MODELLING AND SIMULATION OF INNOVATIVE DECENTRAL DOMESTIC HOT WATER SYSTEMS WITH HEAT PUMPS FOR MULTI-FAMILY BUILDINGS

F. Ochs[1], S. Breuss[1], E. Venturi[1], M. Magni[1], G. Dermentzis[1] and S. Fisco[1]
[1]University of Innsbruck, Unit for Energy Efficient Buildings
E-Mail: Fabian.Ochs@uibk.ac.at

ABSTRACT

Designing cost-optimal and efficient DHW systems for multi-family buildings (MFB) that allow providing a high level of comfort as well as following the hygienic requirements is not trivial. Building and HVAC simulation can help to improve the system design, to find appropriate dimensioning of the components, to improve control strategies and set points, to assist in commissioning the system and finally to detect and fix faults. In order to meet these requirements different decentral heating systems for MFBs were proposed and tested recently.

For decentral, i.e. flat wise DHW preparation systems, it is challenging to model the different scales (flat, building, HVAC system) at different design stages (pre-design, design, commissioning, operation, fault detection) appropriately. DHW comfort (i.e. delay times) can be modelled only on the level of the flat, while the energy performance (distribution and storage losses, efficiency of HVAC system) can only be investigated on building or even district level.

For the entire building, if all flats would be simulated together, different profiles need to be generated in order to account for different times of use (simultaneity of DHW use). Accordingly, stochastic or “smoothed” tapping profiles are required. For large buildings with more than 10 flats such an approach would lead to a very heavy simulation model with extensive simulation times. Contrariwise, a “lumped” model with one heat exchanger would be easy to use but could not predict the dynamics and the return flow temperature correctly.

The paper discusses several modeling approaches and presents results of a case study with decentral DHW heat exchanger in combination with flow type post heater.

INTRODUCTION

In order to reach the goal of a sustainable energy system, the building stock needs a deep refurbishment and new buildings need to be build such that they correspond to best energy standards (nZEB, Passive House), while cost-optimality needs to be considered (EPBD). In these high performance residential buildings, the domestic hot water demand (DHW) has a high to very high contribution (Gustafsson et al. (2014), De Conick et al. (2013)). The useful energy is in the range of 5.8 kWh/day for a typical apartment with a family with two children acc. to EN 16147 (tapping profile M). Several studies (e.g. Schnieders et al (2002), Lutz et al. (2002) show that a design value of 25 l/P/day 60 °C (energy equivalent) of useful energy for DHW is a good guess if no better information is available.

While it is possible to predict, with good approximation to reality, the average DHW consumption for a typical apartment with a certain number of persons over the course of the year, a prediction of the specific behavior is hardly feasible usually and also not required. Standard profiles (such e.g. as acc. to EN 16147 profile M or L) are usually used to dimension or test equipment and to predict the performance and comfort of DHW preparation systems. However, it is harder to predict peak powers in particular for a whole residential building. Typically, simultaneity factors (e.g. according to Recknagel-Sprenger) are used. However, in order to be on the safe side, the DHW preparation system is usually oversized. With increasing energetic quality of buildings (i.e. nZEBs, EPBD 2010), the energy demand for DHW is the dominating one.

DHW PREPARATION IN MFB

Decentral and Semi-Decentral

Designing cost optimal efficient DHW systems that allow to provide a high level of comfort is not trivial. Building and HVAC simulation can help to improve the system design, to find appropriate dimensioning of the components, to improve control strategies and set points, to assist in commissioning the system and finally to detect and fix faults.

In order to meet the requirements of high DHW comfort and high thermal performance as well as addressing hygienic concerns (i.e. Legionella), different decentral heating systems for MFBs were proposed and tested recently. In particular in combination with heat pumps (HP), decentral DHW preparation with fresh water stations (FWS) can be advantageous as it allows to reduce the flow temperature compared to a classical circulation system. Fresh water stations can be combined with

 DOI: 10.3217/978-3-85125-786-1-15

- 2-pipe system (i.e. combined heating and DHW distribution with high flow temperature)
- 3-pipe system (i.e. separate heating and DHW distribution with common return flow or
- 2+2-pipe system (i.e. separate heating and DHW distribution)

In case of the 2-pipe system, in order to reduce the flow temperature, there exist combinations with

- decentral booster (flow type post heater or HP)
- return flow heat pump (RF-HP) in combination with floor heating (Ochs et al. (2014b))
- decentral DHW stores and so-called charging window(s)

Decentral flow type electric (post) heater can be an interesting solution to increase overall system performance and/or to fulfill different comfort needs and account for different economic restrictions.

