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MODEL BASED ANALYSIS OF MONITORING DATA FOR PERFORMANCE OPTIMIZATION IN LARGE MULTI APARTMENT BUILDINGS

Summary

In a large multi-apartment building (MAB) block (four buildings, 307 apartments), a high-resolution monitoring system was implemented alongside heat meters in the technical room, distribution network, and apartment-level fresh water stations (FWS). Monitored losses proved to be higher than pre-design expectations. To address these deviations and improve the system performance, system parameters were adjusted, notably bypass settings in the FWS of two risers, which lowered return temperatures by approx. 7 K (to about 30 °C) and reduced distribution losses by ~30% without compromising user DHW comfort. A white-box model was developed and calibrated with the monitoring data to merge measured and expected performance, enabling attribution of losses to distribution pipes inside and outside the thermal envelope and FWS standby while quantifying the impact of elevated return temperatures. Results are used to derive pre-design tools and planning guidelines for large MAB.

Keywords: HVAC, Monitoring, Domestic Hot Water, Multi Apartment Building, Heat Pump, District Heating

Field of application for the findings: Monitoring, Fault Detection and Diagnosis

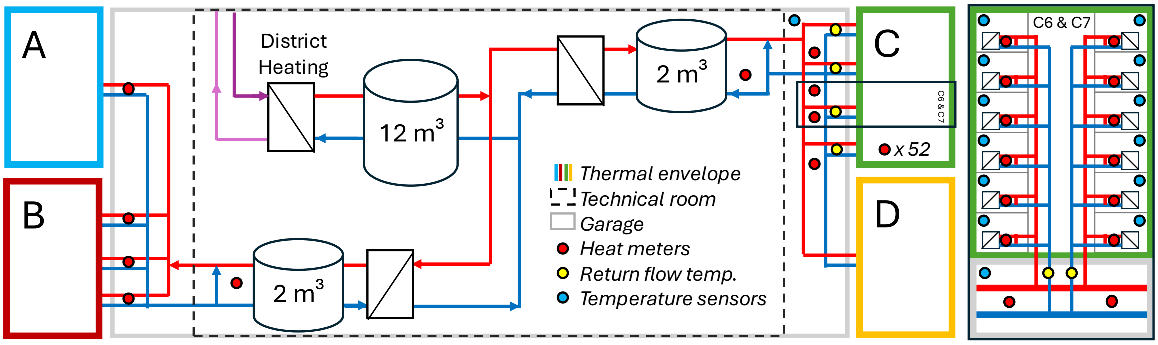
Addressed audience: Scientists, Planners

1. Introduction

In the context of highly energy-efficient buildings, such as passive houses, distribution losses are of particular significance. In these buildings, they serve as a substantial uncontrolled heat source (Hamburg et al., 2021). During the summer months distribution losses from domestic hot water (DHW) can lead to overheating or an increased cooling demand. In conventional DHW systems with circulation pipes, it is necessary to maintain temperatures in the flow and return pipes above 55 °C to meet hygienic requirements, particularly with regard to the prevention of legionella (e.g. in accordance with ÖNORM B 2531:2024-10). Decentral DHW preparation via fresh water stations (FWS) allows lower supply temperatures, provided the apartment-wise distribution volume is below three liters. These systems often have a thermal bypass function, i.e., a thermostatic valve controlling a predefined standby temperature to be set for quick heating-up times. This standby setting is crucial for limiting the return temperature within the system and thus limiting the thermal losses. With the increasing integration of heat pumps (HP) for low-temperature supply, reducing system temperatures becomes essential (Kropp et al., 2025). Energy metering for DHW allows costs to be allocated accurately to individual users and reveals distribution and storage losses that often go unnoticed with central-only metering. As these losses cannot be observed without user-level data, the implementation of energy metering is generally recommended to support transparent operations and promote energy-efficient DHW preparation (Pomianowski et al., 2020), but currently limited to few research projects.

2. Methodology

A sophisticated monitoring system was installed in a large MAB block, with four buildings (A, B, C and D, see Fig. 1) to record both space heating (SH) and domestic hot water (DHW) demand as well as the supplied energy. The buildings are characterized by their highly efficient thermal envelopes: two of the buildings have been certified acc. to the Passive House standard, the other two have components in PH quality (Ochs et al., 2025). In this contribution we focus on the DHW distribution. DHW is supplied by the city district heating network through heat exchangers and storages located in the technical room. From there, heat is distributed to the buildings, where apartment-wise FWS prepare DHW on demand. Heat meters were placed at selected points throughout the distribution system to monitor energy flows at technical room-, riser-, and apartment-levels. In Fig. 1, the DHW distribution system and the technical room, including the monitoring concept, is presented. Building C is monitored in greater detail, with apartment temperature sensors and heat meters installed at every apartment's FWS. This configuration allowed an exact determination of user DHW demand, internal apartment temperatures and, together with the heat meters in the main distribution pipes, enabled detailed analysis of distribution losses along the network. To better capture transient behavior and bypass operation, high-resolution temperature sensors were added (see yellow points in Fig. 1a), and complementary infrared thermography of FWS was conducted to quantify localized heat losses.



a) b)

