Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

NTNU SINTEF

POSSIBILITIES FOR SUPPLYING NORWEGIAN APARTMENT BLOCKS WITH 4TH GENERATION DISTRICT HEATING

ZEN REPORT No. 8 – 2018

Øystein Rønneseth and Igor Sartori | SINTEF

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Preface

Acknowledgements

This memo has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Tegn_3 , Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk (NTE), Smart Grid Services Cluster, Statkraft Varme, Energy Norway and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m^2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Abstract

This report is a part of Work Package 4 Energy Flexible Neighbourhoods. The goal for WP 4 is to develop knowledge, technologies and solutions for design and operation of energy flexible neighbourhoods.

4th generation district heating is evaluated as a sustainable solution for covering the heating demand in Zero Emission Neighbourhoods and reducing the strain on the electricity grid. There are, however, some technical challenges that must be solved before it is introduced. One of them is to determine how low the supply temperature could be in different building types, which again will determine the minimum district heating supply temperature. This report is evaluating the minimum supply temperature in Norwegian apartment blocks based on effects of improving the thermal envelope and reducing the temperature levels for the heating system. The analysis is based on building simulation and focuses on whether the reduced supply temperature guarantees the comfort in the building, considering the coldest room with a heating setpoint of 22 °C and a minimum acceptable indoor temperature of 19,0 °C.

The simulated buildings are based on the data available from the IEE project Tabula. Generic models representative for Norwegian apartment blocks have been developed in IDA ICE. They consist of eight age classes and three levels of energy performance:

- Prior to 1956, from 1956-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010, 2011-2020 and 2020 →.
- Original, intermediate renovation and standard renovation

For the intermediate renovation level, it is only the windows and infiltration rates that have been changed. Tabula also includes an ambitious renovation, but this has not been modelled as the results are expected to be similar to those for the newest age class. Simulations are performed with two different dimensioning temperature levels for the radiators typical for Norwegian buildings; 80/60 and 60/40 °C.

The results showed that it is possible to reduce the supply temperature to the radiators from 80 to 60 °C for buildings from 1971-80 and all newer age classes, even for the non-renovated buildings. This is based on a minimum acceptable indoor temperature of 19.0 °C (according to the Norwegian building regulations, TEK). For the older age classes, an acceptable indoor temperature is not achieved for the non-renovated buildings when reducing the supply temperature. Although it is sufficient to perform the intermediate renovation to maintain temperatures above 19 °C, it is highly recommended to perform the standard renovation for these age classes to reduce the number of hours with a significantly reduced indoor temperature compared to the setpoint temperature. In addition to reduce the heating demand and thus lead to energy savings, this will also ensure that the occupants are satisfied with their thermal environment. It is important to note that the conclusions would be different if the minimum acceptable temperature was set higher, for instance at 20 or 21 °C.

The results can be used by district heating companies, building owners, contractors and consulting companies in order to evaluate the introduction of 4th generation district heating in Norwegian apartment blocks. Both the models and excel sheets with hourly results are available for partners and researchers within FME ZEN.

The authors would also like to acknowledge the contributions of Johannes Brozovsky in extracting results from IDA ICE, Maria Justo-Alonso for making the graphs as well as discussion with several professionals about the modelling.

Contents

1 Background

Zero Emission Neighbourhoods (ZEN) are conglomerates of different types of buildings that can conveniently be grouped into four categories: (1) new buildings with very high insulation levels and very efficient systems, (2) old buildings that are renovated achieving higher energy efficiency to some extent, (3) old buildings with potential for improving the energy performance and (4) old buildings whose energy performance cannot be significantly improved due to architectural reasons.

There are two possibilities for using 4th generation district heating (4GDH) in ZEN. The first is to connect the buildings with the highest temperature requirement to the supply pipe (or to an existing high-temperature DH system) and the low energy buildings to the return pipe. The second is to use a low temperature DH grid to supply the low temperature buildings and use local boosters such as heat pumps or boilers in the buildings with higher temperature requirements. Figure 1 illustrates the development towards low temperature DH systems, whereas 4GDH according to (Lund, Werner et al. 2014) should have supply temperatures between 30-70 °C. The connected buildings should also be low energy buildings with floor heating or low temperature radiators. Regardless of which solution is chosen for implementing 4GDH in a ZEN, it is necessary to determine how low the supply temperature could be in different building types. This will again determine the minimum DH supply temperature.

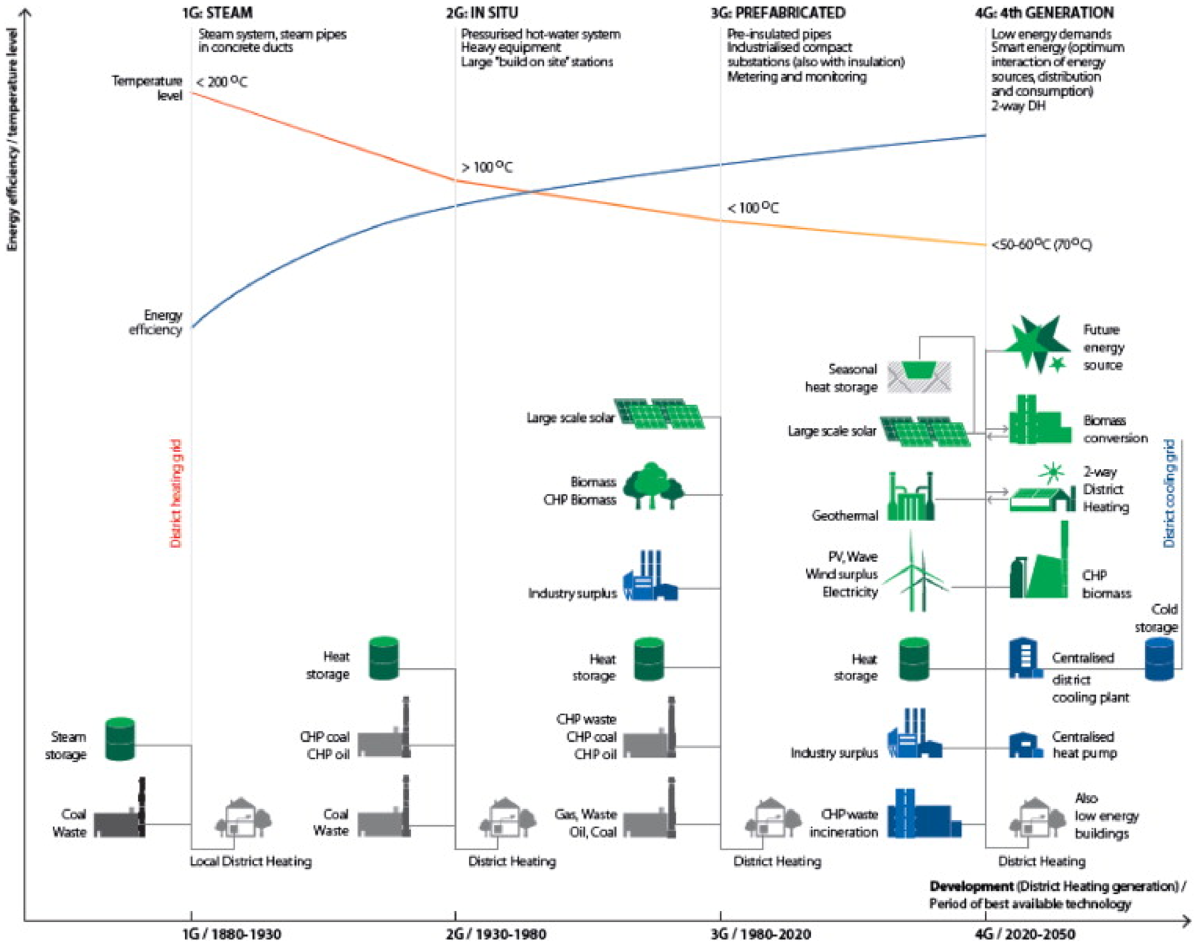

Figure 1 Illustration of the four different generations of district heating. (Lund, Werner et al. 2014)

2 Method

2.1 Simulated archetypes

The report "Typologier for norske boligbygg – Eksempler på tiltak for energieffektivisering" (Brattebø, O'Born et al. 2016) defines a building stock divided in 21 segments, consisting of:

- 3 types of buildings: single family house (SFH), terraced house (TH) and apartment blocks (AB)
- 7 age classes: Prior to 1956, from 1956-1970, 1971-1980 ,1981-1990, 1991-2000, 2001-2010, 2011-afterwards

A synthetic average building is defined for each segment, whose characteristics are representative of the most common features found in the segment based on best available knowledge. Each synthetic average building is described in three levels of energy performance (original, standard renovation and ambitious renovation) for a total of 63 archetypes, see Figure 2. Based on feedback from the district heating companies, this report will focus only on the apartment blocks, but models have been developed for SFH as well. To simplify the number of simulations and extraction of results, a clustering of the building types has been made.