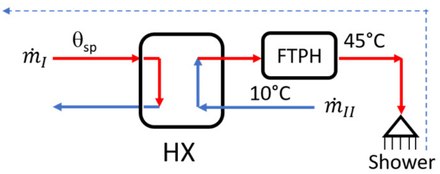

Figure 1: Decentral DHW preparation via freshwater heat exchanger (HX) and flow type post heater (FTPH)

Alternative purely decentral DHW preparation systems are Electro-boiler (EB) or so-called boiler heat pumps (using room air, extract air or ambient air as source), see Dermentzis et al (2018), but these have generally lower efficiencies. All these systems can be combined with shower drain water recovery (SDWR), see e.g. Wong (2010). The maximum possible overall primary energy savings compared to e.g. a standard 4 pipe circulation system (4P-C) depend significantly on the type of system used and the distribution losses. In addition to efficiency and performance aspects (i.e. reduction of distribution losses vs. overall system performance), the following aspects should be considered:

- Reduced investment cost
- Ease of installation (in particular in case of retrofit)
- Billing (combined DHW and electricity bill)
- Maintenance (outsourcing to tenant …)
- Individual comfort (e.g. different set points, switch off during longer absence)
- Space requirements
- Option of cooling (central/decentral), which will be increasingly requested.

Examples and Demo Buildings

Three different demo projects were exemplarily investigated. One consists of two multi-story buildings with altogether 26 flats (see Ochs et al. (2014) and Ochs et al. (2019) for details), each equipped with decentral fresh water stations and a 2 + 2 pipe system as shown on Figure 2.

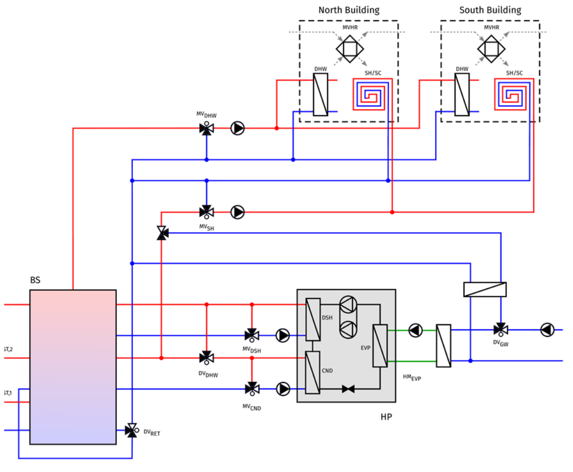

Figure 2: Hydraulic Scheme of the 2+2 pipe system with decentral freshwater preparation

The second building is a rather large residential building with 11 stories and 96 apartments. It will be built in the neighborhood Campagne in Innsbruck (Dermentzis et al. (2019)). The area will consist of 1100 apartments divided in four sections which each four buildings (see Figure 3). The third one is a small 4 story building in Ludwigsburg, Germany, which was renovated to Passive House standard within the EU project iNSPiRe (fp7) and equipped with a 2 pipe system with decentral fresh water stations and flow type post heaters.

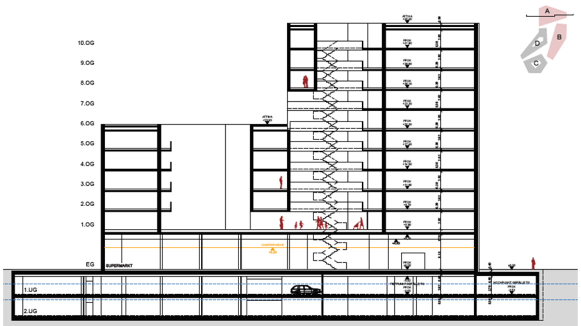

Figure 3: Building A of block 1 of Campagne Areal (source: "bogenfeld ARCHITEKTUR")

RESEARCH QUESTIONS

The overall performance, i.e. the primary energy consumption and/or CO_2-emissions savings should be determined with respect to a reference system (e.g. central 4-pipe circulation). Furthermore, the annual capitalized cost (investment and operation) need to be determined.

For all the above-mentioned systems, the difficulty is to model the different scales (apartment, building, HVAC system) at different design stages (pre-design, design (tender), commissioning) appropriately. DHW comfort (i.e. delay times) can be modelled only on the level of the apartment, while the energy performance

DOI: 10.3217/978-3-85125-786-1-15

(distribution and storage losses, efficiency of HVAC system) can only be investigated on building level.

Hence, a techno-economic analysis is required and the following general research questions can be formulated:

- What are the distribution losses depending on return temperature for each system?
- Can DHW comfort be guaranteed?
- What is the performance (of a central HP) depending on the load and the return temperature?
- How is the peak power (grid load) influenced?
- Can the power of the central HP be reduced, e.g. in case of limited source and or to reduce sound emissions?
- How is the PV self-consumption influenced?

For planers and other practitioners, it is important to show how good the performance can be predicted with simplified tools such as PHPP or energy certificate calculation (monthly balance). In this paper specifically the first two questions are answered with the focus on the 2-pipe-system with FTPH.

METHODS

This contribution focus on the sizing of the system, the DHW comfort and on the prediction of energy performance using different methods. Evaluation and comparison of the different systems requires considering the full range, from apartment level to district level as summarized in Table 1 and illustrated in Figure 4.

