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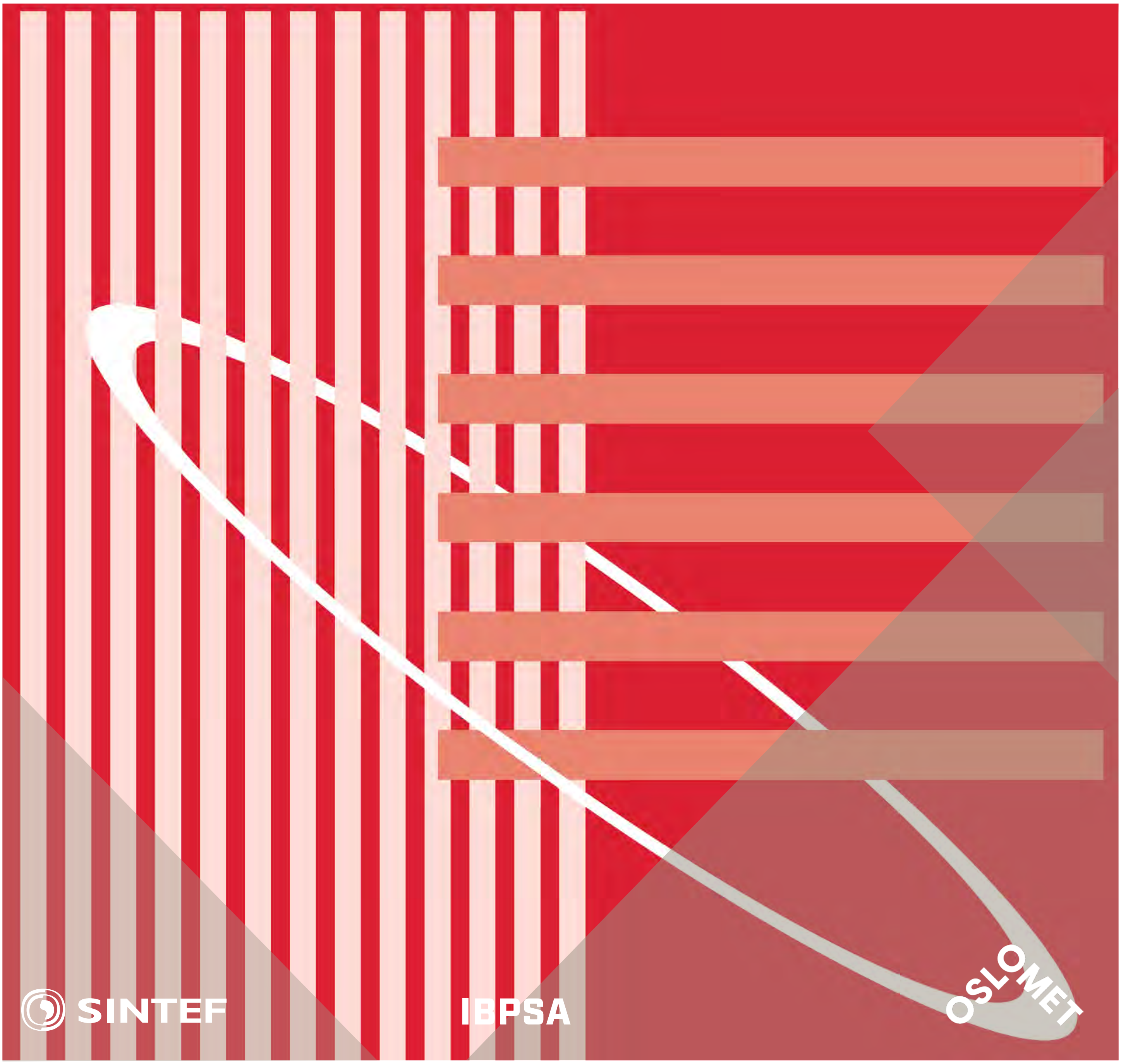

SINTEF Proceedings

Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

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Datasets for grey-box model identification from representative archetypes of apartment blocks in Norway

Hanne L. Bottolfsen[1*], Kamilla H. Andersen[1], John Clauß[2], Igor Sartori[1]
[1]SINTEF Community, Oslo, Norway
[2]SINTEF Community, Trondheim, Norway

* *corresponding author: hanne.bottolfsen@sintef.no*

Abstract

Grey-box models combine a relatively simple physical description of the building with a data-driven inference of key parameters and are often used for this purpose. A challenge with grey-box models is that the model identification process requires 'rich' datasets, meaning datasets containing enough statistical variability on both heating demand and indoor temperatures. Such datasets are scarcely available, usually only from dedicated experiments in living labs or similar research facilities.

