Domestic hot water optimizing potential in existing or renovated multifamily residential buildings

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Abstract. In a Swiss case study of the ReCO2st research project, hot water optimization demonstrated a high potential for energy savings with low investment costs. The optimization started with the end user to reduce first hot water consumption. Energy-efficient showerheads and faucets reduced hot water consumption by 10 to 25%, notably from 65.2 [l/p.day] to 48 [l/p.day] for the period of September to October 2019. A multi-criteria selection of showerheads involved end users considering other qualitative aspects like rinsing efficiency, overall feel of use, noise, and material robustness. Strict control of pipe and storing tank insulation reduced storage and distribution losses. Day and night storage temperature setpoints, water recirculation time, switching off this process after 11:00 p.m., temperature differential of start and stop loading setpoints, creating long loading cycles, ensure that the pipes are not always hot. Reducing Legionella cycles at 60° to once a day avoided the need for continuous high temperatures. The combination of all these soft measures in the Swiss case study resulted in a reduction of energy consumption for hot water of 20-30%. This is equivalent to the installation of expensive solar panels for hot water. A detailed two-year monitoring of the building's hot water consumption shows the contribution of each optimization measure. The encouraging results show that without perfect control of the entire process, it is impossible to avoid a performance gap between planned and actual energy consumption.

1. Introduction
In deeply refurbished residential buildings, the demand of heat for domestic hot water production is equivalent to 21 kWh/m² at 60°C, compared to 30-50 kWh/m² at 40-45°C for heating, which means that 30 to 40% of the total building needs for heat are for domestic hot water production [1] [2]. The high temperature needed to control legionellosis risks results in high production, storing and distribution losses of hot water raising even more the part of heat consumption for hot water. For buildings equipped with heat pumps or condensation boilers, the impact on heat production efficiency is higher at 60°C. In addition, on average, little effort is made to reduce the hot water demand and heat losses. This subject is almost absent from regulations or energy labels. Generally, the authorities and the labeling agencies take into account assumptions with normal values without any possibility to account for any optimization. The construction partners not only ignore basic good practice rules concerning hot water production and distribution, such as for example acceptable insulation or efficient control strategies, they sometimes resist applying them.

The studied building in Switzerland is one in four demonstration cases of the European research project ReCO2st. The aim of this project is to show how to refurbish according to nearly zero-energy buildings (nZEB) [3] standards, while optimizing costs and ensuring quality of life and comfort for the
inhabitants in order to promote energy transition. For the Swiss case study, the optimization effort
targeted not only reduction of heat requirements for space heating but also heat requirements for
domestic hot water production. Usually, the heat meters are placed upstream of the heat production or
the primary distribution group, which is the case for the study building. This makes it difficult to clearly
distinguish the heat consumption for heating the building from the heat for domestic hot water
production. Moreover, domestic hot water is generally neglected in the renovation of buildings despite
the fact that heat demand for DHW is now taking an important part in recent nZEB buildings (from 50% to 70% of the total heat [2]). As a consequence, it is possible to see the future challenges and issues of
energy consumption for domestic hot water production.

The aim of the study is therefore to evaluate the impact of optimization measures on domestic hot
water, both water and energy consumption, by reducing the effective energy demand and the losses of
production and distribution.

2. Description of the building and hot water monitoring set up

The building is located in a residential area near the center of Vevey in Switzerland and was built in
1920. Prior to the renovation of the building in 2018-2019, the 15-apartment building had not undergone
any major transformation after 1959. After refurbishment, two new apartments were created. The total
energy consumption was measured before and after refurbishment using the bills of the energy supplier.
Before refurbishment, the building had a gas boiler. Since refurbishment, district heating supplies the
building with 80% renewable biomass heat. The results show an energy consumption reduction by more
than 50% considering the final energy (150 to 75 kWh/m²) and of more than 75% considering primary
energy (150 to 38 kWh/m² – Swiss regulations do not use primary energy factors but weighting factors
using 2 for electricity, 1 for fossil fuels, 0.5 for biomass energy and 0 for solar energy) [4].

The monitoring device used is a Flexim ultrasonic
portable flowmeter (Fluxus F601), equipped with
a data logger. Six probes were installed, as shown
in the Figure 3.

