mill

NTNU

MILL WIFI HEATERS WITH ADVANCED PID TECHNOLOGY

A simulation-based test

POTENTIAL OF ENERGY SAVING

Outdoor air temperature [°C]	Energy saved [%]
-7°C	29.1
0°C	27.5
7°C	23.2

TECHNICAL REPORT

Submitted by:

- PhD candidate H. Yin,
- Prof. M. Hamdy (NTNU)

Norwegian University of Science and Technology

Submitted to:

- Philip Bryn-Haugland
  Co-owner & Head of Product Development
- Bashir Naimy
  IoT Manager

Mill International AS

Table of Contents

1. Introduction and background

In Norway, buildings sector accounts for 34% of the total energy consumption [1]. Where, over 84% of residential building's energy consumption has been covered by direct/indirect electricity (i.e., electric heaters / heat pumps).

According to the EN ISO 52120-1 Standard [2], Building Automation and Control Systems (BACS) can significantly impact on energy use of buildings and their occupants. In recognition to this fact, the Norwegian Wi-Fi heaters developer (Mill International AS) developing new generations of Wi-Fi heaters that can reducing the heating demands by re-setting the heating temperature setpoint whenever possible.

In this report, NTNU tests the potential of energy saving that can be achieved by the third generation of Mill Wi-Fi heaters with their advanced PID technology.

2. Case study / Test room

The test was conducted by using the detailed building performance simulation software (IDA ICE 5.0) for analyzing the energy consumption and indoor thermal comfort inside a test room, shoebox in Figure 1. Where an adjacent room is set around the heated test room, with constant air temperature of 19°C and exhaust air rate of $0.7 m^3/(h \cdot m^2)$.

The Mill Wi-Fi heaters were tested for two building characteristics (i.e., TEK 10 buildings and typical old Norwegian buildings [3]. TEK 10 buildings fulfil the energy efficiency requirements of residential buildings in Norwegian Building technical regulation TEK10 [4]. Typical old Norwegian buildings represent old residential buildings built between 1960s and 1990s in Norway [5], which were less insulated and had higher infiltration rate. Building envelope parameters for these two types of buildings are summarized in Table *1*.

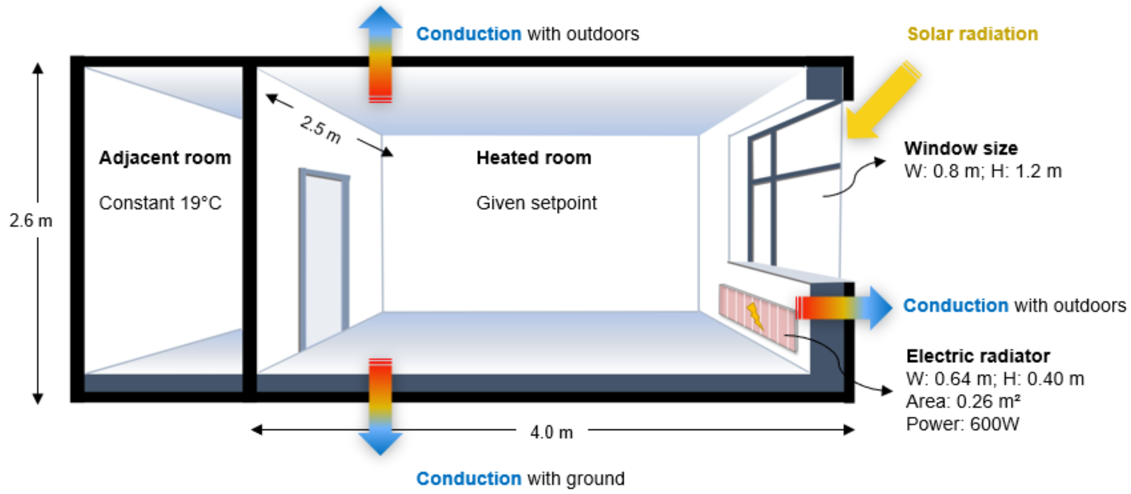


Figure 1. Illustration of the simulated test room where the tested electric heater is set below the window.

Table 1. Building envelope parameters for two study cases.

