Investigating Measures on Space Heating and Domestic Hot Water Preparation Systems in Residential Buildings Regarding their Impact on the Total Heat Demand and Return Temperatures in District Heating Networks

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Abstract

District heating can contribute substantially to a cost-effective decarbonization of the heating sector. Lowering the temperature levels of district heating systems is an important requirement for the efficient utilization of renewable energy sources. As return temperature reductions must precede flow temperature reductions, the consumers in a district heating system play a major role. This simulation study takes a closer look at four exemplary buildings space heating and domestic hot water preparation systems using TRNSYS and investigates influences on the total heat demand and return temperatures. In buildings with high energy efficiency standards the domestic hot water preparation makes up about half of the total heat demand and therefore has a very high impact on the total return temperatures. By reducing the circulation heat losses and switching from storage systems to instantaneous domestic hot water preparation, return temperatures can be reduced significantly. In existing buildings, with higher space heating demand, the space heating system design is a key driver for the total return temperatures. However, user behaviour and especially faults, like unnecessary bypasses also have significant influences and can raise return temperatures.

Keywords: Space Heating, Domestic Hot Water, District Heating, Return Temperatures, Heat Demand

1. Introduction

District heating (DH) systems allow to efficiently utilize renewable heat sources as well as excess heat for the supply of space heating (SH) and domestic hot water (DHW) in buildings. They are more cost-effective for densely populated areas and often more environmentally beneficial (Lake et al., 2017). Because of the aforementioned reasons, Werner (2017) concludes that DH systems have strong potential to be a viable heat supply in the future world. Nonetheless, currently district heating covers only approximately 13 % of the total heat demand of buildings in the European Union (Averfalk et al., 2021). Paardekooper et al. (2018) state that the further extension of thermal grids in Europe is substantial to enable better integration of excess heat sources and renewable heat. In addition to the further extension, lowering of supply temperature in DH grids facilitate the integration of these sources and increases energy efficiency (Averfalk et al., 2021). Lowering temperature levels often also involves reduced investment and operation cost. In existing DH networks a cost reduction gradient of about 0.11 to 0.49 €/(MWh·°C) could be found, while future economic benefits are estimated at about 0.50 €/(MWh·°C) (Averfalk et al., 2021).

In contrast the temperature levels during operation of present DH systems are on average about 10-15 K higher, compared with achievable temperature levels (Averfalk et al., 2017). This can be due to errors in customer substations or heating systems, which increase the return temperature and in turn result in higher supply temperatures (Averfalk et al., 2017, 2021). Hence, the customer installation and substation limit the opportunities to lower the DH network temperatures. Østergaard and Svendsen (2018) investigated heating system operation and occupant behaviour in five Danish single-family houses. Results showed that incorrect heating system design and control as well as occupant behaviour can cause higher return temperatures.

Best et al. (2020) assessed the impact of building systems engineering and building density on the return temperature for newly constructed districts and concluded that instantaneous DHW preparation achieves lower return temperatures. In addition, districts with higher building density show lower total return temperatures.

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Benakopoulos et al. (2021) gave an overview of solutions to achieve low return temperatures in DHW preparation systems with circulation. They identified minimizing the circulation heat losses as a key requirement for low return temperatures and made recommendations for the design of DHW preparation systems. Østergaard et al. (2021) investigated ten Danish buildings that showed low return temperatures in measurements and found that the single-family houses with the lowest return temperatures (25-30 °C) did not have DHW circulation systems.

In the present work, the impact of measures and user behaviour on the total heat demand and mean return temperature of four exemplary buildings is investigated. The buildings as well as SH and DHW systems are modelled and simulated. Two buildings represent existing single family (SFH) and multi-family houses (MFH), which have been partly refurbished. The other two buildings are the same SFH and MFH but considered as new buildings, with a high energy efficiency standard. The impact of measures and behaviour changes on the SH and DHW preparation systems are examined for the building types. Furthermore, the differences between the building types, regarding these parameters, are highlighted.

2. Simulation Models and Reference Conditions

This section gives an overview of the simulation models and reference conditions, which are used for the study. Two separate simulation models are developed for building and SH demand (2.1) and DHW preparation (2.2). Section 2.3 covers the methodology for the aggregation of simulation results of both models and the consideration of possible bypass flows. Fig. 1 shows a simplified hydraulic scheme of the whole system.