This study aims to present a series of datasets that can be used for the identification of grey-box models of apartment blocks. Special test periods are simulated in IDA ICE during which representative archetypes of apartment blocks in Norway are excited with trains of heating events, Pseudo-Random Binary Sequence (PRBS), aiming at exploring a wide and rapidly changing set of indoor temperatures within and outside the thermal comfort zone.

Introduction

To exploit the energy flexibility potential in buildings, some form of smart control is necessary, that can manipulate the energy use based on external factors, such as weather and energy prices while maintaining thermal comfort for the occupants. In particular, it is expected that the thermal part of the energy demand, such as space heating, can be shifted in time and contribute to increasing flexibility of the demand in the energy system (Jensen, et al. 2017). Such types of controls shall rely on accurate, robust, and simple models of heat demand that are suitable for real-time control.

The aim of this study is to present a series of datasets that can be used for identification of grey-box models of apartment blocks and to describe the method used for creating these datasets.

Based on previously developed archetypes in the TABULA/EPISCOPE project, a set of IDA ICE models, representing apartment blocks in Norway is available. The IDA ICE models was developed in the study (Rønneseth and Sartori 2018).

In parallel with this study, two other studies are carried out. In one research activity the load profiles for the IDA ICE archetype models are validated against empirical datasets, while in the other parallel study the datasets created in this study is used for identification of grey-box models. Provided that the load profiles are validated, it is legitimate to assume that the indoor temperature profiles from the IDA ICE archetypes also are representative for the real building stock (Andersen, et al. 2020). Therefore, heating load and indoor temperature profiles from the IDA ICE models may in theory be used for creating grey-box models of those archetypes, likewise datasets from measurements, where available.

A successful grey-box identification process depends upon 'rich' datasets. To create such 'rich' datasets, simulations using a Pseudo Random Binary Sequence (PRBS) to control the radiators in the archetypes have been run, in addition to simulations with normal operation. Some of the strengths of PRBS-signals is that the signal is deterministic, shows no correlation with external factors and that it can be designed before an experiment (Bacher and Madsen 2010). It has been commonly used as an input signal in order to generate large sets of data with high quality that can be used for identification of black-box models (Royer, Thil, et al., Black-box modeling of buildings thermal behavior using system identification 2014) or as in this study, for identification of grey-box models. Such type of data is scarcely available as it can be challenging or expensive to run in real buildings. Data is therefore usually just available form physical experiments done in research facilities such as living labs. Both (Vogler-Finck, Clauß and Georges 2017) and (Thavlov, Bache and Madsen 2010) have done similar experiments in living labs. As an alternative, dynamic simulation models can be a good solution for increasing the numbers if available datasets.

The datasets generated in this study, both for normal operation and special test periods, are going to be made openly accessible on an internet repository by the time of the BuildSim Nordic conference in October 2020.

Methodologies

In this study, a set of previously developed archetype apartment block models with different age classes is used to run dynamic simulations. The simulation program IDA Indoor Climate and Energy (IDA ICE, EQUA, Sweden), version 4.8, has been used to run thermal simulation experiments. Simulations are run for both normal operation and with Pseudo-Random Binary Sequence (PRBS) control of the heating units (water radiators).

The simulations with PRBS signal control are run to obtain a different thermal behavior of the achetypes than what can be achived during normal operation.

Archetypes

A total of 20 archetypes from the TABULA (Typology Approach for Building Stock Energy Assessment) and EPISCOPE (Energy Performance Indicator Tracking Schemes for the Continuous Optimisation of Refurbishment Processes in European Housing Stocks) projects have been used in this study (TABULA/EPISCOPE u.d.). An archetype is the combination of a building category (here apartment block), age-group and renovation variant.

A detailed description of the archetypes are given in (Brattebø, et al. 2014). These archetypes are also used in other studies, and validation of the models against empirical datasets and numerical simulations is done in a parallel study (Andersen, et al. 2020).

The set of IDA ICE models represents apartment blocks in Norway from the 1950s until 2020, and each archetype represents approx. a ten-year interval. Table 1 presents the age classes and the number of floors and apartments for each of the models.

All apartment blocks for the period 1971 to 2020 consist of four floors and 24 apartments. The oldest archetypes (AB01 and AB02) have eight and 16 apartments distributed to four floors.