Parameter	TEK10 building	Typical old building
U-value outer wall (W/m²K)	0.18	0.38
U-value floor (W/m²K)	0.10	0.36
U-value roof (W/m²K)	0.13	0.20
U-value windows/doors(W/m²K)	0.80	2.8
Infiltration rate per hour	0.60	4.0
Normalized thermal bridge (W/m²K)	0.05	0.07

Regarding the TEK10 buildings, the heated room has a balanced CAV system running all the time with a constant supply air temperature of 19°C. The supply/exhaust air rates were set to 1.2m³/(h·m²), which meets the minimum requirement of residence room in TEK10 standard [4]. There is no mechanical ventilation system in typical old Norwegian buildings, the heated room relies on large infiltration rates for air exchange. Again, the adjacent room still has same exhaust air rate of 0.7m³/(h·m²) for comparative analyses.

3. Operational scenarios

3.1. Scheduled heating setpoints

To reduce the energy consumption and maintain thermal comfort, the EN ISO 52120-1 standard suggests implementing Building Automation and Control Systems (BACS) in residential buildings with demand controlled heating system [2]. According to EN ISO 52120-1 standard [2], a variable setpoint with demand response and occupancy detection is recommended to use.

In this report, we used a weekly scheduled heating setpoints to test the thermal performance of our proposed PID control, as shown in Figure 2. The heating system has three operational models, which include:

- **comfort mode**, which maintains an indoor temperature of 22°C
- **sleep mode**, which maintains an indoor temperature of 18°C
- **away mode**, which maintains an indoor temperature of 16°C

During weekdays, the building is unoccupied between 08:00 and 16:00, so the radiator is set to **away mode** (16°C) during this time. During the period of 00:00-06:30 and 22:00-00:00 on weekdays, and 00:00-09:00 and 23:00-00:00 on weekends, the radiator is set to **sleep mode** (18°C). The radiator is set to **comfort mode** (22°C) during all other times.

The scheduled door openings corresponding to the occupant pattern are also marked in figure above, with each opening lasting for 1 minute.

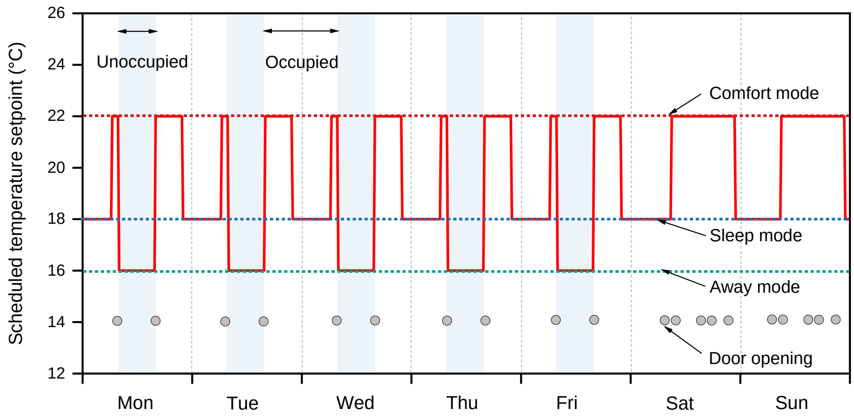


Figure 2. Weekly scheduled heating setpoint with door openings.

3.2. Test outdoor conditions

The performance of the heating control system was evaluated under three different test conditions, which were defined based on fixed outdoor air temperature:

- Outdoor air temperature at -7°C
- Outdoor air temperature at 0°C
- Outdoor air temperature at 7°C

To ensure that our results are representative of real-time condition in Norway, we collected environmental data from Oslo, Norway in January of 2021. This data included various environmental parameters such as relative humidity, wind speed and direction, direct normal solar irradiance, and diffuse horizontal solar irradiance. By including these parameters in our analysis, we can accurately assess the performance of the heating control system under different environmental conditions.

4. Heating Control System

Figure 3 presents the schematic of the heating control system used in this report. The system consists of a controller that receives two input signals: the temperature setpoint and the measured room air temperature, which is monitored by a thermal sensor. The controller then processes the control algorithm and produces a control signal as the output. This control signal is used to regulate the electric radiator in order to heat the room air until the measured temperature reaches the desired temperature setpoint.