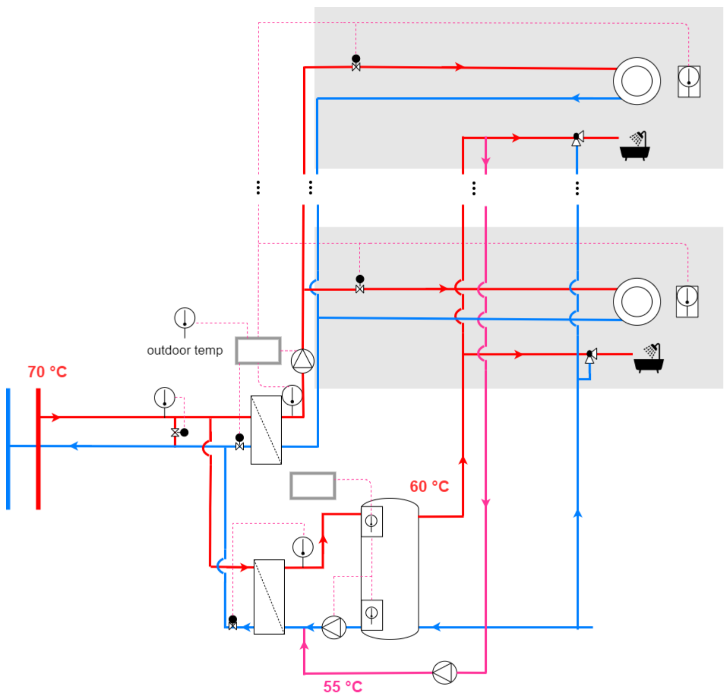

Fig. 1: Hydraulic scheme of the reference substation, space heating and domestic hot water preparation systems

2.1. Building and space heating

Two different residential buildings are generically designed and equipped with two different thermal envelope standards, resulting in four simulations models, which are modelled in TRNSYS 18 (University of Wisconsin, 2017). The building and flat layout is based on statistical data from the German federal office of statistics, while the thermal envelope is dimensioned according to literature values of existing buildings (Loga et al., 2012) or regulation for newly constructed buildings. The first type of building envelope called "refurbished" depicts an existing building in Germany with refurbished windows, roof and basement ceiling. For the second thermal envelope type the efficiency standard "new" is selected, which resembles a newly constructed building with even better structural quality of the building envelope ("KfW Efficiency Building 55") compared to the current minimal requirements given by the current German Building Energy Law (GEG, 2020). Tab. 1 gives general information and heat transmission coefficients of the buildings. The weather data acquired from the German weather service depicts a test reference year of Mannheim, Germany referring to the years 1995-2012.

Each building model is divided into thermal zones within TRNSYS. The SFH consists of eight thermal zones on two floors. The MFH is split into 16 thermal zones on four floors, each zone resembling a whole flat with a living area of 72 m². In addition, a not-heated stairwell is included in the center of the MFH building. Each thermal zone, except the hallway, is equipped with one SH device including a thermostatic valve (THV) modelled as purely proportional controller (TRNSYS-Type 1669). In the refurbished buildings these devices are convectors (Type 362) with a proportional band of 2 K, while all newly constructed buildings are heated by floor heating systems (Type 653) with a proportional band of 1 K. The SH devices are dimensioned in a common way by using the German norm DIN 12831-1 that takes the worst-case outdoor conditions, infiltration and ventilation air change rate as well as a room set point temperature of 20 °C as input. Design temperatures for the convector are 65/45 °C and for floor heating 35/25 °C. The pipe length and diameter are estimated in accordance with the German norms DIN 18599-5 and DIN 1988-300, respectively. The pipework is modelled with Type 604. The supply temperature of the heating system is controlled by a linear heating curve depending on the outdoor temperature. In Addition, internal heat gains by inhabitants as well as technical devices in accordance to German norm DIN 18599-10 are considered in the building model. Internal heat gains by humans are considered independently of the actual number and presence of inhabitants and add up in SFH and MFH to 45 and 90 Wh/(m^2·d), respectively. Technical devices are assumed to constantly deliver 12 Wh/(m^2·d).

Tab. 1: Parameter of the building model. A_{env}: Building envelope area; V_{gross}: Gross volume of building; H'_T: Resulting total specific transmission coefficient for heat-transferring enclosing surface

General Information	B1	B2	B3	B4
Building Type	SFH		MFH	
Number of housing units	1		16	
Gross living area in m²	177		1,257	
A_{env}/V_{gross}	0.63		0.3	
Building envelope standard	Refurbished	New	Refurbished	New
Q_{sh} in kW (DIN 12831-1)	14.3	5.7	57.5	22.4
Heat transmission coefficients in W/(m²·K)				
Outer walls	1.42	0.2	1.42	0.2
Windows (U_w)	1.3	0.95	1.3	0.95
Roof	0.3	0.12	0.3	0.12
Basement ceiling	0.3	0.22	0.3	0.22
Total coefficient H'_T	0.93	0.31	1.16	0.39
Infiltration and Ventilation				
Air change rate by Infiltration	n = 0.14	n = 0.07	n = 0.14	n = 0.07
Window ventilation	Yes	Yes	Yes	Yes
Air change rate through window	n = 0.5	May-Aug: n = 0.5 Sep-Apr: n = 0.1	n = 0.5	May-Aug: n = 0.5 Sep-Apr: n = 0.1
Air ventilation system	No	Yes	No	Yes
Air change rate	-	May-Aug: n = 0.0 Sep-Apr: n = 0.4	-	May-Aug: n = 0.0 Sep-Apr: n = 0.4
Heat recovery	No	Yes (0.8)	No	Yes (0.8)

2.2. Domestic hot water preparation

The useful energy demand for DHW is calculated as a function of the buildings living area as defined in the German norm DIN 18599-10. The energy demand is converted into a mean daily draw-off volume, which is entered as input into the program DHWcalc (Jordan and Vajen, 2001). DHWcalc is used to generate draw-off profiles in a 3-minute time step, which are read into the simulation model that simulates the DHW preparation systems.