Table 1 – Archetypes age classes and size

Model	Age classes	Floors / apartments
AB01	- 1956	4 / 8
AB02	1956-1970	4 / 16
AB03	1971-1980	4 / 24
AB04	1981-1990	4 / 24
AB05	1991-2000	4 / 24
AB06	2001-2010	4 / 24
AB07	2010-2020	4 / 24
AB08	After 2020	4 / 24

In IDA ICE the apartment blocks are modeled with one ground floor, one mid-floor facing zones with the same thermal conditions, and a top floor (Rønneseth and Sartori 2018). 3D-model and floor plan of the model in IDA ICE is shown in Figure 1 and Figure 2.

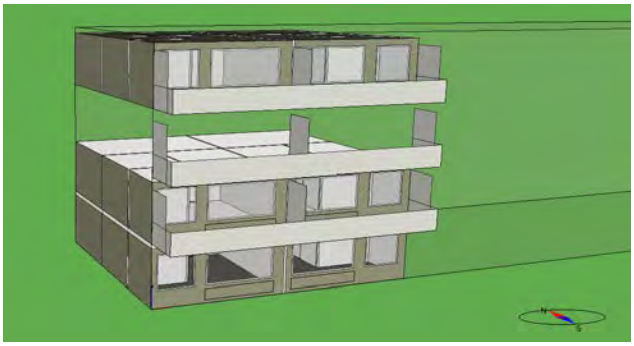


Figure 1 – 3D-model of apartment block in IDA ICE

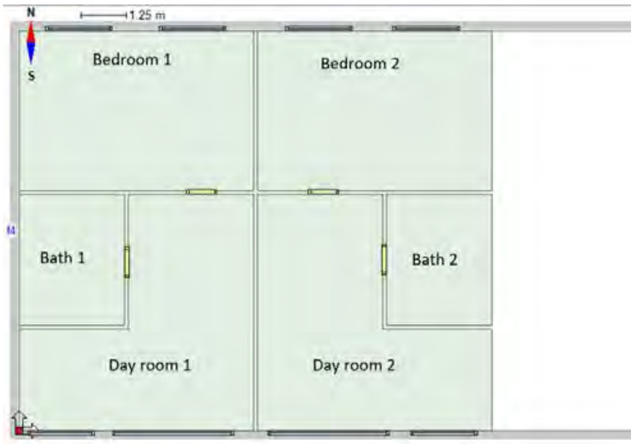


Figure 2 - Floor plan from IDA ICE

Each apartment is 70 m^2. The size is the same for all floors and consists of three zones with floor area as given in Table 2.

Table 2 - Area of zones in apartment

Room type	Floor area, m^2
Dayroom	31,5
Bedroom	28,0
Bath room	10,5

The internal loads in the apratments have not been changed for this study and are the same as in (Rønneseth and Sartori 2018). These loads are set according to SN TS 3031:2016 with the following heat gain:

- Equipment: 17,5 kWh/m^{2}yr, 60 % heat gain
- Lighting: 11,4 kWh/m^{2}yr, 100 % heat gain
- Persons: 13,1 kWh/m^{2}yr, 100 % heat gain

Each zone has a water radiator supplied by district heating. The radiators are dimensioned after the original variant of each archetype, without internal gains and with a dimensioning outdoor temperature (DOT) for Oslo of -20 °C. Setpoints for each zone for normal operation are given in Table 3. The bathroom is excluded in this study as it has electrical heating cables.

Table 3 - Heating setpoint for zone

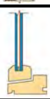
Room type	Heating setpoint
Dayroom	22 °C
Bedroom	18 °C
Bathroom	24 °C

The district heating supply temperature at max. power is 80/60°C. A weather compensated supply temperature from district heating to the radiators is used in the model. At DOT of -20 °C the supply temperature is 80 °C and the supply temperature follows a linear reduction from 80 °C to 60 °C between outdoor temperatures –20 °C and 17 °C. For all the models a distribution loss of 10 % is included for heat to the zones.

A typical meteorological year for Oslo, Fornebu, has been used in the simulations. The weather file is an IWEC-file (International Weather for Energy Calculations) downloaded from EnergyPlus with a resolution of one hour.