Figure 2 Typology matrix for the Norwegian building stock in the IEE projects Tabula/Episcope (www.episcope.eu) (Brattebø, O'Born et al. 2016).

In the Tabula project using simplified simulations, the heating needs (kWh/m²·yr) have been calculated. These, together with the distribution of insulation materials and levels have been used for clustering of typologies. In Table 1, the buildings that will be clustered have the same background. Thereafter the apartment building classes 3 to 5 are clustered together. In addition to the similar heating needs, they also have similar use of materials. The input values from AB_03 will be used, as it represents the worst-case scenario of the three with regard to temperatures, which is the most relevant for the district heating evaluation. The ambitious renovation (to variant 3) has not been modelled, as the results are expected to be similar to those for AB_07. Instead, an intermediate level between the initial building and standard renovation has been included, where only the windows are changed. The standard renovation of AB_07 is considered representative for buildings built after 2020 and will hereby be referred to as AB_08. The simulated values in Table 1 are calculated based on the following standards: NS-EN 15603, NS 3031 and NS-EN 15316.

Table 1 Summarized heating needs (kWh/m^2·yr) for the different AB archetypes from Tabula, not including domestic hot water.

	Initial	Standard renovation	Ambitious renovation
AB_01	174	119	36
AB_02	182	100	36
AB_03	103	79	26
AB_04	93	81	28
AB_05	96	80	28
AB_06	58	49	32
AB_07	44	12	12

2.2 General simulation procedure

The simulation program IDA Indoor Climate and Energy (IDA ICE) has been used for the modelling, and properties of the thermal building envelope and the heat emission system has been in focus. The minimum supply temperature has been evaluated based on effects of improving the thermal envelope and reducing the temperature levels for the heating system. The simulated buildings are based on the data available from the IEE project Tabula (Brattebø, O'Born et al. 2016).

All the different age groups were classified with four floors, but with different number of apartments and total floor area. Table 2 provides an overview of building year, number of floors and apartments, floor area and normalized thermal bridge value. When dividing the total floor area given in Tabula with the number of apartments, the average apartment area for the different age groups ranged between 66-76 m². In order to simplify the modelling, an average apartment size of 70 m² was chosen for all age groups, and then similar apartments with regard to heat loss were added by using zone multipliers. An additional simplification was using the same room height of 2.7 m. The apartment blocks are also simplified to have three zones per apartment.

Table 2 Overview of the different age groups with some of their given and chosen values.

Name	Building year	Number of floors / apartments	Floor area [m^2]	Normalized thermal bridge value [W/(K·m² floor area)]	Window / envelope
AB_01	Before 1956	4 / 8	557	0.08	14.1 %
AB_02	1956-1970	4 / 16	1115	0.08	16.5 %
AB_03	1971-1980	4 / 24	1672	0.05	17.5 %
AB_04	1981-1990	4 / 24	1672	0.05	17.5 %
AB_05	1991-2000	4 / 24	1672	0.05	17.5 %
AB_06	2001-2010	4 / 24	1672	0.06	17.5 %
AB_07	2010-2020	4 / 24	1672	0.07	17.5 %
AB_08	After 2020	4 / 24	1672	0.03	17.5 %

Thermal bridge values are not provided by the Tabula brochures, and there are diverse ways for modelling this in IDA ICE. The easiest method is to specify normalized thermal bridge values. For apartment blocks, this value would also be different for different apartments, based on where they are placed (top, middle or bottom floor, gable wall or in the middle). This has not been considered, and an average value is chosen for the entire apartment block based on the construction method, which is also the recommended procedure for determining thermal bridges in existing buildings. (Norconsult 2013)

A common procedure for modelling multi-story buildings with similar characteristics in IDA ICE, is to model a three-story building, with multipliers for the middle zones. This will reduce both the modelling and simulation time without compromising the results. Each apartment consists of three zones, described in Table 3.

Table 3 Description of the zoning.

Room type	Floor area (% of total area)	Heating setpoint
Day room	31.5 m^2 (45 %)	22 °C
Bedroom	28.0 m^2 (40 %)	18 °C
Bathroom	10.5 m^2 (15 %)	24 °C

The "Day room" is a combined zone for living room, kitchen and entrance. Between the different zones there are two doors, which are all modelled with a leakage area of 0.03 m². The bathrooms have a schedule suggesting their doors are never open, while the bedroom doors are halfway-open 07-24 Monday-Friday and 09-24 Saturday, Sunday and holidays. Figure 3 shows how the model looks in IDA ICE.

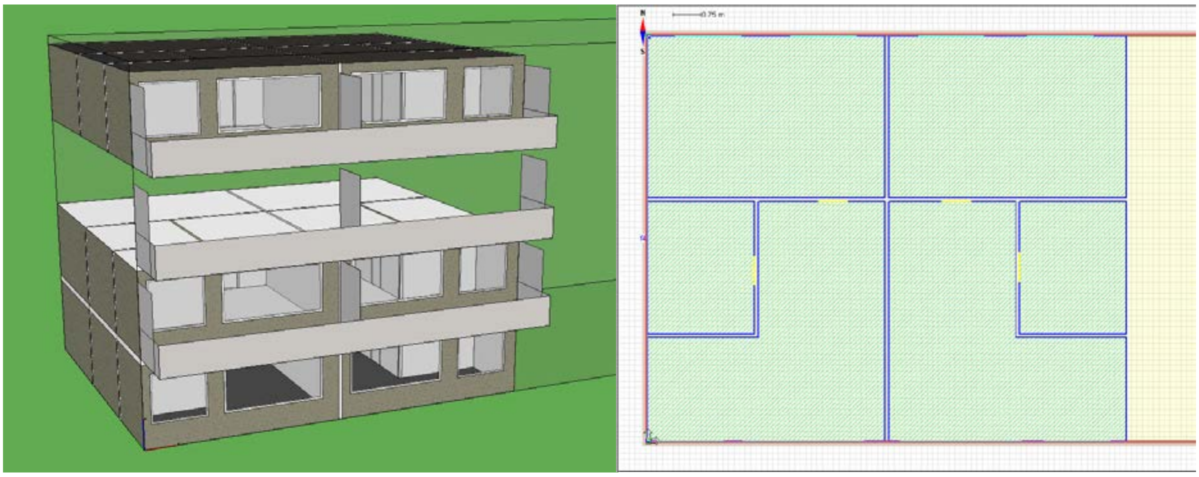

Figure 3 Screenshots from IDA ICE. Left: The model in 3D-view and right: floor plan for two apartments.

The weather file used for the simulations is an IWEC-file (International Weather for Energy Calculations) for Fornebu in Oslo, downloaded via IDA ICE from EnergyPlus. These weather files are commonly used in all energy simulation programs and considered to be most accurate by many experts within the field. Furthermore, the wind profile is chosen as "Suburban" and pressure coefficients as "Semi-exposed".

Internal loads are set according to SN TS 3031:2016 (Standard Norge 2017) for all age classes, although domestic hot water (DHW) is not included in the IDA ICE models. Annual values for internal loads are 17.5 kWh/m^2·yr for equipment (60 % converted to heat), 11.4 kWh/m^2·yr for lighting (100 % converted to heat) and 13.1 kWh/m^2·yr for persons (only as heat gain). The schedules for equipment and lighting can be seen in Figure 4, while the person load is modelled as always present.