Table 1: Matrix of combinations of heat supply, heating system, heat distribution and pipe insulation level

Heat supply system	Heating system per …	Pipe distribution system	Insulation level
heat pump (HP)	building	4P-C	Moderate
district heating (DH)	block	2+2P-FWS	Good
HP & DH	district	2P-FWS	very good
		2P-RFHP	
		2P-EB	

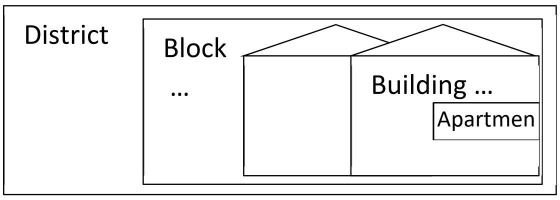

Figure 4: System Boundary from apartment to district

Daily performances with different DHW profiles are evaluated, focusing on the one hand on the dynamic response of the system in order to achieve the request of the user (such as the delay time to reach the desired temperature). On the other hand, the return temperature to the storage, the thermal losses and the energy expense are evaluated.

Reference Buildings and Building Models

A typical medium size residential multi-story building with 5 stories and 10 apartments is used as virtual case study. This type of building represents a large number of multifamily buildings typically build in central Europe in the 50ies and 60ies. Different models of the small multi-family house were developed in Matlab Simulink using the Carnot Toolbox and the building model CarnotUIBK.

Modelling approaches

In order to model the influence on district level, simplified building models are required, contrariwise, in order to evaluate in detail, the dynamics of the decentral DHW-HX detailed apartment-wise models are required.

In this contribution different approaches for modelling innovative decentral DHW preparation systems are investigated and the results are compared to each other. The reference case is the single apartment. The apartment could be simulated in the building with all the distribution pipes to account for the thermal losses and to predict her energy performance. However, the return temperature would never be realistic. For the entire building, if all apartments would be simulated together, different profiles need to be generated in order to account for different times of use and an accordingly for “smoothed” power profiles (simultaneity of DHW use). For very large buildings with more than 10 and up to 100 apartments such an approach would lead to a very heavy simulation model with extensive simulation times. Contrariwise, a lumped model with one heat exchanger would be easy to use but could not predict the dynamics and the return flow temperature correctly. However, if an appropriate DHW profile could be generated for variable number of apartments e.g. by DHWcalc (see below) such an approach would be feasible for energy performance prediction. However, an appropriate model for the heat exchanger and a valid parameterization needs to be found. In the following table the different modelling approaches are summarized:

Table 2: Matrix of modelling approaches

<table>
<tr><td></td><td colspan="4">Approaches</td></tr>
<tr><td>Zoning</td><td colspan="2">Single Zone</td><td colspan="2">Multi Zone</td></tr>
<tr><td>Distribution pipes</td><td colspan="2">Physical</td><td colspan="2">Simplified</td></tr>
<tr><td>Heat emission system</td><td>Physical</td><td colspan="2">Simplified</td><td>Lumped</td></tr>
<tr><td>DHW HX</td><td colspan="2">Physical (1/apartment)</td><td colspan="2">Lumped (1/thermal zone)</td></tr>
<tr><td>DHW tapping profile</td><td>Statistical</td><td colspan="2">Standard</td><td>Lumped</td></tr>
</table>

 DOI: 10.3217/978-3-85125-786-1-15

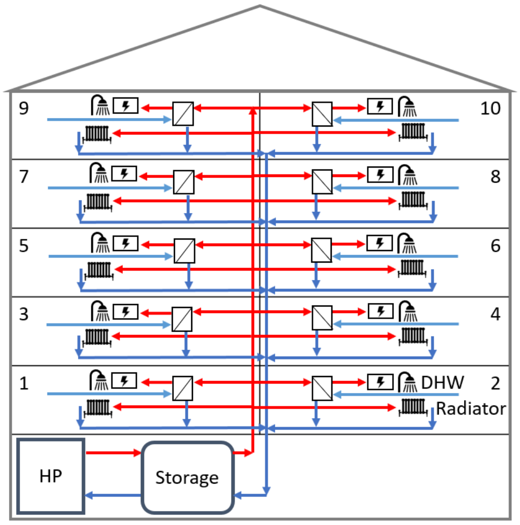

Figure 5: Reference Building with 10 zones and decentral DHW-HX and flow type post heater (FTPH)

DHW profiles

A standard profile (M, EN 16147) and a profile derived by DHWcalc (Jordan (2000)) were considered for a single apartment model in order to create a reference case to compare the simulations with. In the single apartment model, a typical 26 kW heat exchanger is used in order to provide the DHW. Five different DHW profiles were created for the whole building. Four were based on the profile M acc. to EN 16147, while one profile was created with the help of the tool DHWcalc. The different DHW profiles are presented in Figure 6. Individual means here 10 different statistical profiles generated with DHWcalc, one for each apartment; building means one profile for 10 apartments.