As the reference system, a storage system is chosen according to Fig. 1. The storages are dimensioned according to the German norm (DIN 4708). As indicated in Fig. 1, two temperature sensors are installed inside of the storage. One sensor is placed at the top of the storage. When the temperature at this sensor drops below 60 °C, the pump in the charging cycle for the storage is switched on, which charges the storage with a constant mass flow. The pump is switched off when the temperature at the second sensor, which is placed at 20 % of the storage height, is above 60 °C. The storage is modeled with a stratified storage model (Drück, 2006). The heat loss coefficient is calculated according to the EU's energy efficiency label (European Commission, 2013). For the reference case an efficiency label class B storage is chosen. The resulting heat loss coefficient is multiplied with a correction factor of 1.2 to into account take possible installation errors of the insulation.

A DHW circulation system is considered in all buildings. In the SFH, the circulation system is installed between the substation and every draw-off point. In the MFH, only the supply towards every living unit is part of the circulation system. The distribution pipes inside the living units are not part of the circulation system. The return temperature of the circulation system is set to 55 °C, which is a requirement of German regulation for the prevention of legionella (DVGW, 2004). The circulation return is not connected to the storage but flows directly into the heat exchanger (see Fig. 1). In the reference case, the circulation system is operated constantly, without interruption. The pipe lengths are estimated according to a study conducted in Germany by Jagnow et al. (2010). The dimensioning of the distribution and circulation pipes is carried out by the same methodology described by Braas et al. (2020). The heat exchanger for the DHW preparation system is dimensioned for the simultaneous operation of the storage charging cycle and the circulation system. A temperature difference of 3 K between the outlet temperature on the hot side and the inlet temperature on the cold side is considered for the dimensioning of the heat exchanger. All parameters for the reference DHW preparation system are summarized in Tab. 2.

Tab. 2: Parameters for reference DHW preparation systems

Building	SFH	MFH
Occupants	3	29
Specific DHW demand in kWh/(m²·a)	8.5	12.9
DHW demand at 60 °C in l/d	65	702
Storage volume in l	120	400
Storage heat loss rate in W/K	1.9	2.9
Storage charging flow rate in l/h	60	230
Circulation flow rate in l/h	34	209
UA-Value HX in W/K	764	3,019
DHW peak load in kW	3.9	15.4

2.3. District heating grid, result aggregation and primary bypass

As this work concentrates on heat supply systems within buildings, the district heating grid is not part of the simulation models. Nevertheless, a district heating supply temperature had to be determined to investigate the thermal behaviour of the substations and heat supply systems in buildings. A generic low-temperature district heating grid with a supply temperature of 70 °C at the substation is assumed. This supply temperature is high enough to both supply SH for the refurbished existing buildings and guarantee hygienic requirements of DHW. The supply temperature is assumed constant during the year.

The simulation results yield mass flowrates and return temperatures on the primary side of the two separate heat exchangers. To calculate total return temperatures these mass flows are mixed (eq. 1).

$$T_{return,tot} = \frac{T_{return,dhw} \cdot \dot{m}_{dhw} + T_{return,sht} \cdot \dot{m}_{heat}}{\dot{m}_{dhw} + \dot{m}_{heat}} \qquad \text{(eq. 1)}$$

To assess influences on the total return temperature, a yearly mean return temperature is calculated by weighting every time step's return temperature with the corresponding total mass flow rate (eq. 2)

$$\bar{T}_{return} = \frac{\sum_{t=1}^{t_{end}} (T_{return,tot,t} \cdot \dot{m}_{tot,t})}{\sum_{t=1}^{n} \dot{m}_{tot,t}} \quad \text{with} \quad \dot{m}_{tot,t} = \dot{m}_{dhw,t} + \dot{m}_{heat,t} \qquad \text{(eq. 2)}$$

In periods with no or low demand, the house connection pipe and fluid can cool down. This can result in lower DHW preparation comfort as hot water preparation takes longer, especially if instantaneous DHW preparation is considered (see section 3.2). This issue can be solved in practice, by installing a primary bypass, which increases the supply temperature in the pipe in periods with low demand by using a bypass flow (Brand et al., 2014). The effect of such a primary bypass on the total return temperatures is estimated by considering house connection pipes, with a length of 20 m in each building. The pipes are dimensioned considering the peak load of each building. A high insulation standard (series 3) is considered. The necessary bypass mass flow is a function of the heat loss of the supply pipe and the bypass set temperature, which defines the lowest allowed temperature at the heat exchangers. The set temperature is varied to assess sensitivities. The pipe dimensions and specific heat loss ratios are given in Tab. 3.

Tab. 3: Pipe dimension and specific heat loss ratio for house connection pipes. The specific heat loss ratio is in relation to the temperature difference between the DH medium and surrounding ground temperature.