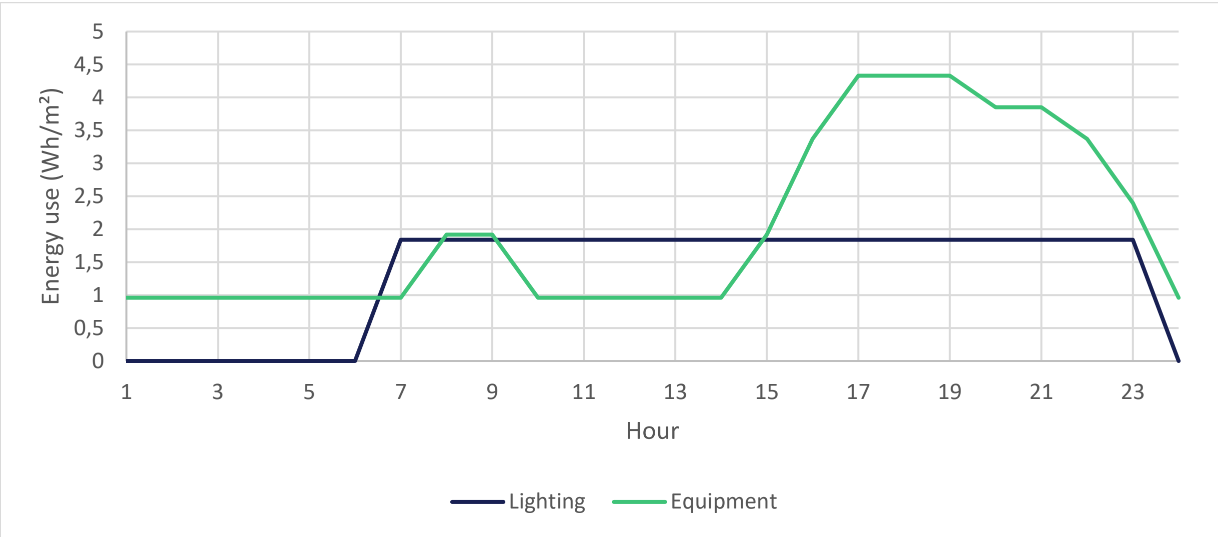

Figure 4 Daily schedule for lighting and equipment from SN TS 3031:2016.

2.3 Simulation of the heating system

The heating is provided to the building by water radiators. The initial cases (before renovation) are based on a heating simulation with dimensioning outdoor temperature (DOT) of -20 °C (Oslo-climate) and no internal heat gains. (Stene and Smedegård 2013) Based on this simulation with "ideal heaters", dimensioning of the radiators is performed, and this size is kept for the other simulations. For the initial district heating system in the original building, the supply and return temperatures for the radiators were T_{in} = 80 °C and T_{out} = 60 °C, respectively. The simulation control method for the radiators is PI.

Simulations are performed based on two different dimensioning temperature levels typical for radiators; 80/60 and 60/40 °C, while the indoor air temperature is maintained at 18-24 °C, depending on the room type. Electric floor heating is chosen as space heating solution in the bathrooms, as this is most common in practice. The purpose of the simulations is to check how low the supply temperature from the district heating may be, while ensuring thermal comfort in the dwellings. The second step is to repeat the same supply temperatures with stepwise renovations. The standard renovation is performed in two steps; first by improving only the windows, then by improving both windows and insulation levels.

Weather compensation curves are implemented according to Figure 5, with a supply temperature equal to the dimensioning value at DOT -20 °C, and a linear reduction of the supply temperature to the value corresponding to the dimensioning return temperature at an outdoor temperature of 17 °C.

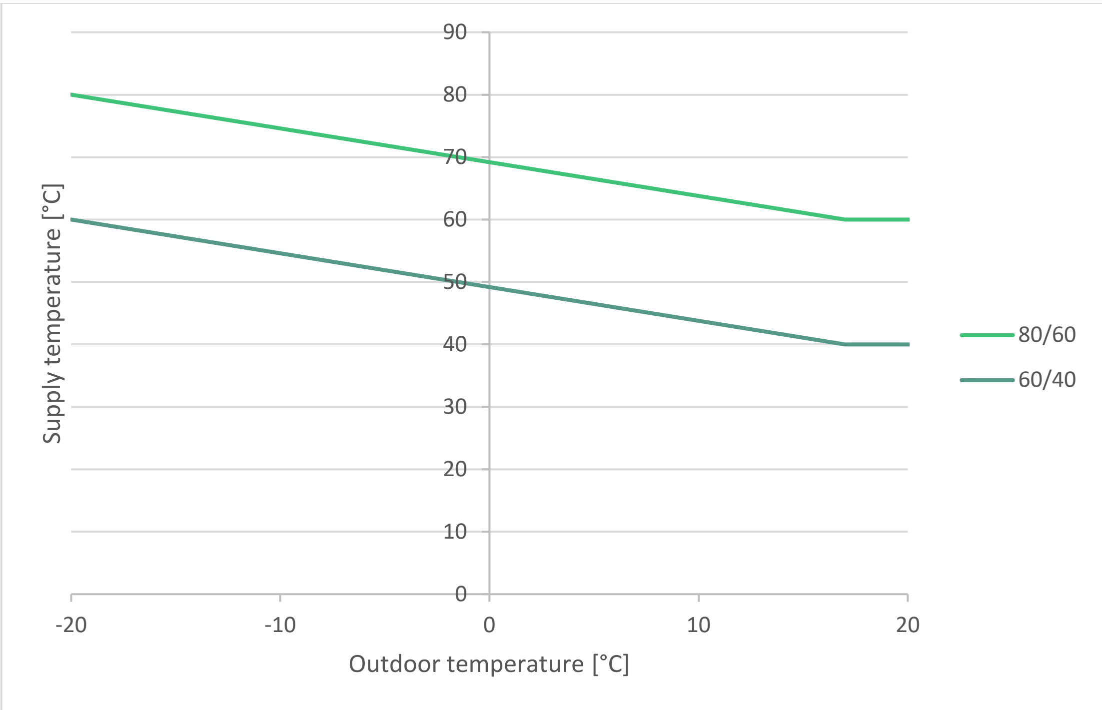

Figure 5 Weather compensation curves for the different temperature levels.

Furthermore, the model includes losses in the distribution system, whereas 10 % of delivered heat to zones are considered lost for all age groups. Water tank losses are neglected in the simulations and the efficiency of the heating plant is set to 1.

2.4 Building envelope and ventilation

The input values for the building envelope defined in Tabula are listed in Table 4 for AB_03, while the other age classes can be found in Appendix A1.

Table 4 AB_03: Construction and respective U-values for the different components of the initial building and for the standard renovation.

Component	**Specification**	**U-value initial built (W/m²K)**	**Specification**	**U-value standard renovation (W/m²K)**
Roof	Concrete slab, 180 mm mineral wool, compact roof.	0.21	70 mm additional mineral wool (250 mm total)	0.14
External wall	Frame-built timber wall, 100 mm mineral wool, 50 mm thermal bridge barrier	0.34	50 mm additional mineral wool on the outside + brick veneer	0.18
Windows	Double-glazed window, regular glass, air-filled	2.60	Double-glazed window, one LE-coating, air-filled	1.90
Floor	Concrete floor, 100 mm mineral wool, unheated basement	0.31	50 mm additional min wool in cold basement	0.26

Internal floors and walls are the same for all age groups; floors are concrete slabs of 200 mm with floor coating and internal walls are frame walls with 73 mm insulation and gypsum boards. The apartment dividers consist of 100 mm of concrete. The model also includes balconies on the southern facade, as this will affect the solar heat gain. They have a depth of 2 meters and separation walls between the apartments. Solar shading is modelled as "Integrated window shading" with External blinds (BRIS) which are activated if the indoor air temperature exceeds 23 °C.

During the last decades, there has been an improvement in procedures and materials used when replacing windows, so the infiltration rates are likely to decrease as well during the intermediate renovation. This will also be the case for the further refurbishment for the standard renovation, by improving insulation levels for roof, floor and external walls. There are, however, large uncertainties associated with the infiltration numbers for buildings, as the leakage number is dependent on many parameters, such as building method and materials, as well as the craftsmanship.