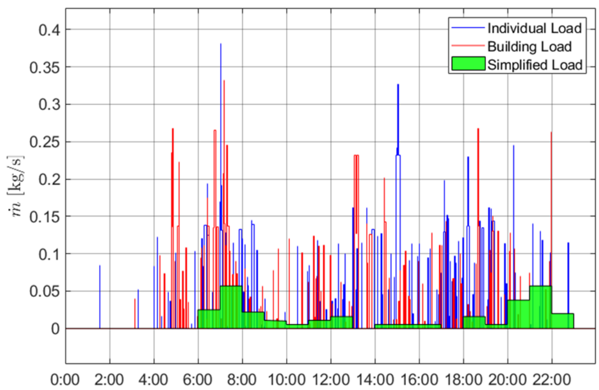

Figure 6: Statistical DHW profiles (DHWcalc) and simplified DHW profile - one day profile

Zoning

In a modelling approach, which is close to reality ("physical" model), the reference building would be split into 10 thermal zones with 10 radiators and 10 DHW HX, one in each thermal zone. All DHW HX are connected in parallel and influence the return flow temperature, see Figure 5. There is a central storage and heat pump and they might be placed inside or outside of the thermal envelope. This approach is possible for 10 apartments (i.e. 10 thermal zones), but for very large buildings (such as e.g. the Campagne neighbourhood, see Figure 3) the modelling effort is enormous and such an approach seems not to be practicable. By reducing the thermal zones to one lumped thermal zone, which represents the thermal envelope of the building, the modelling effort and the simulation duration can be massively reduced. Still, the distribution pipes are arranged in a realistic, i.e. physical correct way (Figure 7) and each of the apartments has its own radiator, DHW HX and optionally FTPH (Figure 8). This model is called "*Semi-Physical" model*.

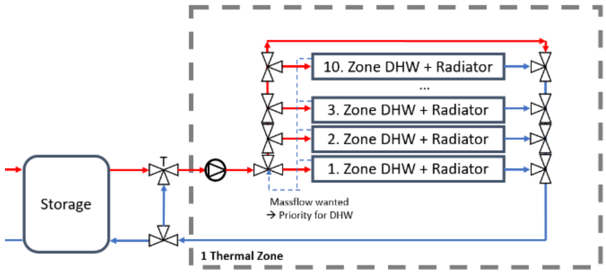

Figure 7: Model of the thermal zone and the decentral DHW HX, "Semi-Physical" approach with one thermal zone and 10 radiators and 10 DHW HX

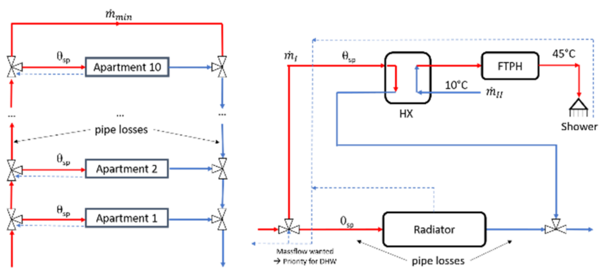

Figure 8: Model of the pipe distribution (left) and of the apartment "Semi-Physical"approach

In order to further simplify the model and reduce the simulation time, one lumped radiator can be used instead of 10 single ones and all the distribution pipes can be placed in series (see pipe losses and single radiator in Figure 9). This approach is called the *Star* configuration.

The *Semi Physical* - and *Star Model* are simulated with the *Individual Load* (seeFigure 6). Finally, the DHW HX and the FTPH can be also reduced to one lumped subsystem (abbreviated with DHW in Figure 10). This lumped model is called the *1 Zone Model* and is simulated with the *Simplified-*, *Building-*, and *Individual Load* (see Figrue 6). The *1 Zone Model* is comparable to the PHPP but is a dynamic simulation instead of a monthly based energy balance calculation.

 DOI: 10.3217/978-3-85125-786-1-15

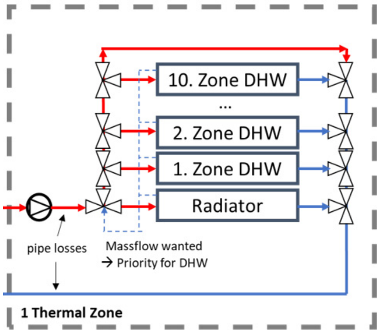

Figure 9: Model of Zoning "Star Model"

For all the previously mentioned models the flow temperature is controlled by a mixer, which is placed right after the storage and it is controlled to be higher as the set point temperature (ϑ_{sp}) depending on the minimum mass flow and insulation level.

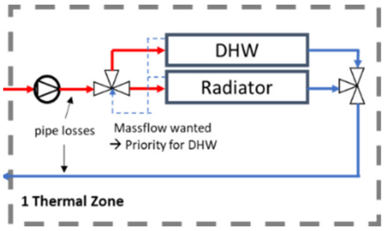

Figure 10: Lumped Model "1 Zone Model"

The chosen DHW demand (DHW) and the climate data (site Innsbruck, Meteonorm 2005) is for all the different modelling approaches the same. PHPP evaluates the heating demand (HD) on monthly basis depending on the climate data. The dynamic models use the same climate data in hourly resolution. In the dynamic model the mass flow of the radiator is controlled depending on the room temperature. In contrast to the evaluation in PHPP the distribution losses of the pipes, which are inside the thermal envelope, are considered as gains, too. For better comparison this is considered in a post-processing step in PHPP, later called PHPP mod*.