	SFH New	SFH Refurbished	MFH New	MFH Refurbished
DN	20	20	20	25
Insulation thickness in mm	49.0	49.0	49.0	45.7
Spec. heat loss ratio in kW/K	1.98	1.98	1.98	2.30

3. Investigated Measures and Influences

In this section the investigated measures and influences on the SH (3.1) and DHW (3.2) systems are described.

3.1. Space heating system

Measures examined for the SH system include user behaviour and system design. First, the impact of occupant behaviour on return temperatures and heat demand is assessed. Second, the influence of a neglected residue of older heating systems on a DH substation is tested, which is a realistic case after conversion of the heat generation unit (Averfalk et al. 2017).

1. Variation of user behaviour: room set point temperature

User behaviour is without doubt an unpredictable influence factor on heating systems and therefore on district heating systems (Østergaard and Svendsen, 2018). Consequently, the influence of an increasing room set temperature is examined. In four separate steps, the set point temperature is increased from 20 °C in the reference scenario in 1 K steps up to 24 °C. The room set temperature is changed in the thermostatic valve which every SH device is equipped with. Each room set point temperature is kept constant during the year.

2. Variation of user behaviour: window ventilation

Additionally, the influence of increased and decreased ventilation through windows is examined. The air change rate of the reference scenario is first doubled and then halved. The air change rate through windows in winter is assumed to be lower than in the refurbished buildings (see Tab. 1), because the new buildings are equipped with a mechanical ventilation system with heat recovery. Accordingly, the hourly air change rates in winter differ from the air change rates in summer in the new buildings. Tab. ***4*** shows an overview of the applied air change rates per building standard.

Tab. 4: Air change rates of the different buildings in the reference scenario compared to the measures concerning ventilation through windows.

Air change rate in h^{-1}	Reference scenario	Measure 1	Measure 2
Refurbished Building	0.5	1.0	0.25
New Building	May-Aug: 0.5 Sep-Apr: 0.1	May-Aug: 1.0 Sep-Apr: 0.2	May-Aug: 0.25 Sep-Apr: 0.05

3. Secondary bypass

Old heating systems in existing buildings using an oil boiler is usually equipped with a three-way diverting valve which maintains a certain return temperature to the heat generation unit (Averfalk et al., 2017). As reported by Averfalk et al. (2017) the removal of this diverting valve may have been overlooked in some cases. Accordingly, a hot short-circuit flow passes the thermostatic controlled valve and keeps the return temperature above a certain temperature. The former purpose of these valves was to maintain a certain temperature in the combustion chamber and therefore avoid condensation inside the boiler. However, in SH systems supplied by DH this is an unfavorable feature, which will lead to elevated primary return temperature. In the TRNSYS models a thermostatic controlled valve is implemented on the secondary side to maintain a return temperature of 50 °C. As this scenario is only likely to happen in existing buildings this feature is only examined in models with refurbished buildings.

3.2. Domestic hot water system

The investigations for the DHW preparation systems include changes to the circulation system control as well as pipe and storage insulations. Additionally, the influence of substation design and design temperatures on return temperature and heat demand is assessed.

1. Circulation Shutdown

For this measure, the circulation system is shut down for 6 hours between 11 pm and 5 am. For houses with more than two living units, German regulations (DVGW, 2004) allow the circulation system to be shut down for a maximum of 8 hours per day. Compared to the reference case this measure is expected to reduce the heat losses of the circulation system by approximately 25 %, as the system is shut down for ¼ of the time. As the circulation system is generally causing high return temperatures, reducing the operation time should also lead to reduced total return temperatures.

2. Ideal Circulation

For this measure it is assumed, that the user activates the circulation system, before tapping hot water. In the simulation, the circulation system runs for one time step before every draw-off occurrence. This measure is only considered in the SFH, as it does not conform with German regulations (DVGW, 2004) for MFH. It is expected that the heat losses of the circulation system, as well as the return temperatures of the total DHW preparation system will be drastically reduced, as the circulation period is much shorter.

3. Increased Pipe Insulation

As stated before, the distribution and circulation pipes for DHW are insulated according to the German building code (GEG, 2020). For this measure, the pipe insulation thickness is doubled. By this, the heat losses of the distribution and circulation should be reduced, which is expected to reduce the heat demand and yield lower return temperatures.

4. Increased Storage Insulation

For this measure, the storage (efficiency label B) is replaced by a storage with a higher level of insulation (efficiency label A). Thus, it is expected that the storage heat losses will be reduced by more than 50 %. As the heat demand for storage heat losses must be met at high temperatures, it is also expected, that return temperatures will be reduced. However, the effect will probably be neglectable in the MFH, as the storage heat losses are very low compared to the total heat demand for DHW.

5. Two Stage Heat Exchanger

Examples from literature (Zeisberger, 2017; Johansson et al., 2009) show that by using two heat exchangers for DHW preparation, return temperatures can be reduced, because the primary flow that reheats the return of the circulation system can be cooled down by DHW demand (Fig. 2). shows a hydraulic scheme. This measure is only considered in MFH, as the added complexity is expected to exceed the benefits in SFH.