Table 5 shows the infiltration values that have been chosen for the model. The infiltration numbers given in air changes per hour (ACH) for the initial buildings are based on Table B.4 in SN TS 3031:2016 (Standard Norge 2017), but are slightly modified to get a gradual improvement for newer buildings. The improved infiltration numbers after renovations are based on technical assessments and discussion with other professionals. Although there is a large uncertainty to these numbers, they are considered more accurate than not improving the infiltration rates at all. An exception is made for AB_07, which is set according to the TEK 10 standard. There, the infiltration number is chosen as 1, an average value between the minimum demand (1.5) and the energy measure value (0.6). The standard renovation corresponds to passive house standard.

Table 5 Chosen infiltration rates (ACH) for the simulations, adjusted according to age group and energy standard.

Name	Building year	Initial built (Var 1)	Intermediate renovation (Var 2 inf+wind)	Standard renovation (Var 2)
AB_01	Before 1956	6	4	3
AB_02	1956-1970	6	4	3
AB_03	1971-1980	5	3	2
AB_04	1981-1990	4	4*	2
AB_05	1991-2000	3	2	1.5
AB_06	2001-2010	3	2	1.5
AB_07	2010-2020	1	0.8	-
AB_08	After 2020	0.6	-	-

* The windows are not changed during the standard renovation for AB_04.

In order to achieve sufficient air change and good air quality in the buildings, and thus have a good reference for comparison, the ventilation system in IDA ICE is used for all models, with airflow values based on TEK 17. (DIBK 2017) This is a simplified method for including the air change caused by window opening and vents in the building envelope that is common for buildings with natural ventilation. Even older buildings will also have installed mechanical exhaust in kitchens and bathrooms. The normal practice of window opening in bedrooms during the night is thus considered to be covered by this solution.

TEK 17 states that the exhaust airflows should be 54 m^3/h for bathrooms and 36 m^3/h for kitchens, and that the supply airflow for bedrooms should be 26 m^3/h per sleeping accommodation. It was assumed that there are two bedrooms (or two people) per apartment, so the supply airflow was adjusted to 52 m^3/h for the bedrooms. These values gave the design conditions, and then the supply airflow in the day rooms were adjusted (to 38 m^3/h) to balance the airflows. AB_06 has a heat recovery efficiency of 50 % for both variant 1 and 2, while AB_07 has a heat recovery of 70 % and 85 % for variant 1 and 2 respectively. The other age groups (AB_01-05) have no heat recovery, as well as no heat gains from fans. The specific fan power (SFP) is further set to 0 for AB_01-05 so that energy use for fans are not included, while AB_06 and AB_07 has SFP's of 2.5 and 1.5 respectively.

3 Results

This chapter presents the results for AB_03, which is considered to be representative for AB_04-05 as well, i.e. apartment blocks from 1971-2000. Hourly values for supply and return temperature, indoor air temperature in the day room and total mass flow rate in the heating system have been extracted and inserted in graphs relative to the outdoor temperature. Although the day room has a higher setpoint than the bedrooms, this room has been considered as the constraint for comfort temperature, as people usually prefer lower temperatures in the bedroom. Graphs with the results for the other age classes can be found in Appendix A2.

3.1 Non-renovated AB_03 building

The supply and return temperatures for the non-renovated AB_03 building can be found in Figure 6. The supply temperatures are fixed by the weather compensation curve, while the return temperatures are calculated based on the heating demand necessary to maintain the setpoint temperature (22 °C), the supplied water flow rate and internal gains. The return temperatures for the 80/60 system is scattered, but there is a linear trend from around 40 °C at Tout -15 °C being reduced to 25 °C at Tout +5 °C. The return temperatures for the 60/40 system are generally higher and show more distinct trends, due to increased mass flow rates.

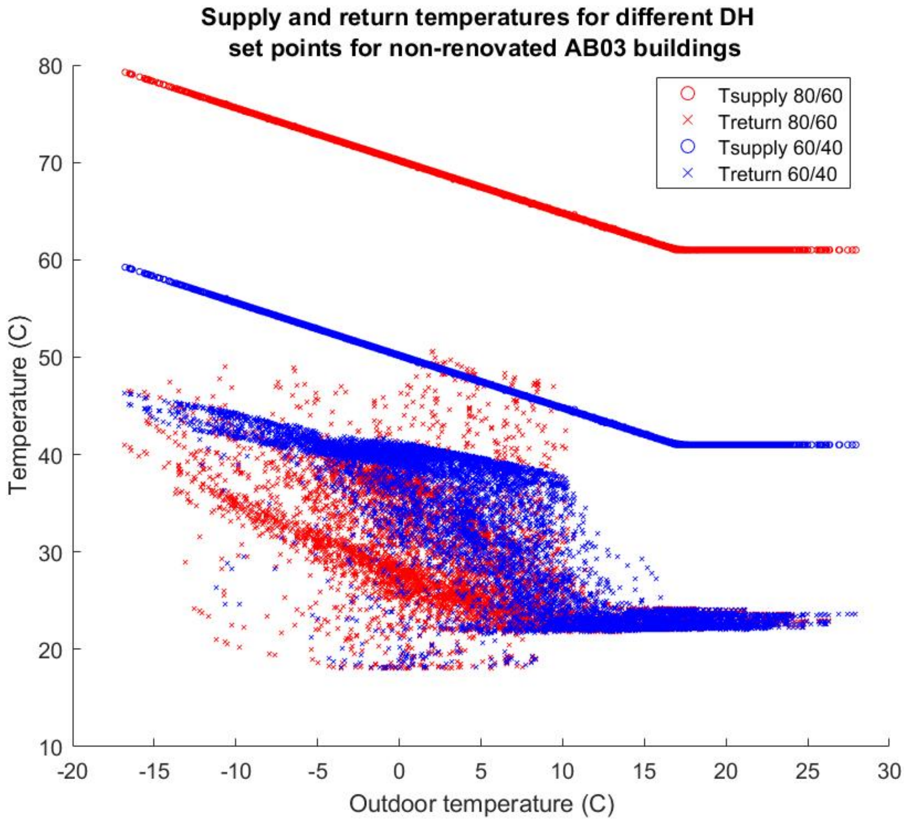

Figure 6 Supply and return temperature relative to outdoor temperature for non-renovated buildings (AB_03 variant 1).

As can be seen from Figure 7, the temperature requirement of 22 °C is maintained for the simulations with dimensioning temperature level 80/60 °C. When the temperature levels are reduced to 60/40 °C, the indoor temperature drops to between 20-22 °C during the heating season. The lowest temperature is 19.0 °C, and the temperature is only lower than 20 °C for 36 hours of the year. Although it may vary from user to user, this should be acceptable for most people, although it should be avoided if possible. The lowest indoor temperatures are not found at the lowest outdoor temperature (-16.8 °C) but rather between outdoor temperatures 0 and 10 °C. These are related to large infiltration rates due to poor airtightness of the building envelope and strong winds in the climate file. For both radiator temperature levels, the indoor air temperature exceeds 22 °C when the outdoor temperature is above 10 °C. This is because there is no active cooling system, but since the temperatures do not exceed 26 °C, this should be acceptable. The scattered values above 22 °C at lower outdoor temperatures than 10 °C are related to solar heat gain, and this will be further explained in chapter 3.4.