Hydraulic Modelling in Simulink

Implementing the pipe losses in Simulink requires connecting several pipes, mixers and diverters. The Carnot Toolbox offers models for thermal and hydraulic modelling. In the *Semi-Physical Model* the pipes, mixers and diverters were modelled such that the distribution pipework was depicted in a realistic way, resulting a large number of differential equations Simulink has to evaluate. In the *Star Configuration* all the pipe losses were lumped and placed in front of all the users (DHW and radiator). As there are no models available that split the mass flow into multiple branches, the number of differential equations could not be significantly reduced, resulting in comparable simulation time. Only with the 1Zone model with lumped heat exchanger a significant simplification was possible. Note that here only results of a thermal simulation are reported, mass flow and pressure drops calculation is possible but was not considered here for sake of simplicity.

Heat Exchanger Model and Parametrisation

The lumped heat exchanger (for the 1-Zone model) and the real heat exchanger (for the apartment) are designed to fulfil following conditions:

Table 3: Heat Exchanger Inlet and Outlet Temperatures for different set points

ϑ_{Ii} / [°C]	ϑ_{Io} / [°C]	ϑ_{IIi} / [°C]	ϑ_{IIo} /[°C]
40	20.0	10	35.0
45	21.7	10	39.2
50	23.4	10	43.3

Here I and II indicate primary or secondary, and i is inlet and o outlet. The reference secondary mass flow for the lumped heat exchanger is 0.4 *kg/s*, for the decentral heat exchanger it is 0.25 *kg/s* in accordance to the DHW profile (see above). The primary mass flow is proportionally increased by the factor 1.25. The power of the heat exchangers, the heat transfer coefficient and the thermal capacity are shown in the following table.

Table 4: Heat Exchanger Parameters, single HX for apartment, lumped HX for 1-Zone Model

	Single HX	Lumped HX
Power $\dot{Q}$ / [kW]	26.2	41.9
heat transfer capability UA / [W/K]	3640	5803
Heat Capacity C / [J/K]	1302	11500

Sensitivity Analysis and Model Parameters

We consider four heat pump qualities based on the Carnot coefficient of performance (COP) and the Carnot performance factor with COP = $\eta_C \cdot COP_C$:

- Moderate ($\eta_C = 0.25$)
- Good ($\eta_C = 0.3$)
- Better ($\eta_C = 0.35$)
- Best ($\eta_C = 0.4$)

Furthermore, we consider four insulation levels (i.e. qualities) of the distribution pipes

- Very good (DN2)
- Good (DN1.5)
- Moderate (DN1)
- Poor (DN0.5)

Here *very good* means the insulation thickness is 2 times the dimension of the pipe (diameter nominal DN). *good* refers to 1.5 times DN, *moderate* to 1 times DN and *poor* to 0.5 times DN. The heat loss coefficient for the distribution pipes was calculated in PHPP. It is remarkable to note that thermal bridges are assumed to be included in this effective insulation level. To guarantee the comparability of the different models the reference point to evaluate the controlled flow temperature at the mixer is the temperature at the inlet of the 10th apartment in the S*emi Physical Model*. As a result of this assumption, the flow temperature for the other apartments is slightly higher, which is assumed to be realistic.

 DOI: 10.3217/978-3-85125-786-1-15

RESULTS

Figure 11: *Sum of electric energy demand compared to the temperature rise of the FTPH, depending on the setpoint temperature of the DHW, PHPP calculation results*reports the results of the total electric energy (central heat Pump + FTPH) for different heat pump qualities (Moderate to Best), pipe insulation levels (poor to very good) and as a function of the flow type post heater temperature difference. Different DHW set point temperatures (secondary side: 45 °C, 50 °C, 55 °C and 60 °C) and heat pump qualities were considered; here the results are reported for the set point of 45 °C and the best heat pump.

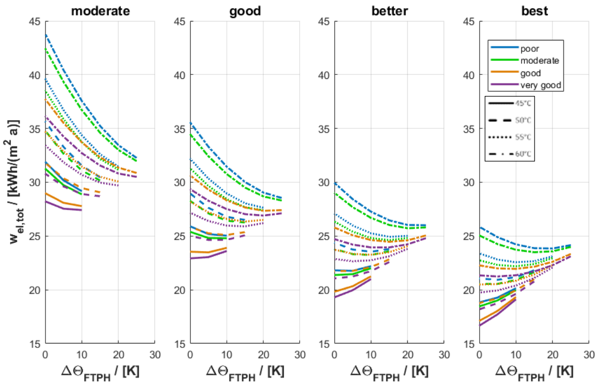

Figure 11: Sum of electric energy demand compared to the temperature rise of the FTPH, depending on the setpoint temperature of the DHW, PHPP calculation results

For poor performing heat pumps and low level of pipe insulation (i.e. high distribution losses) there is an optimum in the range for the operation of a FTPH. However, for good performing heat pumps and good pipe quality, the use of a FTPH increases total electricity consumption. Figure 12 shows the sum of the electric energy demand compared to the temperature rise of the FTPH for the three different dynamic models using the *Individual Load* and the results from PHPP (Best Heat pump).The following tables shows the results of an annual simulation of each previously described model also in comparison to the results from the PHPP. In the Table 5 to Table 7 DHW is the useful domestic hot water demand, HD is the heating demand acc. to PHPP for three different set point temperatures (35 °C, 40 °C and 45 °C). The tables report the useful energy for heating and DHW as well as the contributions of the central heat pump and the flow type post heater to the total required electricity.