For each age group, in addition to the original building, two different variants of energy upgrade have been modeled in IDA ICE; an intermediate and a standard renovation. Intermediate renovation includes improved windows and thus improved air-tightness. The standard renovation includes, in addition, better envelope insulation, and represents a typical whole-building renovation without particular focus on energy efficiency (Rønneseth and Sartori 2018). Table 4 presents the input values for AB03 and the improvement for the renovated model (standard renovation), compared to the original model. For AB07 (representing the building code of 2010, TEK10) only the intermediate variant is available, and for AB08 (representing the passive house standard) there is just the original variant; this because both archetypes are equal to or better than today's building requirements. Thus we have a total of 21 archetypes.

Table 4 - AB03: Difference in input values for inital model and standard renovation (Brattebø, et al. 2014)

AB03 Initial		
Building component		**U-value [W/m²K]**
Roof: Concrete slab, 180 mm mineral wool, flat roof		0,21
External wall: Timber frame, 100 mm mineral wool, 50 mm thermal bridge barrier		0,34
Windows: Double-glazed window, regular glass, air-filled cavity		2,60
Floor: Concrete floor, 100 mm mineral wool, unheated basement		0,31
Infiltration rate (ACH):		5,0
AB03 Standard renovation		
Building component		**U-value [W/m²K]**
Roof: 180 mm mineral wool replaced with 250 mm mineral wool		0,14
External wall: 50 mm mineral wool added on the outside + brick veneer		0,18
Windows: Double-glazed window, one coated glass, air-filled cavity		1,90
Floor: 50 mm mineral wool added on the cold side (basement)		0,26
Infiltration rate (ACH):		2,0

Normal operation

For simulations with normal operation, no changes are made to the initial archetypes. The radiators are controlled by a PI-controller, which is regulated by the indoor temperature and the heating setpoint.

PRBS-signal

A Pseudo-Random Binary Sequence (PRBS) has been used to control the heat input for the water-borne radiators in the zones for the archetypes. By using PRBS-signal, the heat input for the radiators are excited with trains of heating events of shorter or longer time intervals, leading to a wide and rapidly changing set of indoor temperatures within and outside the comfort zone. The design of the PRBS-signal is described in the following.

Compared to other types of controls, the predefined PRBS-signal will not be affected by any external factors, such as the meteorological data, or limited by setpoints or normally acceptable indoor temperatures. The signal has only two levels, 0 or 1, to turn the radiator off and on. The used PRBS-signal is designed after guidelines given in IEA, EBC Annex 58 (Madsen, et al. 2016). The design of the signal is important, as it will impact the results from the simulations.

For these simulations, the total period of the predefined signal is 468 hours, including an entrance time of 126 hours. For the entrance time the signal has several short time intervals for on/off, while the following period of approx. two weeks, have longer periodes where the signal is on or off, Figure 3.

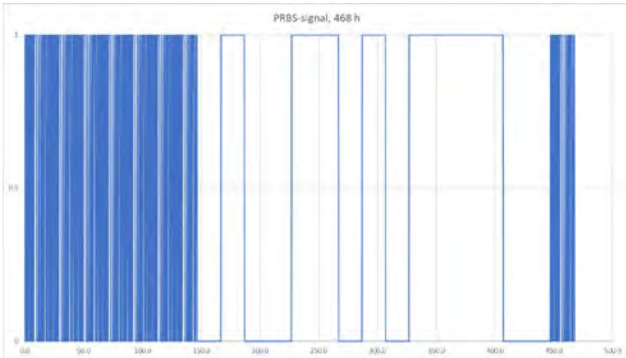


Figure 3 - PRBS-signal

A control module where the PRBS-signal is used as a source has been created in IDA ICE, presented in Figure 4. The control module is applied to each radiator in every zone (dayroom and bedroom).

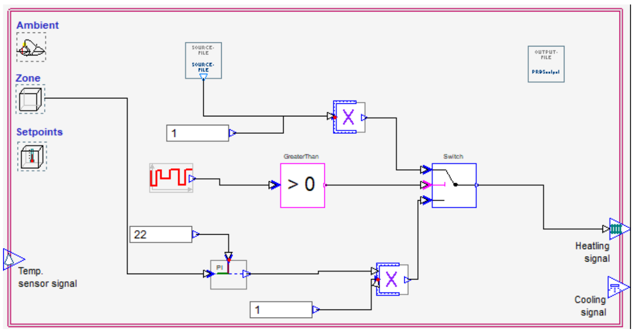


Figure 4 - Control module in IDA ICE

Simulations are run for one year for all archetypes. In the control modul in Figure 4, a source file, which is the predefinend PRBS-signal, is used as an input to control the heating units for the first 468 hours of a month.