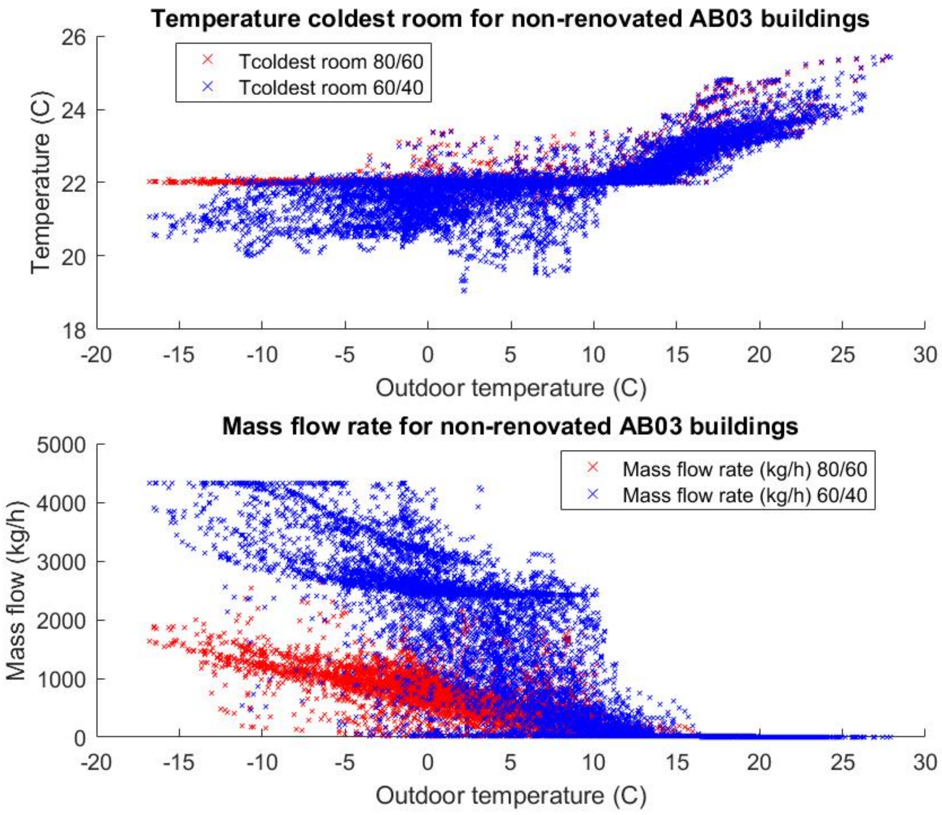

Figure 7 Temperature in the coldest room and mass flow rates relative to outdoor temperature for non-renovated buildings (AB_03 variant 1).

Both of the mass flow rates are fluctuating due to solar heat gain and wind-driven infiltration. The mass flow rates for 80/60 is showing a linear reduction from around 2000 kg/h towards 0 kg/h at around 15 °C outdoor temperature. For 60/40, the maximum flow rate of 4300 kg/h is reached for some of the coldest periods of the year, and the values are in general more scattered.

3.2 Intermediate renovated AB_03 building

Figure 8 and Figure 9 show the results for the intermediate renovated buildings for AB_03, where only the windows and infiltration rate have been changed. The supply temperatures are still fixed for both heating systems, and the return temperatures are now more stable as the influence of infiltration has been reduced. Compared to the non-renovated building, both return temperatures and mass flow rates have been slightly reduced, and both are showing more distinct trends. The indoor air temperature is still maintained close to the setpoint for the 80/60 model, where the lowest temperature is 21.9 °C. For 60/40 the indoor temperatures are still scattered, but now mostly between 21-22 °C, and with 20.4 °C as the lowest temperature. Thus, the intermediate renovation provides a significant improvement of the lowest indoor temperature. There is also fewer hours where the mass flow rate reaches the maximum limitation.

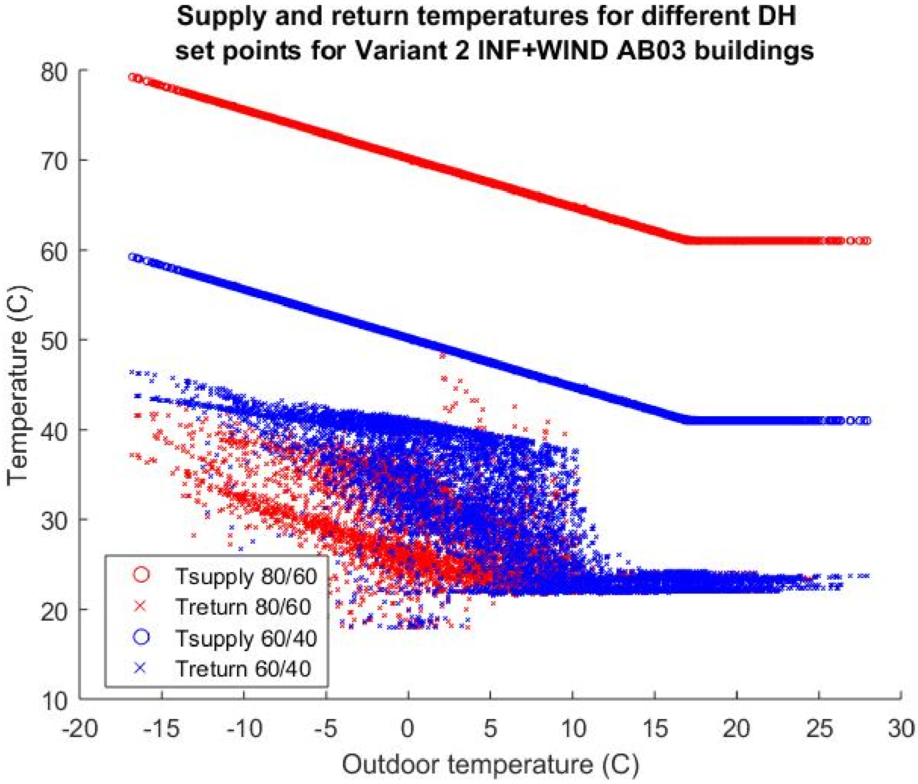

Figure 8 Supply and return temperatures relative to outdoor temperature for intermediate renovated buildings (AB_03 variant 2 inf+wind).

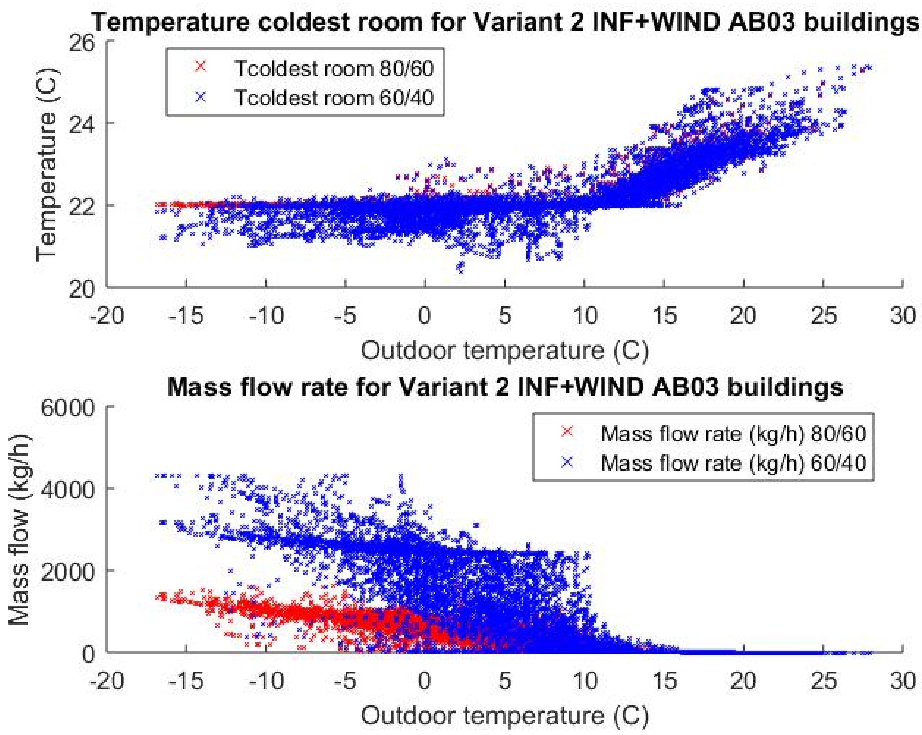

Figure 9 Temperature in the coldest room and mass flow rates relative to outdoor temperature for intermediate renovated buildings (AB_03 variant 2 inf+wind).

3.3 Standard renovated AB_03 building

Figure 10 show the supply and return temperatures for the standard renovated building (Variant 2). Here, the return temperatures are even more stable than for the intermediate versions, and has been slightly more reduced, as the building envelope and infiltration numbers have been further improved.