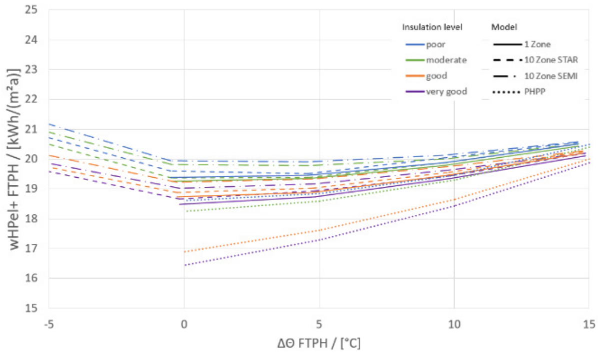

Figure 12: Sum of electric energy demand compared to the temperature rise of the FTPH, dynamic model results

DH is the delivered heat in the simulation models as the sum of the delivered radiator energy, HP W_{el} is the required electric energy by the heat pump. PHPP mod* indicates the modified case of the PHPP, which allows to compare it directly with the dynamic model.

Table 5: summary of annual simulation results, for the case with "poor" insulation (DN 05) and set point temperature of ϑ_{SP} = 35 °C

			1 Zone			10 Zone	
	PHPP	mod*	Simplified	Building	Individual	Star	Semi
DHW / [kWh/(m²a)]	21.7	21.7	21.7	21.7	21.7	21.7	21.7
HD / [kWh/(m²a)]	23.3	23.3	-	-	-	-	-
DH / [kWh/(m²a)]	-	-	20.9	20.9	20.9	20.9	22.4
HP Q / [kWh/(m²a)]	54.7	42.1	40.9	39.8	39.8	40.1	40.7
HP W_{el} / [kWh/(m²a)]	13.3	12.7	12.8	12.4	12.4	12.5	12.6
FTPH W_{el} /	6.2	6.2	6.2	7.5	7.5	7.5	7.5
Storage loss /	0.25	0.25	0.29	0.29	0.29	0.29	0.28
Pipe loss /	5.8	5.8	4.7	4.7	4.7	5.0	4.2
Average ϑ_{return} / [°C]	33.1	33.1	32.7	33.1	33.1	33.0	33.0

Table 6: summary of annual simulation results, for the case with "poor" insulation (DN 05) and set point temperature of ϑ_{SP} = 40 °C

			1 Zone			10 Zone	
	PHPP	mod*	Simplified	Building	Individual	Star	Semi
DHW / [kWh/(m²a)]	21.7	21.7	21.7	21.7	21.7	21.7	21.7
HD / [kWh/(m²a)]	23.3	23.3	-	-	-	-	-
DH / [kWh/(m²a)]	-	-	20.2	20.2	20.2	20.0	22.4
HP Q / [kWh/(m²a)]	57.0	46.1	44.7	43.3	43.3	43.5	44.8
HP W_{el} / [kWh/(m²a)]	15.7	15.5	15.2	14.7	15.1	14.7	15.1
FTPH W_{el} /	3.1	3.1	3.3	4.7	4.8	4.8	4.8
Storage loss /	0.30	0.30	0.34	0.34	0.34	0.34	0.33
Pipe loss /	7.5	7.5	6.0	6.1	6.1	6.5	5.4
Average ϑ_{return} / [°C]	37.5	37.5	36.9	37.5	37.5	37.4	37.3

Table 7: summary of annual simulation results, for the case with "poor" insulation (DN 05) and set point temperature of ϑ_{SP} = 45 °C

			1 Zone			10 Zone	
	PHPP	mod*	Simplified	Building	Individual	Star	Semi
DHW / [kWh/(m²a)]	21.7	21.7	21.7	21.7	21.7	21.7	21.7
HD / [kWh/(m²a)]	23.3	23.3	-	-	-	-	-
DH / [kWh/(m²a)]	-	-	19.7	19.7	19.6	19.5	22.5
HP Q / [kWh/(m²a)]	59.3	50.1	48.8	47.2	47.1	47.5	48.9
HP W_{el} / [kWh/(m²a)]	18.6	18.5	18.1	17.5	17.4	17.6	18.0
FTPH W_{el} /	0	0.0	0.2	1.9	1.9	2.0	1.9
Storage loss /	0.35	0.35	0.39	0.38	0.38	0.39	0.38
Pipe loss /	9.2	9.2	7.3	7.4	7.4	7.9	6.5
Average ϑ_{return} / [°C]	41.9	41.9	41.3	42.0	42.0	41.8	41.8

 DOI: 10.3217/978-3-85125-786-1-15

In Figure 14, the pipe losses are shown for the different distribution systems, depending on the insulation level and set point temperature. The *1 Zone Model* is simulated with the *Individual Load*. For higher set point temperatures and poor or moderate insulation level deviations between the models are significant. Figure 13 shows the return flow temperature to the corresponding mass flow. The dashed line in the temperature subplot is the set point temperature, the dashed line in the mass flow subplot represents the minimum mass flow which is always circulating through the distribution pipes.

