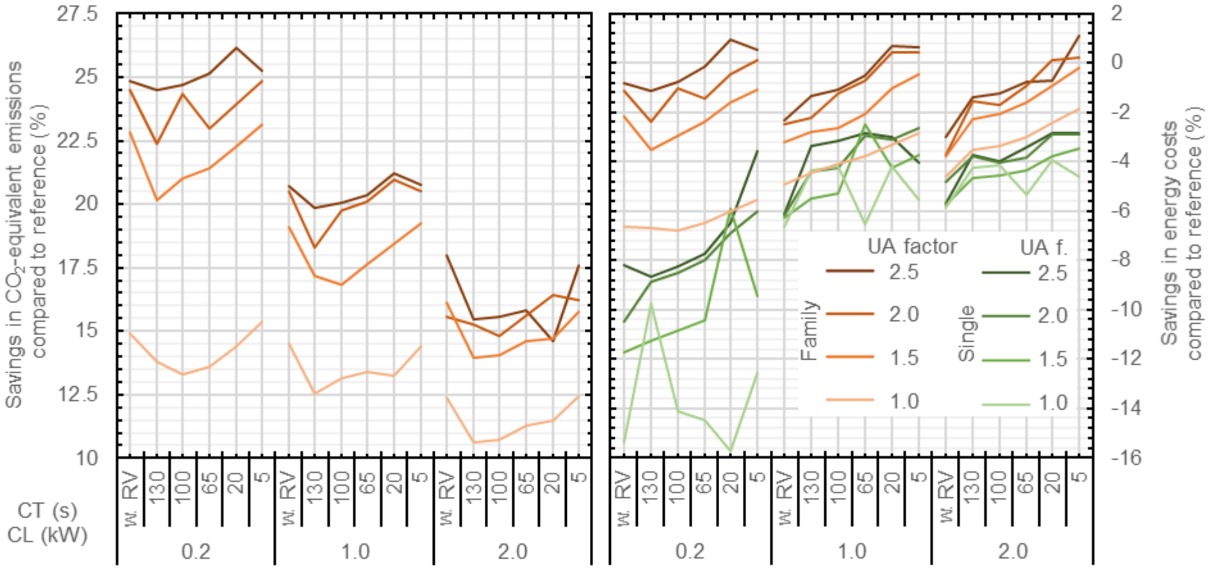

Figure 5: Illustration of the CO_2-equivalent savings (left) and the energy cost savings of the heat pump & gas boiler system compared to the reference system via the changeover time (CT) of the return valve and the circulation load (CL) (w. RV: without return valve).

Heat pump & electric instantaneous water heater system

Figure 6 shows the potential savings of the HP&El.IWH system with IWH variation in terms of CO_2 equivalents and energy costs compared to the reference system. The tapping profile has only a minor influence on the CO_2 savings. For a better overview, only the tapping profile Family is therefore shown. With a lower tapping profile and higher circulation load, however, the savings due to a higher UA factor are significantly smaller.

A higher UA factor always has a positive effect on savings. It can increase savings by up to 26 % points. The smaller the circulation load, the greater the influence. This influence is to be expected, as the temperatures in the BS are lowered with a higher UA value and the HP can therefore provide a higher proportion of the heat generation. In extreme cases, its share can be increased by up to 30 % points. The influence in this system is significantly higher than in the HP&GB system, where the HP already achieves more savings than the El.IWH from an SPF above 0.98.

A slow return valve usually reduces the savings significantly, in extreme cases by up to 10 % points. However, in the case of small circulation load, the savings can increase again with shorter changeover time, but usually not to the original level. Two effects work against each other here. The share of HP falls significantly with the introduction of a return valve (up to 25 %), but then stagnates as the changeover time decreases. On the other hand, the SPF of the HP increases continuously (by up to 0.25).

When analysing the energy cost savings, a higher UA factor always has a positive effect. Particularly in the case of small tapping profile, these can be very large and increase by up to 37 % points. This influence is to be expected, as the temperatures in the BS are lowered with a higher UA value and the HP can therefore provide a higher proportion of the heat generation.

A slow return valve usually reduces the savings significantly, in extreme cases by up to 15 % points. However, as the changeover time becomes shorter, they can increase again, but usually not to the level without return valve. The effect here is similar to that of emissions and contrary to the energy cost savings of the HP&GB system. Here it is always an advantage if the HP has a higher share of heat generation. The explained influences are significantly higher in this system than in the HP&GB system, as electricity performs significantly worse than gas in a direct comparison, even if the poorer efficiency of GB is considered.