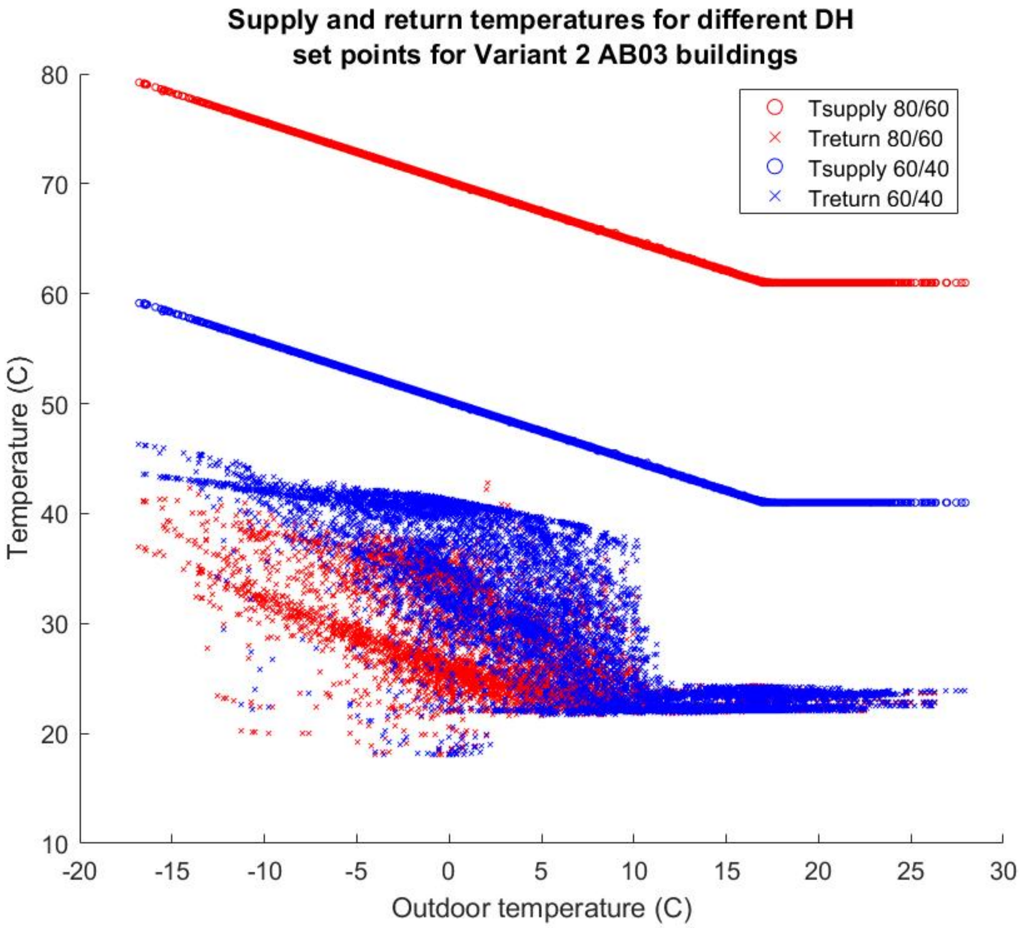

Figure 10 Supply and return temperatures relative to outdoor temperature for standard renovated buildings (AB_03 variant 2).

Figure 11 show the indoor air temperatures and mass flow rates for the standard renovated building. Now, the lowest indoor air temperature is 20.9 °C, and aside for only five hours the indoor temperature is maintained above 21 °C. The thermal comfort of the residents is thus expected to be considerably improved following the standard renovation. The mass flow rates have also been further reduced. The maximum limit is no longer reached, however, there is still a number of hours close to the maximum value.

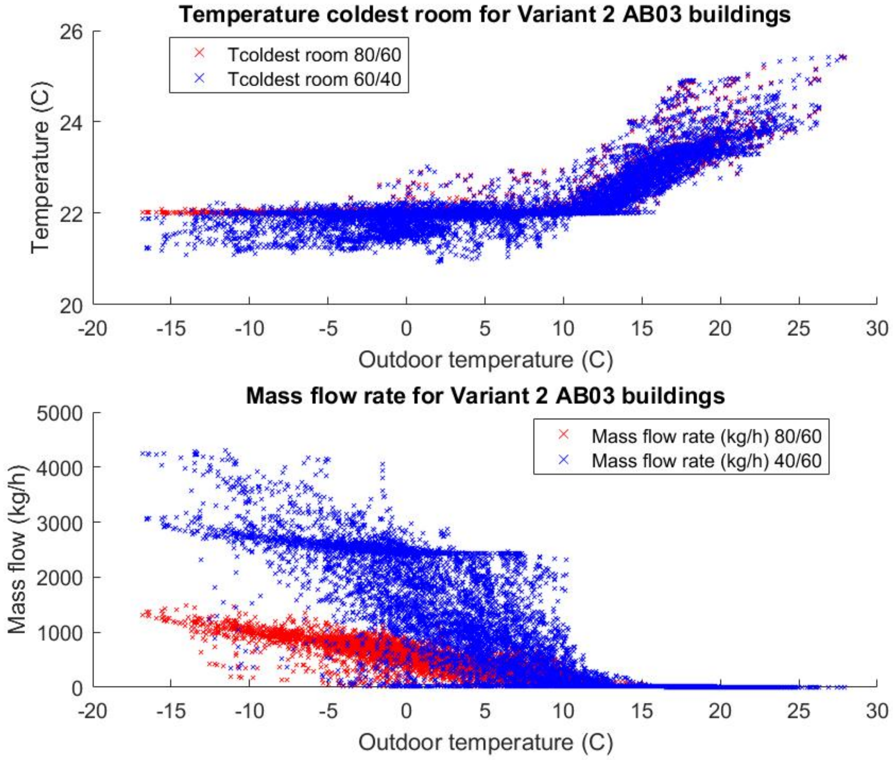

Figure 11 Temperature in the coldest room and mass flow rates relative to outdoor temperature for standard renovated buildings (AB_03 variant 2).

The more energy efficient models have more hours with temperatures above the heating setpoint of 22 °C for moderate temperatures during the heating season (i.e. -5 to +10 °C). An explanation is that these models maintains a generally higher indoor temperature close to the setpoint, so when there suddenly is solar heat gain the indoor temperature will thus exceed the setpoint temperature. This phenomenon occurs for all age classes. It also appeared more often and for lower outdoor temperatures for the most energy efficient buildings. Overheating for these periods is not expected to be an issue as the hourly temperatures does not exceed 24 °C. For the highest outdoor temperatures, it may be considered uncomfortable, as the indoor temperature slightly exceeds 26 °C for all variants of AB_06-08. The highest temperature of 27.3 °C was found for AB_06 var 2, where there were 126 hours with temperatures above 26 °C. For residential buildings this is however not considered a problem as the occupants have the possibility to reduce their clothing level. They are also likely to open the windows, which would reduce the indoor temperature through cross-ventilation. This is not included in the simulations, as the focus has been on the heating season.

3.4 Analysis of mass flow rates

The highest mass flow rates occurred for Variant 1 60/40 for all the age classes. AB_03 had the highest mass flow rate, with a mass flow limit reached at 4309 kg/h. Though AB_01-02 has a higher heating demand per square meter, they have a lower total floor area than AB_03-07, resulting in lower mass flow rates. As mentioned earlier, AB_01 consist of 8 apartments, AB_02 have 16 apartments, while AB_03-08 has 24 apartments. AB_01 and AB_02 also reached their maximum mass flow rates at 1894 and 3740 kg/h respectively, while AB_06-08 did not reach any limitation due to improved building envelope and thereby lower heating demand. The highest values for AB_06-08 were 2288, 1802 and 987 kg/h respectively.

There is also a fluctuation in mass flow due to solar heat gain, as illustrated in Figure 12. When the solar radiation increases, the mass flow goes to virtually zero, and the mean inside air temperature still rises. When the solar radiation becomes less, the indoor temperature goes down to 22 °C, and then the mass flow rates will increase again. In addition, the values in the other figures used previously in this chapter are sorted dependent on the outdoor temperature, so the hours next to each other is not necessarily from the same days. This means that there could be differences with regard to other variables than solar radiation, such as internal loads, wind-driven infiltration, etc, and these fluctuations are therefore expected.