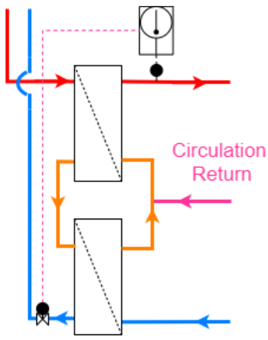

Fig. 2: Two stage domestic hot water preparation system

6. Instantaneous DHW Preparation

Instead of charging a storage, DHW can be heated instantaneously by a heat exchanger. This setup leads to much larger heat exchangers and peak loads but promises lower return temperatures as shown by Best et al. (2020). For the SFH, the peak load increases to 34 kW. For the MFH the increase is lower (100 kW), because of simultaneity effects. The increased peak load is also taken into account for the dimensioning of the house connection pipes, which are considered to assess the influence of bypass flows. For the SFH the house connection pipe dimensioned stay unchanged. For both MFH DN32 pipes with a specific heat loss of 2.51 kW/K must be installed.

7. Reduced Supply Temperature

The DHW supply temperature of 60 °C is required for hygienic reasons (legionella). German regulation (DVGW, 2004) however does not make requirements if the total DHW systems pipe volume is below 3 liters. This can be achieved by separating the supply towards and the distribution inside apartments of the MFH with additional heat exchangers. This decentralized DHW system is investigated for the new MFH. The flow temperature of the DH system is assumed 55 °C at the substation instead of 70 °C during the reference scenario. Inside the building, the set point temperature in the storage is set to 48 °C, while the DHW is supplied at 45 °C inside the apartments. For the new SFH a supply temperature of 45 °C is also assumed. As the regulations do not apply in SFH, no additional heat exchangers are needed. As the circulation system is running at much lower temperatures, it is expected that both the heat demand as well as the return temperatures will be reduced for these systems.

4. Results & Discussion

4.1. Final Energy Demand

On the top of Fig. 3 the yearly mass flow weighted return temperatures for the SH system, the DHW preparation system as well as the total mixed return temperature (see eq. 2) are depicted. On the bottom the specific heat demand for each building type is shown. The heat demand is composed of useful energy demand and heat losses for each SH and DHW.

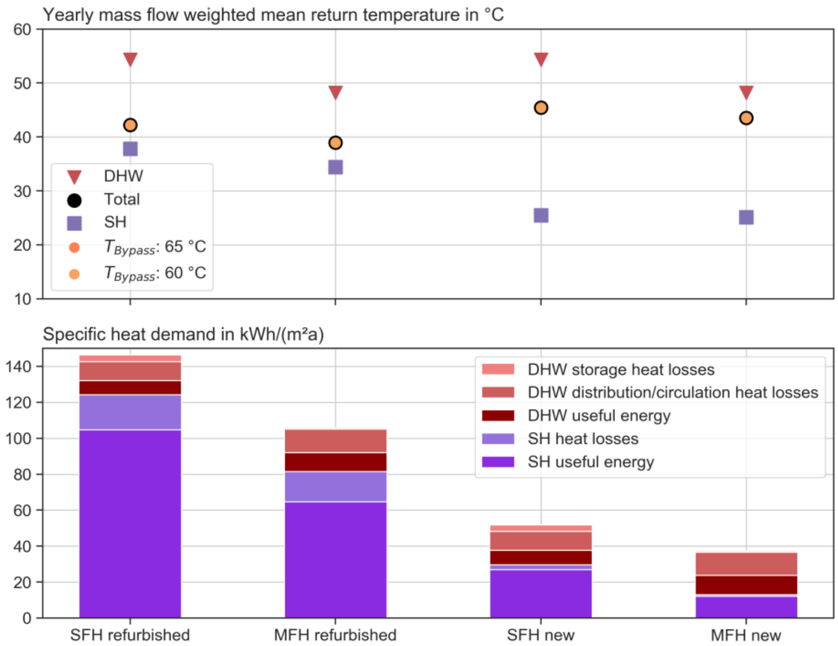

Fig. 3: Simulation results for all reference buildings. Top: Yearly mass flow weighted mean return temperatures for SH, DHW and total. Total return temperature without (black) and with bypass influence (orange). Bottom: Specific heat demand divided into SH and DHW demand as well as useful energy and heat losses

For SH in the new buildings the heat losses are a rather small portion of the total heat demand (7 to 9 %). In the refurbished buildings, the heat losses represent a higher share (16 to 21 %). For DHW the heat losses make up 56 to 64 % of the total DHW demand. In the MFH the storage heat losses are marginal compared to the total DHW heat demand (2.6 %).

Looking at the return temperatures it is obvious that the DHW systems have very high return temperatures (48 to 54 °C). As the MFH are more densely populated, the share of circulation heat losses, which cause high return temperatures, is lower compared to the SFH. Thus, the return temperatures in the MFH are lower than in the SFH. The SH return temperatures are dependent on the heating system: in the new buildings, the floor heating system yields very low return temperatures at about 25 °C. In the refurbished buildings with convectors, the return temperatures are higher (34 to 38 °C). The total return temperatures are closer towards the SH return temperatures in the refurbished buildings because the SH system has a much higher (77 to 85 % of total heat demand) energy demand than the DHW system (15 to 23 %). In the new buildings, the DHW systems are dominating the total return temperatures. This is because the energy demands are at about the same level (DHW: 43. 65 %; SH: 35 to 57 %), but because of the high return temperatures, the DHW has much higher mass flows. The influence of the bypass is neglectable in all reference cases, since the circulation systems are always running.