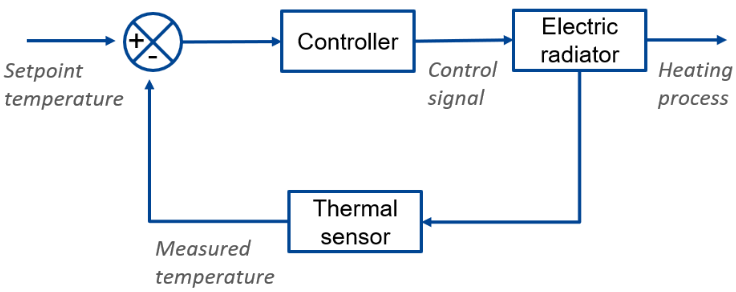


Figure 3. Schematic of heating control system.

Mill Wi-Fi heaters with the maximum heating power of 600W, surface area of 0.26m², and longwave emissivity of 0.3 was used for testing. The thermal sensor was placed 0.5m height besides the radiator in simulation model, which allowed to measure the room air temperature surroundings, as shown in the Figure 4.

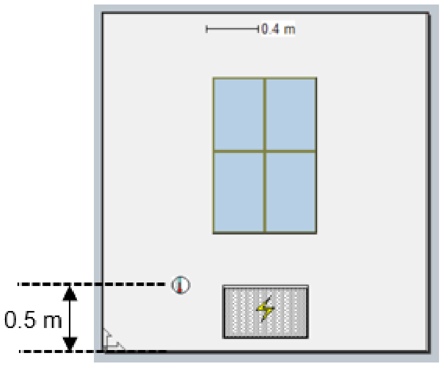


Figure 4. Thermal sensor and electric radiator.

In most buildings, heating control is performed using an on-off controller on the radiator. With this controller, the radiator will use its full capacity of heating power when the room air temperature falls below the acceptance limit, which can cause oscillation around the temperature setpoint. However, a PID controller with proper tuning can provide a more stable and accurate response, particularly when the setpoints vary.

In this report, we compared the performance of our PID controller to baseline on-off controller in different building characteristics and outdoor conditions.

- **Baseline on-off controller**

An **on-off controller** with a deadband of ±1°C was used as a baseline controller, which reacted to a constant heating setpoint of 22°C. When the measured air temperature falls below 21°C, the electric radiator switches on. When the temperature rises above 23°C, the electric radiator switches off.

- **Scheduled PID controller**

A Proportional–integral–derivative (PID) controller with the scheduled heating setpoints was named "**scheduled PID controller**". The scheduled heating setpoint profile was shown in Figure 2.

Generally, the PID controller consists of three terms: proportional (P), integral (I) and derivative (D):

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$$

where $e(t)$ representing the error between desired setpoint and measured room air temperature, and $u(t)$ is the control signal. K_p, K_i, and K_d are the control parameters. Figure 5 shows the averaged room air temperature of the heated room when using the scheduled PID controller during two representative days. The scheduled PID controller provides a stable and accurate control of the electric heating system when it reacts to a resetting temperature setpoint.

During steady-state periods, it also found that the averaged room air temperature was typically around 0.5°C higher than the temperature setpoint. This difference was mainly due to the variations between the measured point air temperature from the thermal sensor and the actual averaged room air temperature.

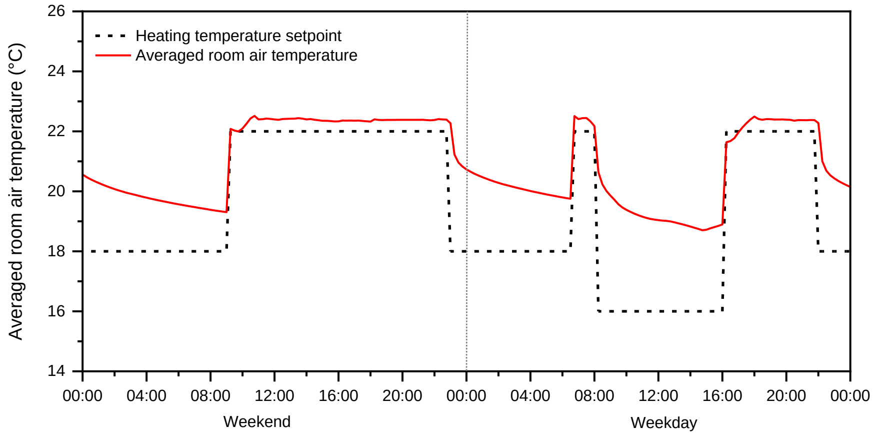


Figure 5. Scheduled PID controller characteristic curve.