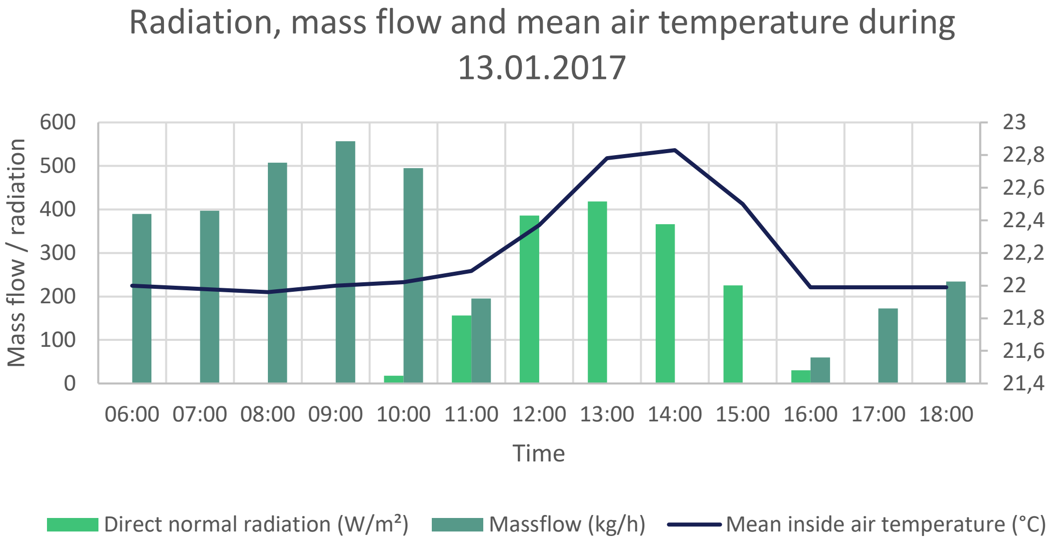

Figure 12 Solar heat gain, mass flow and indoor air temperature during a day in January.

3.5 Calculated energy need for heating

The space heating need for radiators, heating battery and electric floor heating can be found in Table 6. These are found for the versions with temperature level 80/60 °C for the radiators. The efficiency of the heating plant is set to 1, there is virtually no storage tank for hot water and the distribution loss from heating plant to radiators is set to 10 %. AB_07 variant 2 (passive house standard) was renamed to AB_08 variant 1, representative for buildings built after year 2020.

Table 6 Energy need for radiators, el. floor heating and heating battery in kWh/(m²·yr).

	Building year	**Non-renovated buildings (Variant 1)**	**Standard renovated buildings (Variant 2)**
AB_01	Before 1956	196	129
AB_02	1956-1970	175	112
AB_03	1971-1980	108	89
AB_04	1981-1990	95	89
AB_05	1991-2000	104	88
AB_06	2001-2010	52	40
AB_07	2010-2020	36	-
AB_08	After 2020	19	-

4 Discussion

The results are useful for determining the minimum supply temperature for space heating systems in apartment blocks. However, this study has not evaluated methods for DHW heating. Although Norwegian building regulations (TEK) do not provide concrete regulations on temperatures in DHW systems, a minimum temperature of 65 °C is recommended in circulation systems to avoid problems with legionella. (DIBK 2017) This will pose as a constraint for the DH supply temperature if the district heating grid is to cover this heating need as well, which for 3GDH has been normal practice. 4GDH could still be used to preheat DHW to a certain temperature, and then local boosters (electric heaters or heat pumps) could cover the remaining temperature lift. It might also be possible to introduce other measures, such as UV treatment, chemical treatment or limiting the system volume of DHW from the heat source to the tapping points, to prevent legionella while lowering the DH supply temperature.

Another issue that has not been fully covered is the temperature level in DH grids versus temperature levels in buildings. If the heat load remains unchanged, a reduced supply temperature in the buildings will lead to reduced temperature difference in the DH grid and thereby reduced capacity due to limitations of the mass flow. The simulations for supply and return temperatures in the building are based on the dimensioning values 80/60 and 60/40 °C, which means that the supply temperature in the DH grid must be higher than 80 and 60 °C respectively. How much higher has not been investigated. The DH network must supply all the buildings in the concession area, whereas the worst and furthest building will determine the temperature requirements. More on this topic can be found in (Walnum and Fredriksen 2018).

Another issue open for discussion is the definition of "acceptable" indoor temperature in the buildings. If the introduction of 4GDH leads to reduced indoor temperatures, what would be deemed as "acceptable" by the users? Is there a minimum temperature that should never be surpassed, or should it be defined similar to TEK's (Norwegian technical regulation for buildings) requirement for overheating? TEK allows maximum 50 h/year to be above 26 °C (DIBK 2017), and similar requirements could be introduced for lower temperatures during the coldest days of the year. For "light work" TEK recommends an operative temperature between 19-26 °C, whereas the minimum temperature of 19 °C should always be maintained except if there are special problems with the operation. Based on the current regulation, the indoor temperature should always be above 19 °C. The research project EBLE (Thomsen, Gullbrekken et al. 2017) however, showed that users preferred indoor temperatures between 22-24 °C in day rooms, while for bedrooms they wanted lower temperatures, preferably 15-19 °C. Based on this result, it is most important to maintain the temperature in the day rooms, whereas the users actually want lower temperatures than the regulation requires for the bedrooms. Thermal comfort could be maintained in the day rooms either by using larger heat emission surfaces, or by implementing personal heating devices. More information on such devices can be found in (Rønneseth 2018).

Regarding dimensioning of radiators, it has been common practice to overdimension heating systems "just in case". They might even be "sufficiently" overdimensioned, so that it is possible to introduce lower DH temperature levels for most parts of the year without making changes to the heating systems. This was investigated in (Ingebretsen 2014), which made similar findings as those in this report. Walnum and Fredriksen (2018), however, states that measures in substations and buildings are necessary before the supply temperature can be reduced. This is in cases where the heat load remains unchanged, as a reduced supply temperature will lead to reduced temperature difference in the DH grid and thereby reduced capacity due to limitations of the mass flow. The dimensioning outdoor temperature (DOT), i.e. the lowest outdoor temperature for three consecutive days, is usually the basis for the dimensioning. For Oslo, the location used for this simulation, DOT is set to -20 °C. Due to global warming, these DOTs may no longer be representative for dimensioning of heating systems, and the temperatures are expected to continue to rise (Tajet, Hygen et al. 2018). The lowest outdoor temperature for the weather file used in the simulations is -16.8 °C, so the radiators in this model are thus also overdimensioned relative to the weather file.

5 Conclusion

Based on the analysis of the results from AB_03, it should be possible to reduce the supply temperature to the radiators from 80 to 60 °C, even for the non-renovated building. The lowest simulated indoor temperature was 19.0 °C, which is exactly within the requirement in the Norwegian building regulation, TEK, although this might be experienced as slightly cold for the occupants. For the newer age classes (AB_06-08), the indoor temperature is kept above 20 °C for all variants. For the older versions, AB_01-02, the indoor temperature in the non-renovated buildings is too low, especially for AB_02, where the lowest temperature is 18.0 °C, and the temperature is lower than 19 °C for close to 200 hours. Both intermediate and standard renovation of AB_01-02 is sufficient for maintaining an indoor temperature above 19 °C, although the intermediate renovation has so many hours with temperatures lower than the setpoint of 22 °C that the occupants are expected to be dissatisfied. For the standard renovated buildings, the temperatures are above 21 °C for most of the time. It is important to notice that the conclusions would be different if the minimum acceptable temperature was set higher, for instance at 20 or 21 °C.

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Appendix

A1 Construction and U-values for the different age classes

Table 7 AB_01: Construction and respective U-values for the different components of the initial building and for the standard renovation.

Component	Specification	U-value initial built (W/m²K)	Specification	U-value standard renovation (W/m²K)
Roof	150x200 mm beams with pugging (clay)	0.75	Replace pugging with 100 mm mineral wool	0.30
External wall	Bricks non-insulated or concrete with 75 mm wood fibre plate	0.82	50 mm additional min wool on the outside	0.41
Windows	Two ordinary panes in coupled frames	2.50	Double-glazed window, one LE-coating, air-filled	1.90
Floor	150x200 mm beams with pugging (clay)	0.75	Replace pugging with 100 mm mineral wool	0.30

Table 8 AB_02: Construction and respective U-values for the different components of the initial building and for the standard renovation.