Each month of the year starts with a new period of the predefined signal. After the period of 468 hours the control module has a swich-unit that changes the input signal to the PI-controler, shown in the lower part of Figure 4. The swich is controlled by a time schedule. When using the PI-controler the heating units is controlled as normal operation with the same setpoints as given in Table 3. This way, the same PRBS-signal is repeated for each month of the year, leading to a larger set of data.

Results

Even though datasets for a totalt of 21 archetypes have been created, the presentation of the results in this study is limited to four different archetypes. The archetypes AB03, AB03 with standard renovation, AB07 and AB08 is chosen to be a representative selection. Also, datasets from February are used to present the results as this month has usually the lowest average outdoor temperature.

Normal operation

During normal operation the indoor air temperature is almost constant at the zone setpoint. Figure 5 is showing the indoor temperature for two days (12. - 14. February) for the zone (Day room 2 in Figure 1) located in the middle of the building, with only one external wall and a heating setpoint at 22 °C. For all of the archetypes there is a small peak in the indoor temperature around noon on the 13th of February, this peak is related to solar heat gain which has a peak between 10.00 – 12.00.

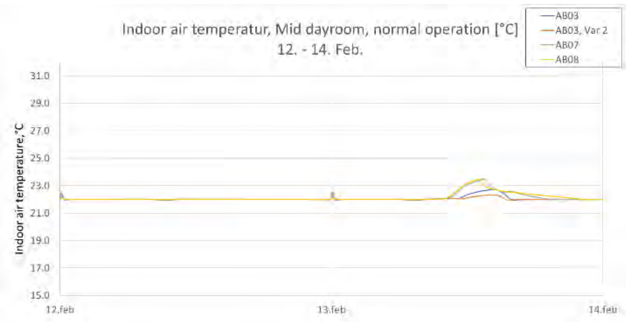


Figure 5 - Indoor air temperature, normal operation, Mid. Dayroom.

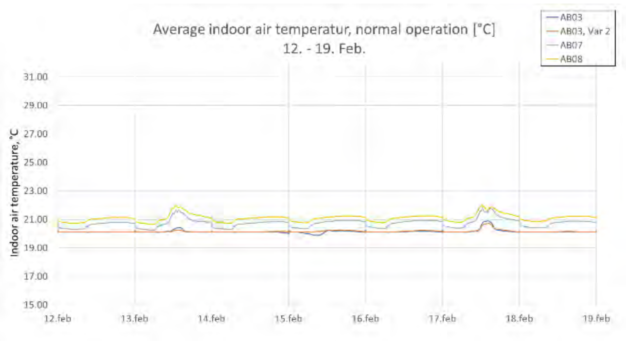


Figure 6 - Average indoor temperature, normal operation

Figure 6 shows the average area-weighted indoor air temperature for each archetype. As the radiators for each zone have been dimensioned after the original variant of each archetype and due to difference in thermal heat loss, the temperature trend is different for each of the archetypes. In addition, the temperature varies for the different zones, as the indoor temperature also will be influenced by orientation of the room, solar radiation and the different heating setpoints in the different zones

Total heat power from the plant to the zones is shown in Figure 7 for the same week in February as for the average indoor air temperature in Figure 6. The (inverted) outdoor temperature for the same period is shown as a red line in Figure 7. As the supply temperature from the district heating to the radiators is weather compensated the delivered power varies with the outdoor temperature. For this period the outdoor temperature varies between -5 °C and 4 °C.

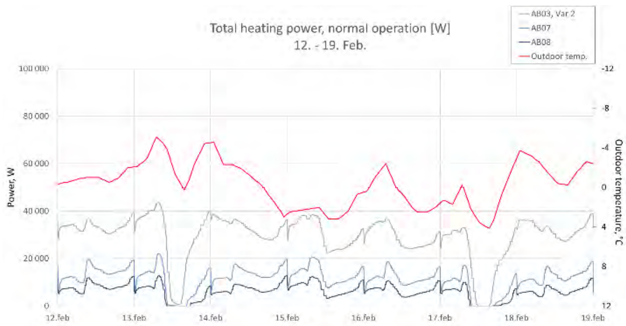


Figure 7 - Total heating power from plant to zones, normal operation

PRBS-signal

In the following Figure 8 to Figure 11, the indoor air temperature and totalt heating power for the plant from the whole simulation period with PRBS-signal is presented. The average indoor air temperature for each archetype is, as previously, weighted based on area and the number of apartment types (different location within the building).