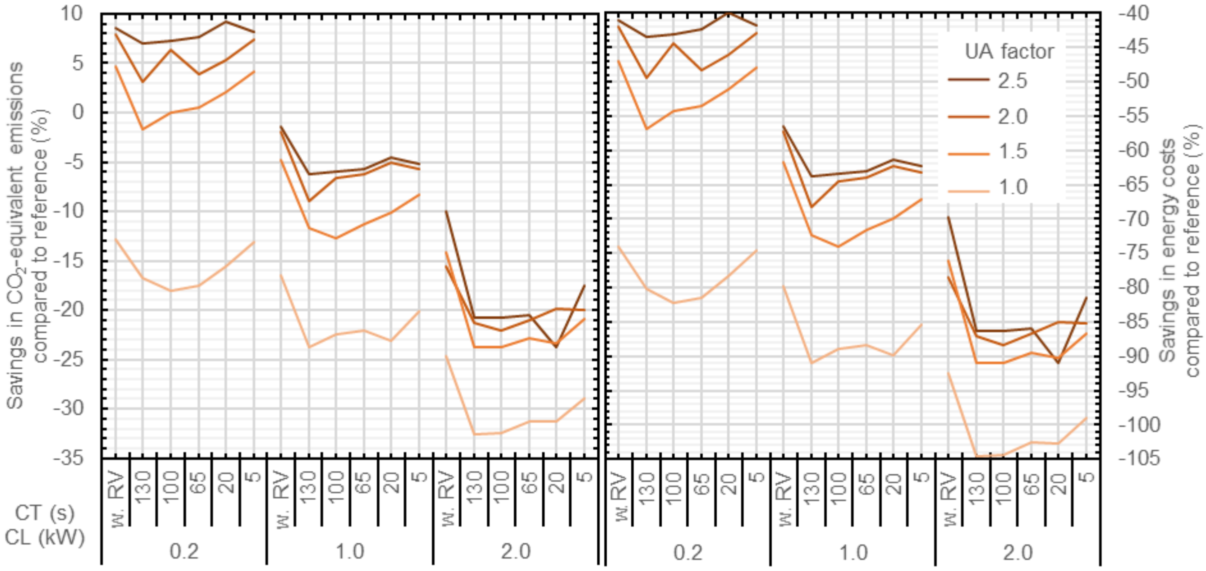

Figure 6: Illustration of the CO_2-equivalent savings (left) and the energy cost savings of the heat pump & electric instantaneous water heater system compared to the reference system via the changeover time (CT) of the return valve and the circulation load (CL) with tapping profile Family.

6. Summary

In this work, the influence of technical properties of IWH on the efficiency of three different (regenerative or hybrid) water heaters with BS was investigated. The central water heater supply 8-party apartment blocks with PWH. The results were compared with a fossil reference system.

In the reference system, the circulation load and the tapping profile were varied in three steps. In each case, the storage volume was minimized on a system-specific basis. For the three (regenerative) systems, the exact influence of the area-specific heat transfer coefficient (UA value) of the IWH and a return valve with variable changeover time was also analyzed. In addition, a minimization was carried out for the setpoint temperature in each case.

The focus of the analysis was on the savings in CO_2-equivalent emissions (ratio electricity/gas 2.17) and energy costs (ratio electricity/gas 3.34) of the hybrid systems compared to the reference system using higher-quality IWH in terms of UA value and a quicker return diversion with return valve or two pumps.

A higher UA value always has a positive influence on the savings. This is not the case for the return diversion.

In the case of solar thermal and gas boiler systems, a high UA value of the IWH can result in savings in emissions and costs of up to 8 % points. A return valve is advantageous at higher circulation load and can result in savings of up to 8 % points. Savings can also be reduced at lower circulation load. If a return valve is used, the lower the changeover time, the higher the savings.

The savings with the heat pump and gas boiler system can be increased by over 10 % points in terms of emissions by a high UA value, and by almost 7 % points in terms of costs. A slow return valve reduces the emission savings. return valves with short changeover time only have the same level as a IWH without return valve. However, the energy cost savings can be increased by a few % points with a fast return valve.

The heat pump and electric instantaneous water heater system can be significantly improved by a higher UA value of the IWH. The savings in emissions can be up to 26 % points, and in energy costs even up to 37 % points. A return valve, on the other hand, is always negative. The savings in emissions can be reduced by up to 10 % points and in energy costs by up to 15% points.

As this study could give the impression that the fossil reference system is better than the partially regenerative systems, the values for the year 2030 are shown in Figure 7. The figure shows that the HP&EL.IWH system will have the lowest emissions in just a few years, despite the direct electric heater. However, emissions from the HP&GB system will also fall significantly, while those from the other two systems will remain constant.

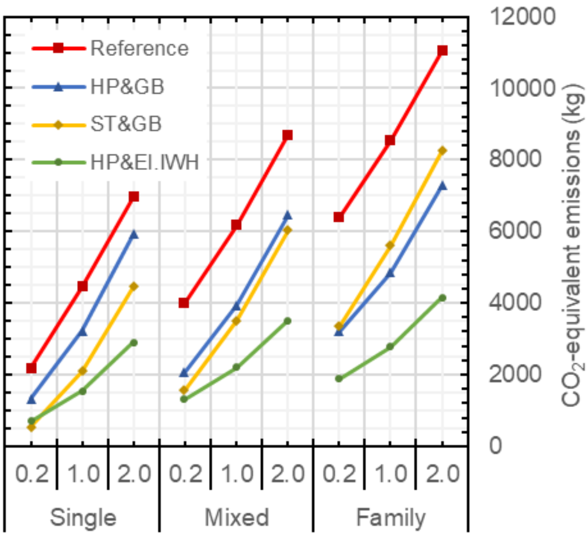

Figure 7: Comparison of the CO_2-equivalent emissions of the four systems over the circulation load and the tapping profile calculated with expected CO_2 emission factors for electricity in 2030 (with UA factor of 1 and without return valve).

In future, the linear search will be used to find the lowest target storage tank temperature. Although this requires more computing time, the global minimum will be found. The simulations are to be extended to include a monovalent heat pump system. Another relevant option in real life is the use of the roof area for PV to generate electricity for the heat pump. In further investigations, the systems are to be used to simulate real tapping profile for non-residential buildings. Possible optimization strategies will also be developed and tested.

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