5. Results and discussion

The total heating energy consumption of the baseline on-off control and the scheduled PID control during January were recorded and compared, and the percentage of energy savings was calculated as:

$$Energy\ saved\ (\%) = \frac{E_{onoff} - E_{PID}}{E_{onoff}} \times 100\%$$

where E_{onoff} and E_{PID} (kWh) are the total heating energy consumption of baseline on-off control and scheduled PID control system in January.

The results for TEK10 buildings and typical old Norwegian buildings under three different outdoor conditions were summarized in following two sections, respectively.

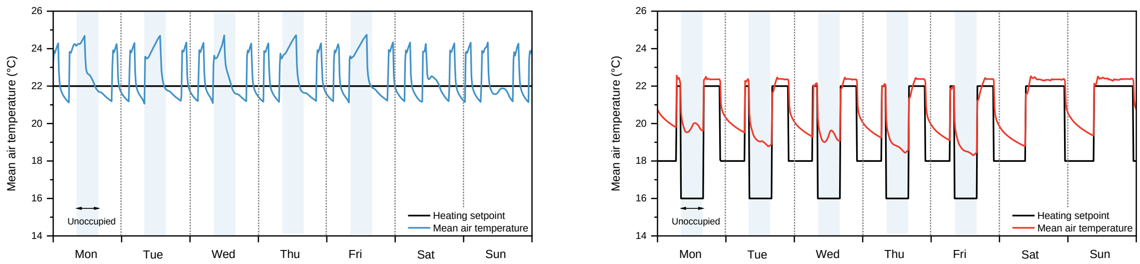
5.1. TEK10 buildings

The scheduled PID control had lower energy consumption compared to the baseline on-off control under the same outdoor condition, as shown in Table 2. The potential of energy savings increased with a decrease in outdoor air temperature. Epecifically, our PID control could save up to 14.7% heating energy use per month at -7°C outdoor condition, while it saved 7.5% at 7°C outdoor condition.

To better understanding the thermal performance of two heating control system, the mean air temperature and heating power in TEK10 buildings at an outdoor temperature of -7°C were analyzed. Figure 6 shows the weekly variation in mean air temperature, and Figure 7 shows the weekly variation in heating power.

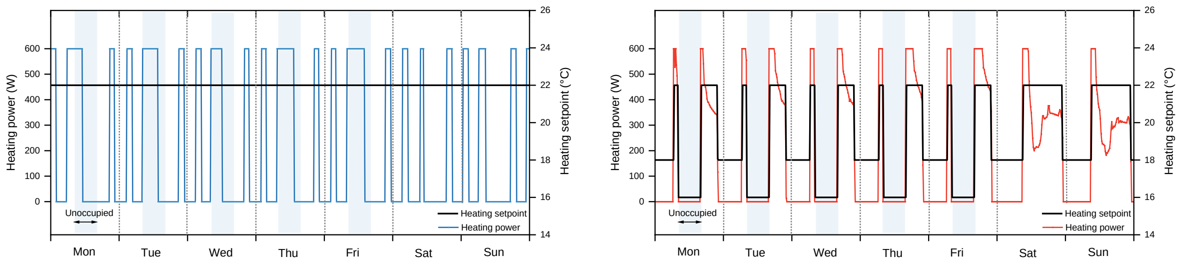
Table 2. Monthly heating energy consumption of on-off control and PID control in TEK10 buildings.

Outdoor air temperature [°C]	Baseline on-off control [kWh]	Scheduled PID control [kWh]	Energy saved [%]
-7°C	154.4	131.7	14.7
0°C	104.6	92.3	11.8
7°C	55.7	51.5	7.5



Baseline onoff control *Scheduled PID control*

Figure 6. Mean air temperature of TEK10 building at -7°C outdoor condition.



Baseline onoff control *Scheduled PID control*

Figure 7. Heating power of TEK10 building at -7°C outdoor condition.

We observed that the baseline on-off control resulted in high fluctuation in mean air temperatrue, with the room air temperature sometimes reaching up to 24°C when the temperature setpoint was kept at 22°C. This large temperature variation can result in occupant discomfort and energy wastage.

However, compared to the baseline on-off control, our scheduled PID control prodivided better temperature control with less offset and more stability. The PID control system enables to maintain a more consistent temperature within the desired temperature range, leading to improved energy efficiency and occupant comfort.

Overall, our results in high-insulated TEK10 buildings demonstrate that the scheduled PID control is a more effective and efficient control strategy compared to the traditional baseline on-off control. By using this advanced and precise heating control system, building owners and occupants can enjoy improved energy efficiency, reduced heating costs, and increased thermal comfort.