4.2. Measures on the space heating system

Fig. 4 shows the resulting return temperatures and specific heat demands of five measures on the SH system for the refurbished SFH and MFH, respectively, compared to the reference scenario. With increasing room set point temperature up to 24 °C (see no. 1a, b) there is a clear trend to increasing primary return temperatures in existing refurbished SFH and MFH. The increase from 20 to 24 °C room set temperature results in a total increase of the primary return temperature of the SH heat exchanger of 7.2 K in SFH and 6.6 K in MFH. This indicates a rising return temperature of approximately 1.7 K per 1 K increase of the room set point temperature. Whereas the total primary return temperature increases slightly less by 4.3 and 3.7 K in SFH and MFH, respectively. Additionally, the specific heat demand rises, which is, in combination with increasing return temperatures, the worst case for a DH network.

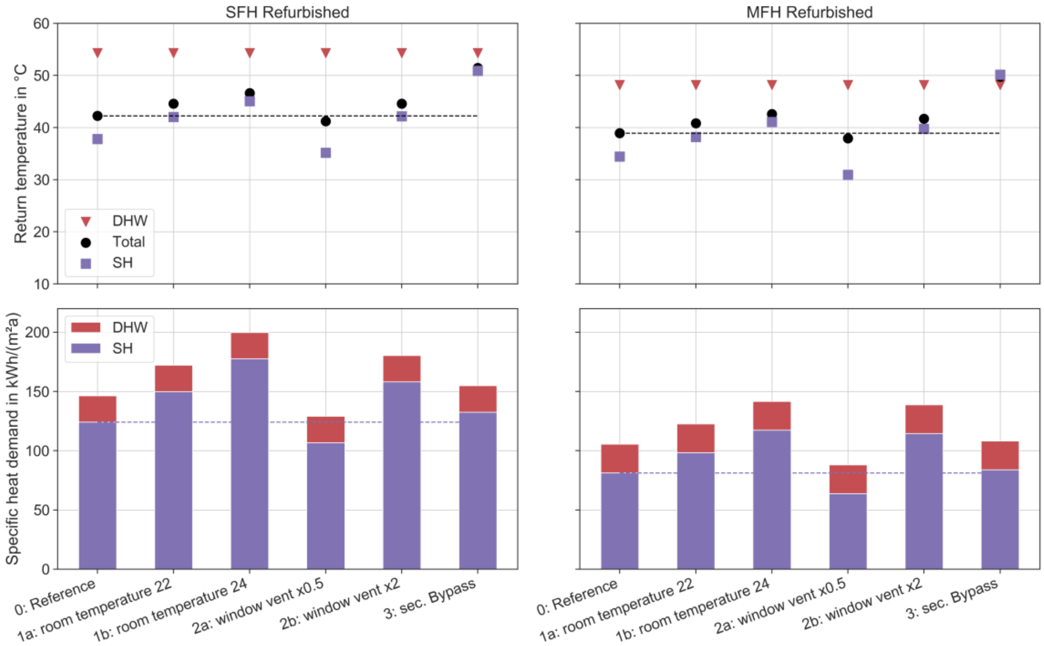

Fig. 4: Return temperatures and specific heat demand of reference scenario compared to different space heating measures in the existing refurbished SFH and MFH.

An explanation for this are the undersized SH devices for this load, leading to insufficient cooling of the SH mass flow. SH devices were originally designed to heat the room to 20 °C. Consequently, the insufficient cooling of the mass flow results in rising primary and secondary return temperatures. The heat transferring power of SH devices is essentially dependent on the heat transferring area and the temperature difference between the device and the room air. Increasing the room set point temperature at the thermostatic valve (THV) increases the valve opening. As a result, the THV closes slower depending on the room air temperature. A high mass flow but not enough power due to lower temperature difference leads to insufficient cooling of the mass flow and increasing heat demand. A similar case occurs when the actual ventilation through windows is higher than assumed during the dimensioning process (see no. 2a, b). Although there is a slightly lower mean room air temperature over the year and therefore, the temperature difference of SH device and room air temperature is higher, the mass flow running through the SH device cannot be sufficiently cooled. This discrepancy indicates that the configuration of the THV plays a crucial role. Østergaard und Svendsen (2018) also conclude that improper mass flow can cause higher return temperatures. Reversely, the primary and secondary return temperature decreases with lower ventilation. In this case, the partial load results in stronger cooling of the SH mass flow compared to the reference scenario leading to lower return temperatures.