Fig. 1(a): Scheme of the monitoring of the central technical room and the DHW distribution system supplying buildings A, B, C and D; (b): detailed view on riser shaft group C6 & C7 in Building C

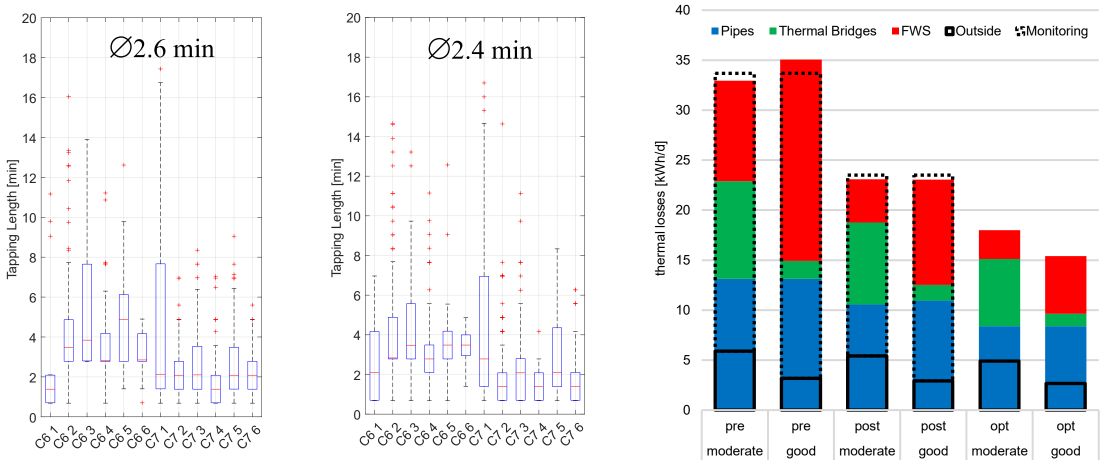
A white-box thermal model of the DHW distribution and the decentralized FWS was developed to support the analysis of the monitoring data and to attribute losses to individual pipe segments. Pipe lengths and insulation levels were derived from drawings and site verification. Loss attribution was performed by combining the heat meter data of the FWS with the distribution measurements to infer segment-level losses. The exact attribution of thermal losses to individual system components is challenging because pipe losses occur both inside (e.g. green frame of C6&C7 detail in Fig. 1b) and outside the building's thermal envelope (e.g. grey frame of "Garage" in Fig. 1b), and part of the losses inside originate from the FWS standby itself.

To address this uncertainty, the system was modeled using two bounding scenarios. In the first scenario, pipe losses and mounting-related thermal bridges were characterized as "moderate" in accordance with PHPP (Passive House Planning Package) methods. In the second scenario, improved "good" thermal-bridge conditions were assumed, resulting in a higher relative share of losses attributed to the FWS. The riser shaft group C6&C7 was subject to a detailed investigation, as this group has the least distribution pipe lengths outside the thermal envelope and the least uncertainty of determining the pipe lengths in general.

An initial comparison between expected performance and monitoring data revealed substantially higher distribution losses in operation than anticipated by default assumptions. A stepwise calibration was performed to adjusted pipe loss coefficients within the two bounding scenarios and to fit parameters of the FWS using infrared thermography and return flow temperature data. The calibrated model was validated on separate operating periods and focused on loss magnitudes, return temperature profiles, and the consistency of loss attribution across time. Further optimization potential and its effects were predicted using the model.

3. Results

The analysis of the monitoring data indicated that high return temperatures were a dominant driver of distribution losses along the analyzed risers. Based on this insight, an operational intervention reduced the bypass setpoint temperature of some FWSs. In the risers C6 and C7 the return temperature was reduced to about 30°C (from >40 °C) in eleven of twelve apartments without measurable changes in average tapping time (i.e. no comfort reduction). Fig. 2 shows the average tapping time of the users in C6 and C7 pre-intervention (06.2025 - Fig. 2a) and post-intervention (07.2025 - Fig. 2b). The deviations in median tapping time were approximately 8%, confirming no comfort penalty. In Fig. 2c) the post intervention state was compared to the pre intervention baseline under both thermal bridge scenarios (average daily losses of one month each), and an additional optimal operation case explored the effects of reducing the flow temperature to 50 °C.



a) **b)** **c)**

Fig. 2: median tapping time pre (a) and post-intervention (b). (c): Thermal losses of pipes, thermal bridges and the FWS pre-, post-intervention and under optimal operation conditions. Share of losses outside the thermal envelope and monitored losses.

After the intervention, distribution losses in risers C6 and C7 decreased by roughly 30 % relative to the pre intervention state and under optimal operation by 50 %. This reduction is robust with respect to the two thermal bridge scenarios and measured conditions, which bracket the absolute loss values while showing consistent relative savings. The solid line box in Fig. 2c) represents the losses to the ambient of each case (including pipes and thermal bridges), while the remaining gap indicates that pre intervention, the pipe losses increased the cooling demand by 1.9 W m^{-2}. Decentralized FWS gain in popularity and enable low-temperature operation, which is especially beneficial for HP-based heating systems. Monitoring-assisted commissioning and control is required to guarantee that the system is operated with maximum possible performance.

4. References

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