Figure 8 and Figure 9 present the start of the period where the signal has shorter time intervals leading the heating power and indoor temperature to change more rapidly. Figure 10 and Figure 11 presents the period with longer time intervals. Compared to normal operation, the results from simulations with the PRBS-signal shows that a different thermal behavior is obtained for the archetypes and the temperature intervals has a wider range.

Ideally, when applying a PRBS-signal, the heating power curve, in Figure 9 and Figure 11, should be flat when the signal is 1 and the radiators are turned on. But as the signal is applied to the controller of the radiators in each zone and the supply temperature from the plant (representing a district heating substation) to the raditors is weather compensated, the heating power curve will change with the to the outdoor temperature, due to the linear reduction from 80 °C to 60 °C between outdoor temperatures of -20 °C and 17 °C.

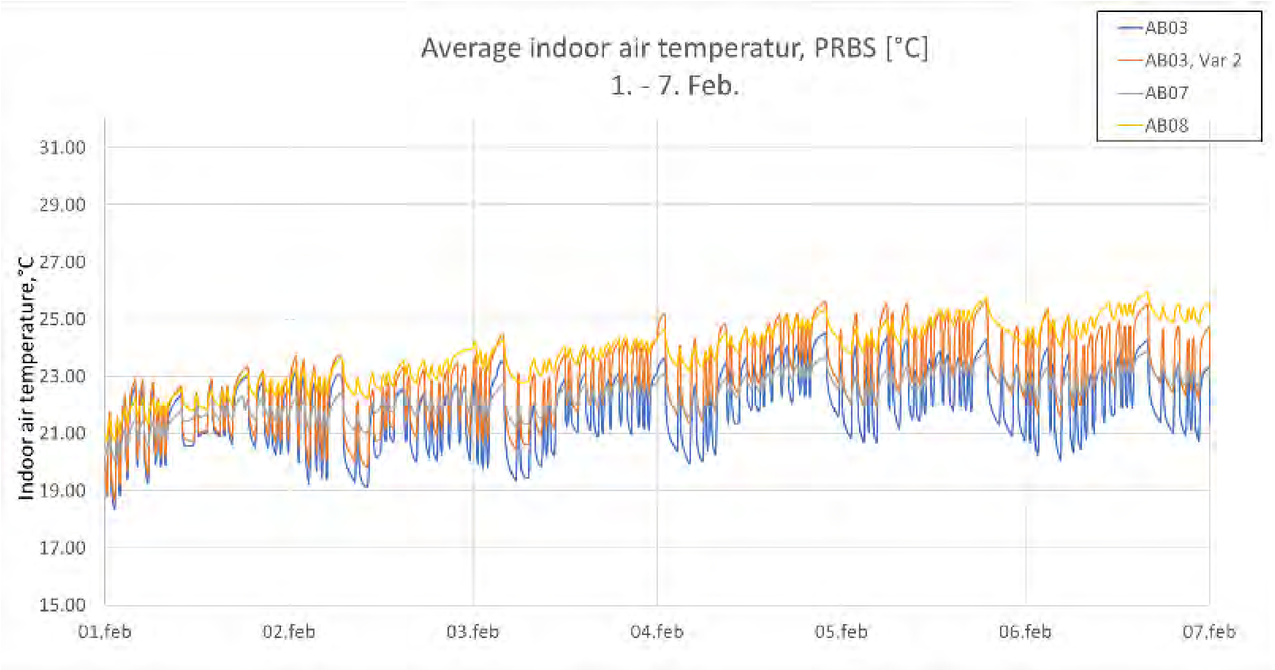


Figure 8 - Average indoor air temperature, PRBS

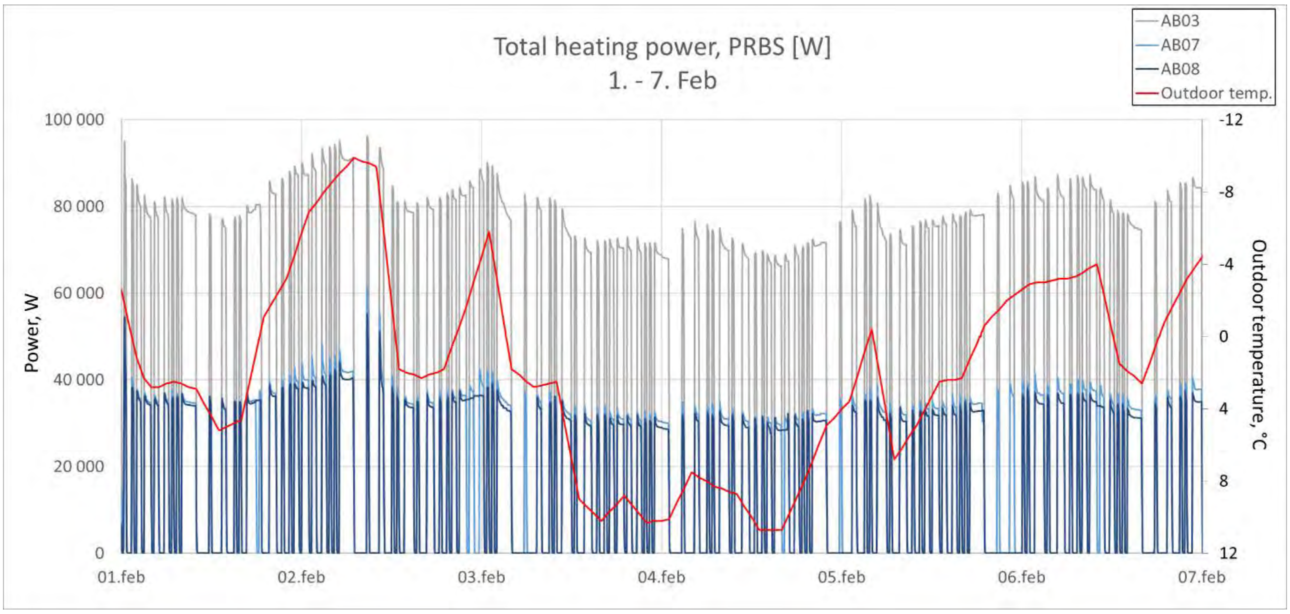


Figure 9 - Total heating power from plant, PRBS