For the new buildings, the reported findings for the measures are similar when comparing the SH return temperature, but not when comparing the total primary return temperature. The total primary return temperature falls when a higher room set temperature is applied, because the share of SH demand in total heat demand increases. As the return temperature from floor heating is only around 25 °C, the higher influence of SH lowers the total return temperature but increases the heat demand. As the new building is equipped with a mechanical ventilation including heat recovery, the influence of higher or lower ventilation is practically not given.

The effect of a secondary bypass shows a slightly increased heat demand as well as a return temperature constantly around the set point of the bypass (see no. 3). In the analyzed case, the set point is set to 50 °C, which is close to the reported mean return temperature.

4.3. Measures on domestic hot water system

Fig. 5 shows the results for the measures on the newly constructed SFH. The measures are numbered according to the numeration in the previous section. The results A, B and C represent combinations (see Fig. 5) of different measures. The results show that the circulation shutdown and increased pipe insulation have similar effects (see no. 1 and 3). The circulation heat losses are reduced, which also leads to reduced total return temperatures. For the storage system, the largest impact is reached by the ideal circulation (no. 2), which leads to a total return temperature below 40 °C. Increasing the storage insulation (no. 4) also reduces the energy demand and yields a small return temperature reduction (1.7 K). By combining the measures for the storage system (A), the total heat demand can be reduced by 21 % and the total return temperature reduced by 12 K.

Changing to instantaneous DHW preparation (no. 6) reduces the heat demand, as there are no storage heat losses. In the reference case the total return temperature is reduced substantially (-5 K). By adding the ideal circulation and increased pipe insulation (B), the return temperature of the DHW system is reduced below 20 °C.

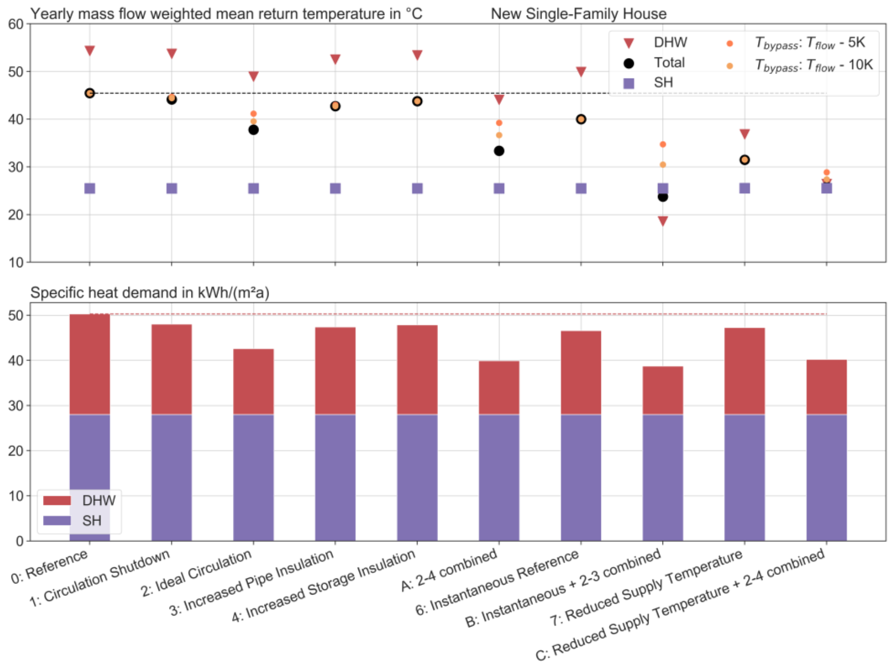

Fig. 5: Simulation results (return temperatures and specific heat demand) for measures on the new SFH

The results of all variants considering a primary bypass show that a bypass flow becomes necessary when the operation time of the circulation system is reduced. For the instantaneous system, the need for a bypass flow is higher. A bypass at a constant temperature of 60 °C would increase the total return temperature for the “ideal” instantaneous system (B) by 6.7 K. Still, the return temperature would be lower than for the storage system.

By reducing the DH supply temperature (no. 7), the return temperature is also reduced because the circulation system is running on lower temperature levels. This also leads to a small reduction (6 %) in the total heat demand. Considering ideal circulation and increased pipe insulation, total return temperatures of approx. 25 °C can be reached. The influence of the bypass is smaller because the heat losses of the house connection pipe are also reduced due to the lower flow temperature.

For the refurbished SFH, the results are similar. However, because of the high SH demand, the effect on the total return temperature is a lot smaller. The instantaneous DHW preparation with ideal circulation, which has the highest potential to reduce return temperatures, only reduces the total return temperature by 5.4 K (from 42.2 to 36.8 °C). The bypass' influence is also reduced, as the heating period is longer.

The results for measures on the DHW system for the newly constructed MFH (Fig. 6) show the same tendencies as for the SFH. The effects on the total return temperature are higher because the share of DHW on the total heat demand is higher. Reducing the circulation heat losses through circulation shutdown (no. 1) or increased pipe insulation (no. 3) leads to reduced return temperatures. Increasing the storage insulation has almost no effect in MFH. As expected, changing the substation type to a two-stage heat DHW preparation system reduces the return temperature. By combining the measures for the storage system, the return temperature can be reduced by 8.5 K (from 43.5 to 35.1 °C). This also yields a total heat demand reduction of 12 %. An even higher return temperature reduction can be reached with instantaneous DHW preparation (11 K to 27.9 °C). As for the SFH, reducing the supply temperature also yields very low return temperatures of about 25 °C. Because of the more evenly distributed DHW load in the MFH, the primary bypass has very low impact on the results.