5.2. Typical old Norwegian buildings

Compared to TEK10 buildings with well-insulated building envelopes, typical old Norwegian buildings are poor-insulated with high infiltration rate. This results in a relatively higher heating demand, especially during cold outdoor conditions. To heat the room with same size of electric radiator, it takes longer for room air temperature to reach the desired temperature setpoint. We found that the desired temperature cannot be reached when the same temperature setpoint was applied in typical old Norwegian buildings. Therefore, a preheat setpoint with a two-hour preheating time was created and used in these types of buildings.

The variations of mean air temperature of PID control system with two different scheduled setpoints are compared for the typical old Norwegian building at -7°C outdoor condition, as shown in Figure 8. The energy consumption of scheduled PID controls with normal setpoint and preheat setpoint were summarized in Table 3 and Table 4, respectively. With two-hour preheating time, the thermal comfort was almost satisfied although it resulted in slightly higher energy consumption. Therefore, the preheat setpoint is a cost-effectively approach to addressing the high heating demand of poorly insulated buildings with high infiltration rates. By allowing for a longer preheating time, the electric radiator can achieve the desired temperature more efficiently and effectively, without requiring the additional expense of purchasing a larger size of electric radiator.

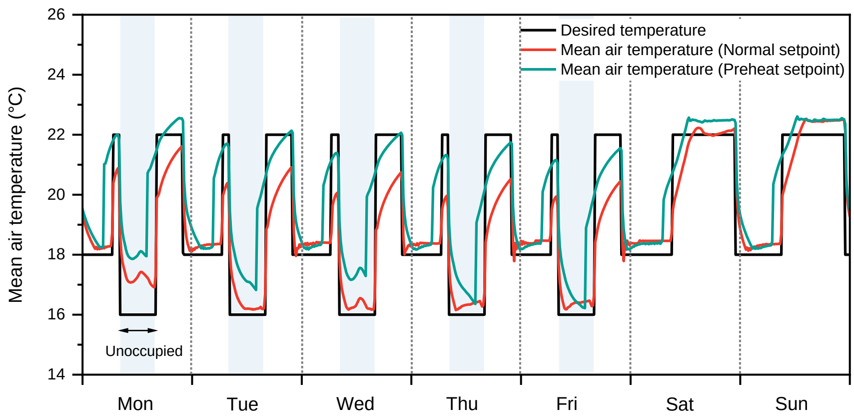


Figure 8. Mean air temperatures of scheduled PID control with normal scheduled setpoint (red line) or preheat scheduled setpoint (green line) in typical old Norwegian buildings at -7°C outdoor condition.

Table 3. Monthly heating energy consumption of on-off control and PID control in typical old Norwegian buildings (**Normal setpoint**).

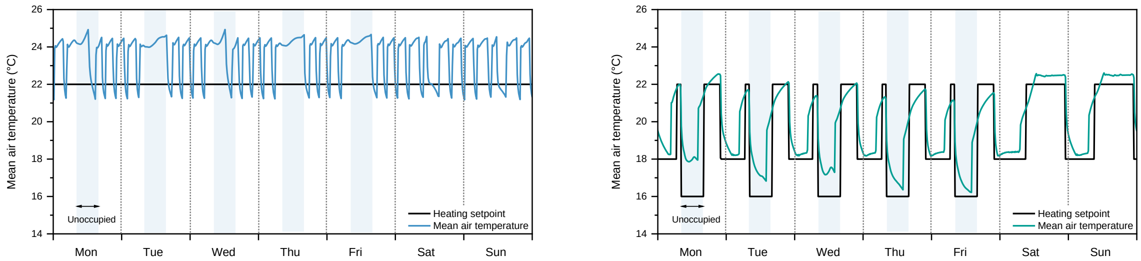
Outdoor air temperature [°C]	Baseline on-off control [kWh]	Scheduled PID control [kWh]	Energy saved [%]
-7°C	316.0	224.0	29.1
0°C	229.6	166.0	27.5
7°C	142.8	109.6	23.2

Table 4. Monthly heating energy consumption of on-off control and PID control in typical old Norwegian buildings (**Preheat setpoint**).