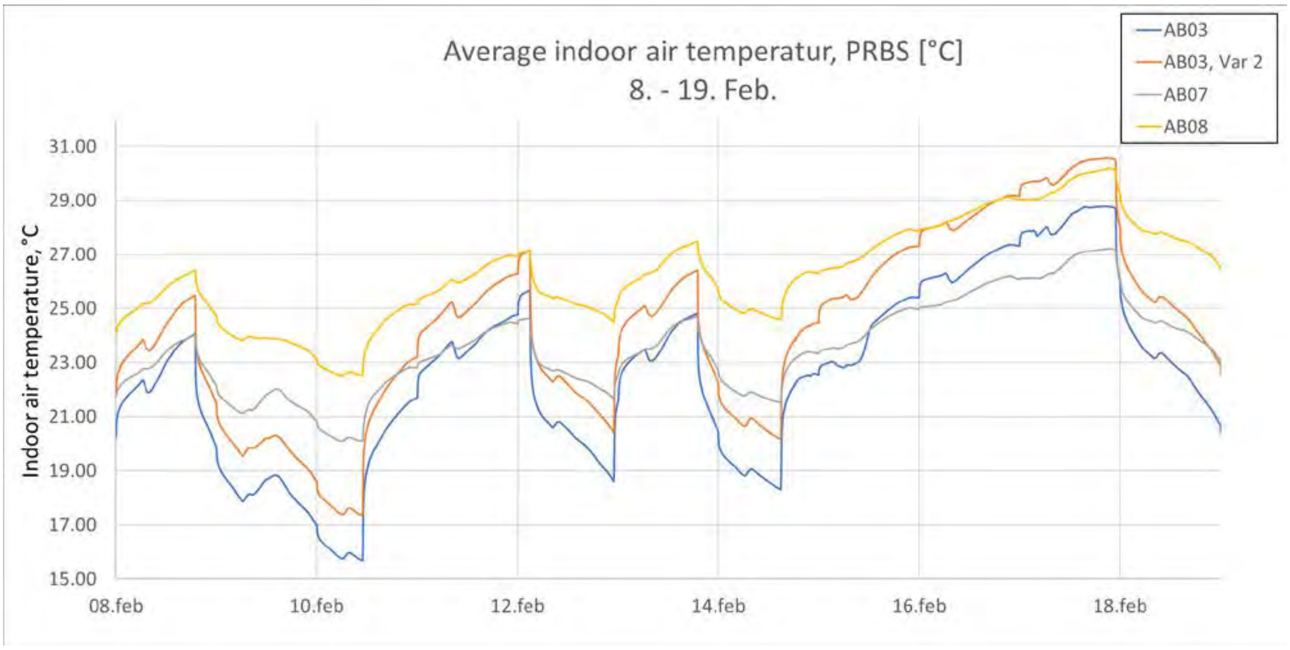


Figure 10 - Avergage indoor air temperature, PRBS

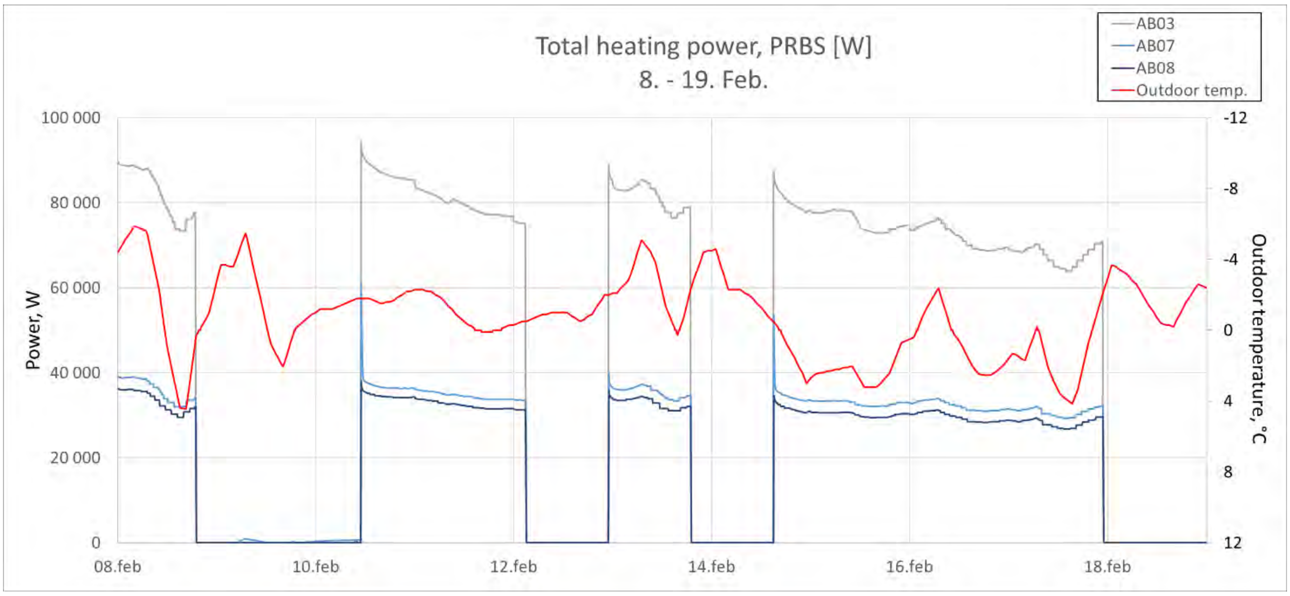


Figure 11 - Total heating power from plant, PRBS

Datasets

After running the simulations in IDA ICE, the data have been extracted from the result files and merged into full datasets in .csv files.

A total of 80 datasets have been created, in two versions: comprehensive and reduced files. This includes datasets for each archetype, including the initial and the two variants of energy upgrade, for both PRBS and normal operation.

The same data is extracted from simulations with PRBS and normal operation. For the comprehensive file, the following data is included with a five-minute resolution:

- Indoor air temperature for each zone
- Room heating for each zone
- Total heat power from the plant
- Weather data; wind, solar radiation, relative humidity, outdoor temperature

For the reduced file, the following data is included with a resolution of one hour:

- Average indoor air temperature
- Total heat power from the plant
- Weather data; wind, solar radiation, relative humidity, outdoor temperature

Conclusion

In this study a large series of datasets from representative archetypes of apartment blocks in Norway have been created.

The datasets consist of values for both normal operation and special test periods. For the special test periods the heat input for the water radiators are excited with trains of heating events of shorter and longer intervals. Simulations with PRBS leads to rich datasets with a wide and rapidly changing set of indoor temperatures within and outside the themal comfort zone.

Values have been extracted from the result files and merged into full datasets in .csv files. The generated datasets, both under normal operation and under special test periods, will be openly available online by the time of the BuildSim Nordic conference in October 2020.

In this study the control module with the PRBS-signal was applied to the water radiator in each zone. For further work the same experiments can be applied directly to the plant so to exclude the influence of the weather compensated supply temperature. This would improve the usefulness of sych datasets, as pointed out in (Bagle, Walnum og Sartori 2020).

Acknowledgment

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