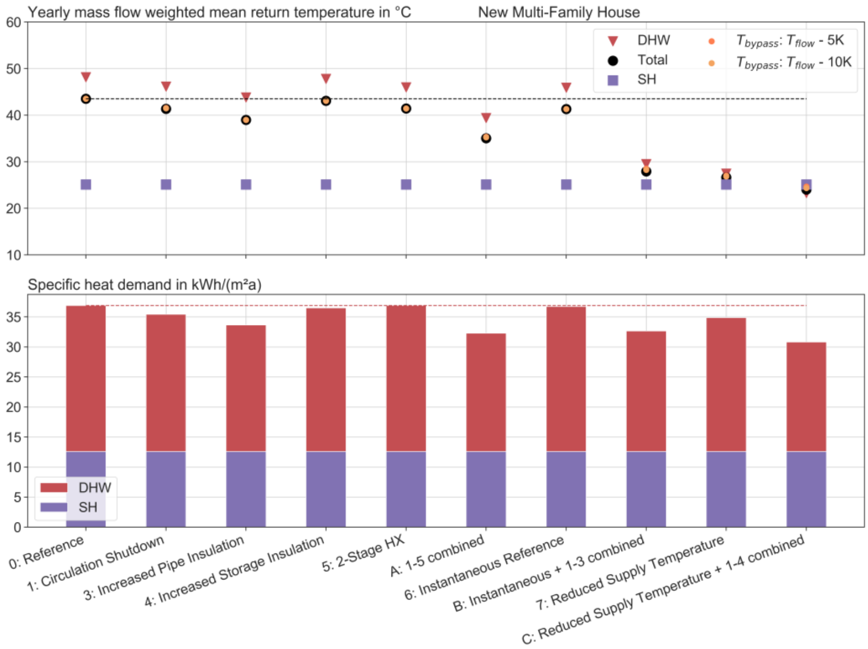

Fig. 6: Simulation results (return temperatures and specific heat demand) for measures on the new MFH

5. Conclusions

The relation of DHW to the SH demand highly depends on the building envelope, the SH and ventilation system as well as the relation of envelope area to gross volume of the building (higher in SFH than in MFH). For new buildings, the DHW demand makes up 44 and 66 % of the total heat demand for SFH and MFH, respectively. This has crucial impact on the district heating system supplying these buildings. With a higher share of DHW demand, the heat demand in the summer becomes more important, which for example make higher shares of solar thermal heat supply economically feasible. In addition, the increasing importance of energy efficient DHW systems that yield low return temperatures has to be emphasized, especially with the ongoing improvement of the thermal building envelope.

For all reference buildings, the return temperatures from the DHW preparation system (48 to 54 °C) are higher than for the SH systems (25 to 38 °C). In the refurbished buildings, the SH system is the primary driver of the total return temperatures. In the new buildings the DHW preparation system is the primary driver. Thus, measures on the DHW system have higher influence on the total return temperatures in the new buildings, while in the refurbished buildings measures on the SH system have higher influence. Notably, measures on the SH system that increase the return temperature as well as the heat demand of the SH system, yield lower total return temperatures in new buildings.

For SH systems in the refurbished buildings, the results show that if the actual heat load is higher than assumed for the dimensioning of the system (due to higher room temperatures or window ventilation) the return temperatures increase significantly. Therefore, considering occupant behaviour in combination with SH system design is essential when low return temperature is the objective. The results for the secondary bypass show that they must be removed to allow the efficient operation of DH systems, when connecting old buildings to a DH network.

The investigated measures for the DHW systems show that the key to reducing return temperatures is reducing the heat losses (storage and circulation) of the system. The best solution for SFH is to omit circulation systems altogether as they are mostly used for comfort reasons. If this is not possible, it is important to find intelligent control solutions that reduce the operation time as much as possible. This can be intelligent controls that learn the user behaviour or technical solutions, which allow the users to activate the circulation system manually. For MFH circulation shutdown times are beneficial. Whether increasing the pipe or storage insulation is economically feasible is not investigated in this work. On the one hand additional costs and potential space requirements must be considered. On the other hand, the end user saves energy costs because of the reduced heat losses. Additionally, the return temperature reduction might favor the DH systems heat supply, capacity and pumping costs.

Switching from DHW preparation systems with storage to instantaneous systems can yield greatly reduced return temperatures, even when a primary bypass is considered. In this case, too, the additional costs (larger heat exchanger, possibly larger house connection pipe) must be weighed against the benefits (lower return temperatures).

By installing decentralized heat exchangers in every apartment of multifamily houses, the supply and return temperatures of DH systems can be reduced without the risk of legionella growth. This can have many benefits for the DH system. However, the additional costs for the heat exchangers could outweigh the benefits.

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