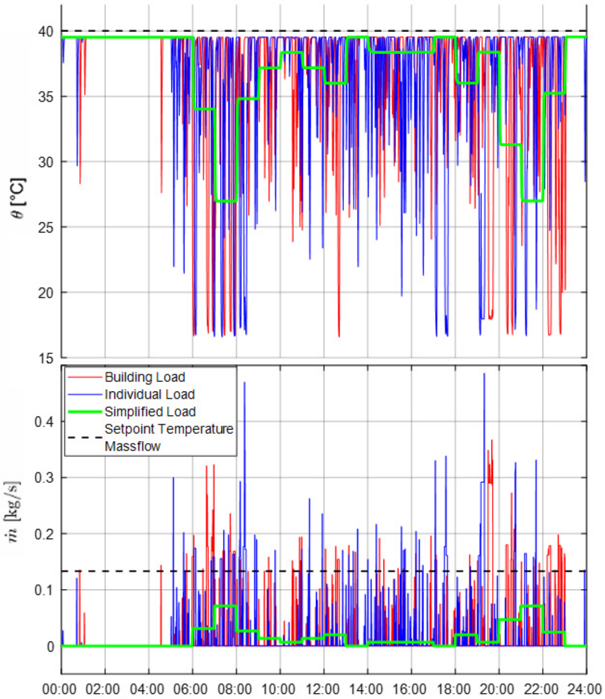

Figure 13: Return flow temperature of "1 Zone Model" over a day depending on the chosen DHW load

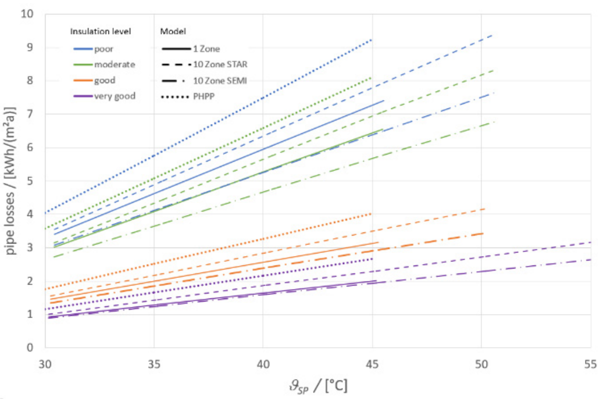

Figure 14: Pipe losses depending on distribution, insulation level and set point Temperature (ϑ_{sp})

DISCUSSION

A design and evaluation tool for HVAC systems for multifamily buildings should consider the details (apartment level) as well as the influence on district level (district heating, energy mix). A (close-to) physical model is often not feasible because of the extensive simulation times. With such a model a multi-objective optimization is hardly possible. A "lumped" model - even after careful parameterization, cannot predict the dynamic behavior accurately, but the general trends can be well projected.

The simulation time can be significantly decreased. Compared to the *Semi Physical Model* the simulation duration of the *Star Configuration* was 98%, whereas the *1 Zone Model* only took approx. 20%. The annual simulation time also depends on the chosen DHW tapping profile. The arrangement of the distribution pipes should be as realistic as possible. The pipe losses of the *Semi-Physical Model* were compared with those of the simplified models. The influence of the distribution pipes is obviously decreasing with better insulation and increasing with higher flow temperatures (Figure 14).

The PHPP and the simplified dynamic models overestimate the thermal losses of the distribution system compared to the semi-physical model (see Table 5 to Table 7). The choice of the DHW tapping profile and the size and the characteristics of the "lumped" heat exchanger for the entire building influences not only the thermal behavior of the heat exchanger, but also the return temperature to the storage and accordingly the distribution losses and the stratification. The latter is critical for the performance of the HVAC system in particular in case of a heat pump. As can be seen in Figure 13, the peaks in the return temperature are influenced significantly by the choice of the DHW profile, in particular in case of the simplified profile. However, the deviation of the average return temperature, which is relevant for the prediction of the losses, is relatively small. The overall performance of the central heat pump, the distribution losses and of the flow type post heater electricity demand depend significantly on the set point temperature, but because of the presence of the buffer store the performance of the HP is not influenced by the return temperature . For the case with the "very good" heat pump the optimal performance is obtained without operation of post-heating, i.e. with a set point temperature high enough to fulfil the DHW comfort requirements. However, for poorer performing heat pumps and low level of pipe insulation quality (or large distribution networks) the use of FTPH can be beneficial. PHPP seems to slightly underestimate the electric energy demand compared to the dynamic simulation models. This because of dynamic effects (inertia of the heat exchanger). However, the trend is predicted correctly. Overall, the better the insulation level is, the smaller is the difference between the different models (see also Figure 14).