- T1: Boiler water inlet [°C]
- T2: Boiler water outlet [°C]
- T3: Return of the heating element [°C]
- T4: Heating element flow [°C]
- ṁ: Boiler inflow volume [m³/h]
- ˙q: Heat flow rate out of the boiler [kW]

The water roughness, pipe diameter and type and
probe spacing had to be set up too. The precision
of the flow meter depends on internal turbulence,
roughness assumptions, internal diameter
assumptions.
Monitoring of the building started before refurbishment and is continuing. Hot water monitoring in a multifamily building presents several difficulties: changes in the number of occupants, changes in the occupant activities, such as holidays or presence at home during the pandemic, changes in the building occupation during the refurbishment works. The smaller the building is, the higher the influence of these changes in the results is. Non-invasive ultrasonic measurement of water flow rates also presents inaccuracies, because of network turbulence, due to pipe roughness and pipe direction changes.

3. Optimisation of water and energy consumption

The optimization measures aimed at quantifying the potential savings on both water and energy consumption. The first optimization targeted the effective water demand for DHW. Tap and showerhead replacement with more efficient elements reduced hot water consumption and consequently heat demand for DHW. Then the optimization focused on reducing storage and distribution losses, thus decreasing the heat required to meet the DHW demand. To achieve this, the DHW production settings and insulation were optimized. Standard values are commonly used to determine DHW demand and storage and distribution losses. The applicable Swiss SIA standard indicates a standard value for DHW demand for 20.8 kWh/m² [4] for multifamily residential buildings, while a notice from the canton of Geneva states that the efficiency of 65% for storage and distribution losses is adequate. The required heat to be given to the boiler is then 32 kWh/m² [5]. All values are shown in Figure 4.

![Figure 4](image-url): Key values considered for the DHW system

3.1. Overall timeline of the DHW optimization actions

The renovation of the building began in mid-2018. Shortly thereafter, ESTIA took over the monitoring of the DHW. During the refurbishment, several apartments were vacant (between 3 and 4) while the others were occupied. Therefore, during this period, the effective occupied surface area was lower than the one before refurbishment. In July 2019, the first optimization took place with the replacement of taps and showerheads. At the end of the refurbishment process, 5 months later, the pipe insulation was completed. Just after that action, heat production and distribution settings optimised storage and distribution losses. The general timeline of the milestones is summarized below:

![Figure 5](image-url): The overall timeline of monitoring and the DHW optimization step.
3.2. Actions to reduce water consumption

In order to choose the best showerheads, we organized a multi-criteria evaluation of several devices present in the Swiss market [6]. 10 families used 6 different devices for one week each and gave a satisfaction score on the following aspects: rinsing efficiency, overall feel of use, noise, and material robustness. It was found that the majority of class A showerheads either make a lot of noise or have a poor rinsing efficiency for long hair. Although devices spending more water are generally preferred for their qualitative characteristics and economic class A devices often present a poor rinsing efficiency or make noise, we found one class A device with a flow of 5.5 l/min giving a high degree of satisfaction on all qualitative criteria.

User satisfaction is essential since they may very easily replace a class A shower head with a cheap class E or F device from the supermarket to get higher rinsing efficiency, hence neutralizing the refurbishment action. The final showerhead selection made by the architect replaced the class E existing devices by new class B ones reducing water consumption from 15 - 19 liters/min to 6 - 9 liters/min. The architect preferred to combine two water saving strategies instead of selecting a class A showerhead. He combined a class B device with a faucet having two flow positions, economic and full flow. This change in sanitary appliances and their improved flow performance should then be visible in the total flow consumed per person per day.

3.3. Actions to reduce storage and distributions losses

In a second intervention the pipes’ insulation and the primary distribution group were optimized. It is a general practice in Switzerland to insulate only linear pipes and leave difficult parts, joints, angles, valves, pumps poorly or not at all insulated [7]. We paid attention to a perfect execution of pipe insulation all over the piping network.

Just following insulation in December 2019, several controls were optimized to reduce the storing tank and distribution network mean day temperature. These settings are the following:

- Stop hot water recirculation from 23h to 6h to reduce distribution losses. It is not necessary to have hot water immediate availability during the night. Even if a single tenant occasionally needs hot water and spends some water while waiting a few minutes for hot water to arrive, the overall gain is clearly positive.
- Install a second temperature sensor on the hot water storage tank bottom in order to wait until all stored hot water is consumed before starting a new charging cycle of the boiler with hot water. The top sensor stops charging when $T_{\geq 55^\circ}$ and the bottom sensor start charging when $T_{\leq 43^\circ}$. This temperature differential of 12°C reduces the number of charging cycles to 2-4 according to the capacity of the storing tank. Longer cycles of heat production optimise the boiler efficiency and reduce the time during which primary pipes are hot.
- Reduce the storing temperature to 55°C during day and 45°C during the night programming a single anti-legionellosis cycle per day at 60°C. This reduces the storing and distribution losses.