Outdoor air temperature [°C]	Baseline on-off control [kWh]	Scheduled PID control [kWh]	Energy saved [%]
-7°C	316.0	247.5	21.7
0°C	229.6	190.0	17.2
7°C	142.8	121.6	14.8

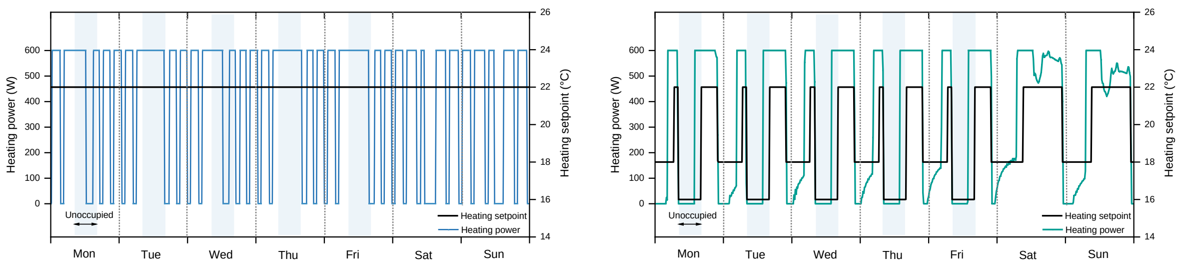
The energy saving is more obvious in typical old Norwegian buildings. By implementing the scheduled PID control system with preheat setpoint, the monthly heating energy consumption can be saved within the ranges of 14.8% to 21.7%, which has higher potential of energy savings compared to the TEK10 building.

The weekly variations of mean air temperature and heating power in typical old Norwegian buildings at -7°C outdoor condition are presented. Figure 9 compares the mean air temperature of baseline on-off control and scheduled PID control with preheat setpoint, and Figure 10 shows the heating power of two heating control systems.



Baseline onoff control *Scheduled PID control (Preheat)*

Figure 9. Mean air temperature of typical old Norwegian building at -7°C outdoor condition.



Baseline onoff control *Scheduled PID control (Preheat)*

Figure 10. Heating power of typical old Norwegian building at -7°C outdoor condition.

6. Conclusion

We conducted a comparison between the scheduled PID control and baseline on-off control applied to the electric heating system in two types of buildings under three different outdoor conditions. Our simulation results showed that the scheduled PID controller achieved better energy and thermal performance in these conditions. The main findings are:

- The scheduled PID controller provided more stable and accurate temperature control, leading to improved energy efficiency and occupant comfort.
- Scheduled PID control performed better in high heating demand scenarios. Compared to baseline on-off control, it saved **7.5% ~ 14.7%** energy consumption in well-insulated TEK 10 buildings, and energy savings could reach up to **23.2% ~ 29.1%** in poor-insulated old Norwegian buildings.
- Scheduled PID control demonstrated significant of energy saving potential, especially in cold outdoor conditions, where ***lower outdoor temperature, leads to higher energy saving potential***.
- The preheat setpoint can improve the thermal comfort in poorly insulated old Norwegian buildings, but also limits energy-saving potential with relatively lower energy savings of **14.8% ~ 21.7%**. To overcome this limit, larger-sized heaters would be required.
- There is typically a temperature difference between the averaged room air temperature and the sensor temperature, which should be taken into account when setting the temperature setpoint.

In conclusion, our study highlights the effectiveness and efficiency of the scheduled PID control in achieving improved energy efficiency and occupant comfort, especially in high-heating demand scenarios. By implementing this more advanced heating control system, building owners and occupants can enjoy improved energy efficiency and reduced heating costs.

Reference

[1] IEA, Norway 2022, IEA, Paris, 2022. https://www.iea.org/reports/norway-2022.
[2] ISO 52120-1:2021, Energy performance of buildings Contribution of building automation, controls and building management - Part 1: General framework and procedures, European Committee for Standardization, International Organization for Standardization, 2022.
[3] L.C. Felius, M. Hamdy, F. Dessen, B.D. Hrynyszyn, Upgrading the Smartness of Retrofitting Packages towards Energy-Efficient Residential Buildings in Cold Climate Countries: Two Case Studies, Buildings. 10 (2020) 200. https://doi.org/10.3390/buildings10110200.
[4] Direktoratet for byggkvalitet TEK10, (n.d.). https://dibk.no/regelverk/tek/ (accessed October 31, 2022).
[5] T. Marit, T. Dyrstad Pettersen, T. Haavik, Energy analysis of the Norwegian dwelling stock, IEA Task 37, 2009.