 DOI: 10.3217/978-3-85125-786-1-15

CONCLUSIONS AND OUTLOOK

In this contribution different approaches to model and investigate the influence of decentral DHW preparation systems were investigated and compared. Sizing of the system, the DHW comfort and the prediction of energy performance using different methods are discussed. Energy performances with the different statistical and simplified daily DHW profiles are evaluated, focusing on the one hand on the dynamic response of the system in order to achieve the request of the user (such as the delay time to reach the desired temperature). On the other hand, the return temperature to the storage, the thermal losses and the energy expense are evaluated. It is demonstrated that with simplified approaches, i.e. 1-Zone model and PHPP, the general trends can be predicted, but careful parameterization is required. PHPP delivers good predictions with respect to the general trend, but only with a dynamic model the real PH consumption can be predicted well. The results can be the basis for future work in order to develop algorithms for design tools (e.g. Energy Certificate, PHPP) for investigating, dimensioning and optimizing innovative DHW system for multi-family buildings. In a future work, also a full physical model (i.e. with 10 thermal zones) should be developed and results should be compared with those of the simplified approaches. The investigation of different user behavior (such as different heating and DHW set points or times with absence) should be included in the investigation. In addition to the existing models, a hydraulic calculation which includes pressure drops etc. should be included in the future to include the electric power consumption of the pumps. Furthermore, a techno-economic evaluation of the different concepts including the return flow heat pump is required. Detailed hydraulic calculation including pump control should be further investigated.

ACKNOWLDEGEMENT

This publication is part of the Austrian research project “Smart City Campagne-Areal Innsbruck”. This project is financed by the Austrian “Klima- und Energiefonds” and performed in the frame of the program “Smart Cities Demo 2016”. The authors highly appreciate the support and cooperation of the companies IIG, NHT, IKB and Klimatherm. Special thanks goes to Vaillant for the support to the study on the flow-type post heater.

REFERENCES

De Coninck R., Baetens R., Saelens D., Woyte A., Helsen L., Rule-based demand-side management of domestic hot water production with heat pumps in zero energy neighbourhoods, Pages 271-288 | Received 05 Feb 2013, Accepted 29 Apr 2013, Published online: 14 Jun 2013

Dermentzis G., Ochs F., Ksiezyk A., Venturi E., Magni M., Gstrein H. Heating with PV Façade in a Passive House, 13th Conference on Advanced Building Skins, Bern, Switzerland, Oct. 1-2, 2018 - website: abs.green October 2018 - PDF 1.19MB

Dermentzis, G., Ochs, F., Thuer, A., 2019. Primary-energy Based Optimization of a New Building District through Simulations on Flat, Building, Block and District Level, in: IBPSA (Ed.), 16th IBPSA Conference Rome, Italy, Sept. 2-4, 2019. pp. 3628–3635. https://doi.org/https://doi.org/10.26868 /25222708. 2019.210919

Gustafsson M., Dermentzis G., J. Are Myhren, Bales C., Ochs F., Holmberg S., Feist W., Energy performance comparison of three innovative HVAC systems for renovation through dynamic simulation, Energy and Buildings, Volume 82, October 2014, Pages 512-519

Jordan U., Vajen K., Influence of the DHW-profile on the Fractional Energy Savings – A Case Study of a Solar Combisystem, in: CD-ROM of the Third ISES Europe Solar Congress EuroSun00, Copenhagen, Denmark, 2000

Lutz J. D. , Klein G., Springer D., Residential hot water distribution systems: Roundtable session, Lawrence Berkeley National Laboratory, 2002

Ochs F., Dermentzis G., Feist W., Minimization of the residual energy demand of multi-storey passive houses–energetic and economic analysis of solar thermal and PV in combination with a heat pump, Energy Procedia, Volume 48, 2014, Pages 1124-1133

Ochs F., Dermentzis G., Monteleone W., Simulation-assisted Optimization of the HVAC system of NZE Multi-family Buildings, “Proceedings of Building Simulation 2019: 16th Conference of IBPSA” (ISBN: 978-1-7750520-1-2)

Ochs F., Krimbacher P., Siegele D., Feist W., Niedertemperaturheizung in Kombination mit einer dezentralen Boiler-Wärmepumpe, Bausim 2014 ibpsa.org

Recknagel - Taschenbuch für Heizung + Klimatechnik 77. Ausgabe 2015/16: Basisversion Print Taschenbuch – 17. November 2014

Schnieders J., Hermelink A., CEPHEUS results: measurements and occupants’ satisfaction provide evidence for Passive Houses being an option for sustainable building, Energy Policy, Volume 34, Issue 2, January 2006, Pages 151-171

Wong L.T., Mui K.W., Guan Y., Shower water heat recovery in high-rise residential buildings of Hong Kong, Applied Energy, Volume 87, Issue 2, February 2010, Pages 703-709