4. Results

Several measurement campaigns of variable duration took place before and after refurbishment and optimisation actions. Refurbishment work and Covid-19 related situation interrupted the measurements several times, but it was possible to have periods of significant duration before and after refurbishment. During the two years of monitoring, and especially during the refurbishment, the occupied heated surface and the number of people living in the building changed several times. In the beginning of the study, only 918 m² was rented with 21 tenants for more than 6 months until June 2019. Then for 6 more months the occupied area was near the initial building surface, 1222 m² with 27 people living in from July to December 2019. When the 2 newly constructed attic apartments were finished, the final surface was raised to 1434 m² with 33 people living there by January 2020 until now. The difficulty to have a precise counting of the people living in the building is evident. However, the numbers represent the
mean occupation ±1.5 people. We normalise the water and heat consumption according to the occupied heated area per m² and according to the effective number of occupants per p.day. We must also take into account two Covid-19 total lockdown periods of total lock down in March-June 2020 and partial lock down from October 2020 to May 2021. These lock downs seem to affect the hot water consumption with longer presence of people at home.

4.1. Reduction of water consumption after tap and showerhead replacement

![Figure 6: Graph of the total daily water consumption of each period of measurement.](image)

As we can see in Figure 8 water consumption during this first measurement period, from March to May 2019 before any action indicates an average daily consumption of 65.2 [l/p.day]. This consumption is about 25% higher than the Swiss average of 50 [l/p.day] [1]. After the change, during the period of September to October 2019, average consumption decreases to 48 [l/p.day] and shows a reduction in total water consumption of 25%. The new average is now below the Swiss average of 50 [l/p.day]. During the periods that include lockdown, water consumption increases significantly to 65 [l/p.day] for the year 2020 and 62.5 [l/p.day] during 2021. During the 2 months of total initial lockdown the monthly hot water consumption increase was spectacular with peaks of 80 [l/p.day]. However, these extreme values have not been repeated in the partial lock down and we can see it on the graph with the mean period water consumption. Latest measures in June 2021 tend to stabilize hot water consumption to 56 ±2 [l/p.day]. Because of the changing parameters and the inherent errors (errors of measuring instruments, variation of the number of people, changes in the living conditions due to refurbishment and due to 2 different pandemic conditions), it is not safe to consider the absolute values for hot water consumption but only to see the tendencies: after changing the tabs and showerheads immediately with similar occupation conditions. There is a clear reduction of hot water consumption and during the pandemic there is a clear rise of hot water consumption.

4.2. Reduction energy demand

In the monitoring device of Figure 3, we are measuring the net hot water consumption flow rate and the difference between the network temperature and the consumed water temperature giving a very close value of the heat demand. The only missing heat is the one corresponding to the temperature loss between the water storage tank and the tap. We are also measure the heat directly charging the tank. The ratio between heat demand and the energy to charge the boiler gives the overall system efficiency. In our case, as we are measuring heat of district heating, we do not have production losses. These measurements are averaged every hour.

In the following graphs we may see the boiler load in gray, the effective energy demand in orange and the efficiency throughout the year in a dotted line before and after optimisation actions. From the
graph we can see that before refurbishment efficiency is very low, ~50% while after the optimisation works efficiency increases to 60%. We can see that with lower energy consumption, the efficiency is lower. From this, we understand that a significant part of the losses is constant independently of the water consumption (pipe losses for example or recirculation losses).

Figure 7: Boiler load, energy demand and efficiency of the DHW in 2019.

Figure 8: Boiler load, energy demand and efficiency of the DHW

Energy consumption before refurbishment amounted to 51 kWh/m², representing 34% of the total energy consumption of a non-refurbished building, and 35-40 kWh/m² after optimisation representing 50% of the total consumption after refurbishment. These values are higher than 32 kWh/m² considered by the normal conditions although the maximum optimisation potential is exploited.

5. Conclusions
Energy consumption for DHW production is a significant issue for building refurbishment representing 30 to 50% of the energy consumption. Although little attention is paid to DHW optimization, there is great potential for reducing hot water consumption by up to 25% and total energy consumption by 20 to 30%. These soft and low-cost actions produce energy savings with results that are of the same order of magnitude as the installation of solar collectors. Further research is necessary with larger buildings offering more reliable results with less sensibility to use variations.

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