Component	Specification	U-value initial built (W/m²K)	Specification	U-value standard renovation (W/m²K)
Roof	Concrete slab, 100 mm mineral wool	0.32	50 mm additional mineral wool in cold attic	0.23
External wall	Concrete, 100 mm air-entrained concrete	0.96	100 mm additional mineral wool on the outside	0.29
Windows	Double-glazed window, regular glass, air-filled	2.60	Double-glazed window, one LE-coating, air-filled	1.90
Floor	Concrete floor, 50 mm mineral wool	0.49	50 mm additional min wool in cold basement	0.32

Table 9 AB_04: Construction and respective U-values for the different components of the initial building and for the standard renovation.

Component	Specification	U-value initial built (W/m^2K)	Specification	U-value standard renovation (W/m^2K)
Roof	Concrete slab, 180 mm mineral wool, compact roof.	0.20	50 mm additional mineral wool in cold attic	0.16
External wall	Frame-built timber wall, 150 mm mineral wool, 50 mm thermal bridge barrier	0.29	50 mm additional mineral wool on the outside + brick veneer	0.17
Windows	Double-glazed window, one LE-coating, air-filled	1.90	No changes	1.90
Floor	Concrete floor, 120 mm mineral wool, unheated basement	0.25	No changes	0.25

Table 10 AB_05: Construction and respective U-values for the different components of the initial building and for the standard renovation.

Component	Specification	U-value initial built (W/m^2K)	Specification	U-value standard renovation (W/m^2K)
Roof	Concrete slab, 180 mm mineral wool, compact roof.	0.20	50 mm additional mineral wool in cold attic	0.16
External wall	Frame-built timber wall, 150 mm mineral wool, 50 mm thermal bridge barrier	0.29	50 mm additional mineral wool on the outside + brick veneer	0.17
Windows	TEK 87-window	2.40	Double-glazed window, one LE-coating, air-filled	1.90
Floor	Concrete floor, 120 mm mineral wool, unheated basement	0.25	No changes	0.25

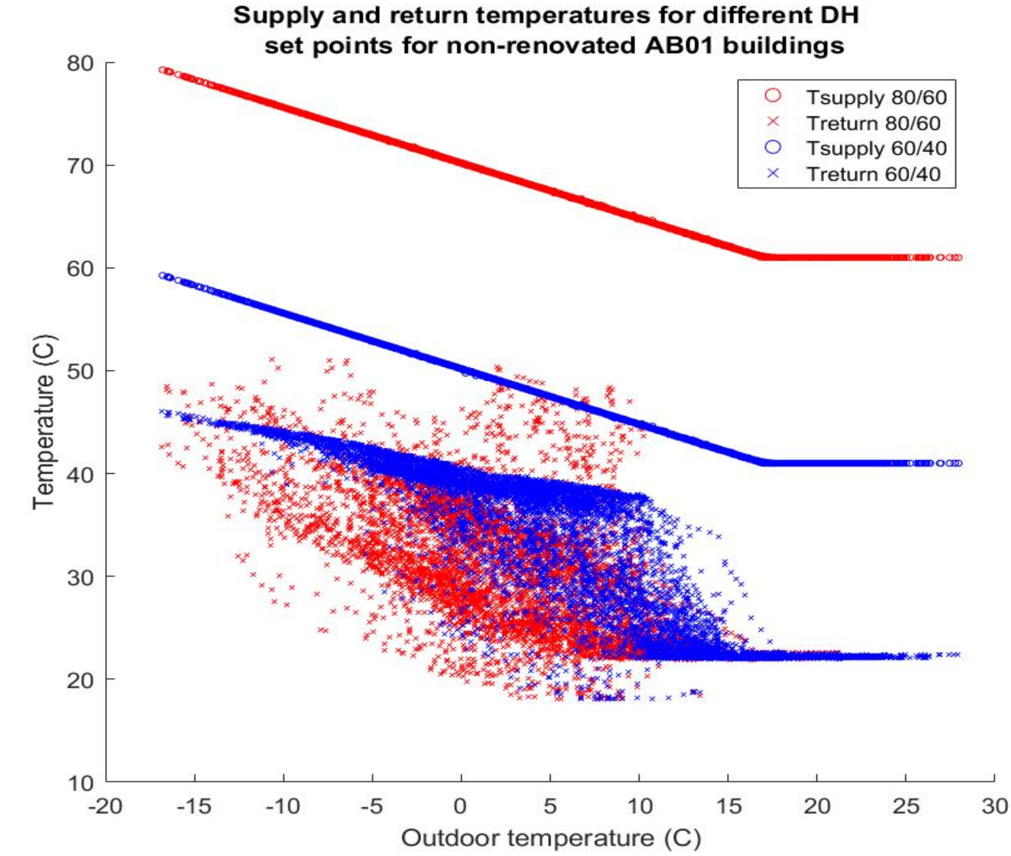
Table 11 AB_06: Construction and respective U-values for the different components of the initial building and for the standard renovation.

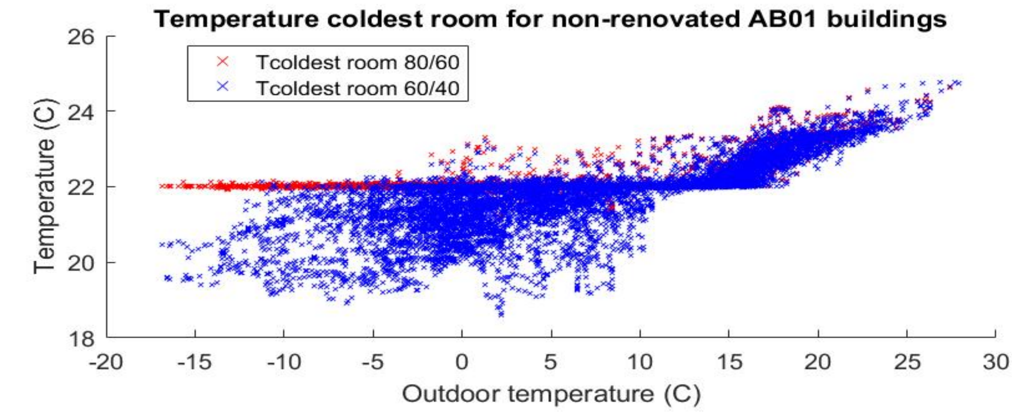
Component	Specification	U-value initial built (W/m²K)	Specification	U-value standard renovation (W/m²K)
Roof	Concrete hollow core slab, 220 mm mineral wool	0.14	No changes	0.14
External wall	Frame-built timber wall, 150 mm mineral wool, 50 mm thermal bridge barrier	0.27	50 mm additional mineral wool on the outside + brick veneer	0.16
Windows	TEK 97-window	1.60	TEK 10-window	1.20
Floor	Concrete hollow core slab, 220 mm mineral wool	0.13	No changes	0.13

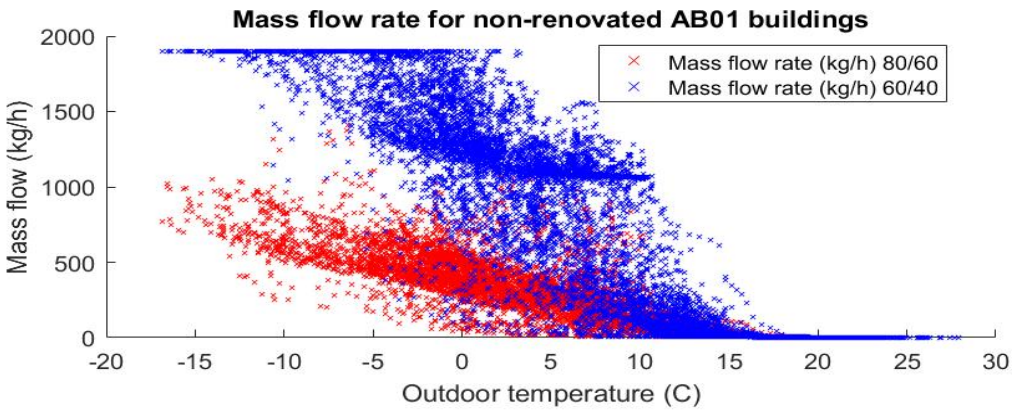
Table 12 AB_07: Construction and respective U-values for the different components of the initial building and for the standard renovation.

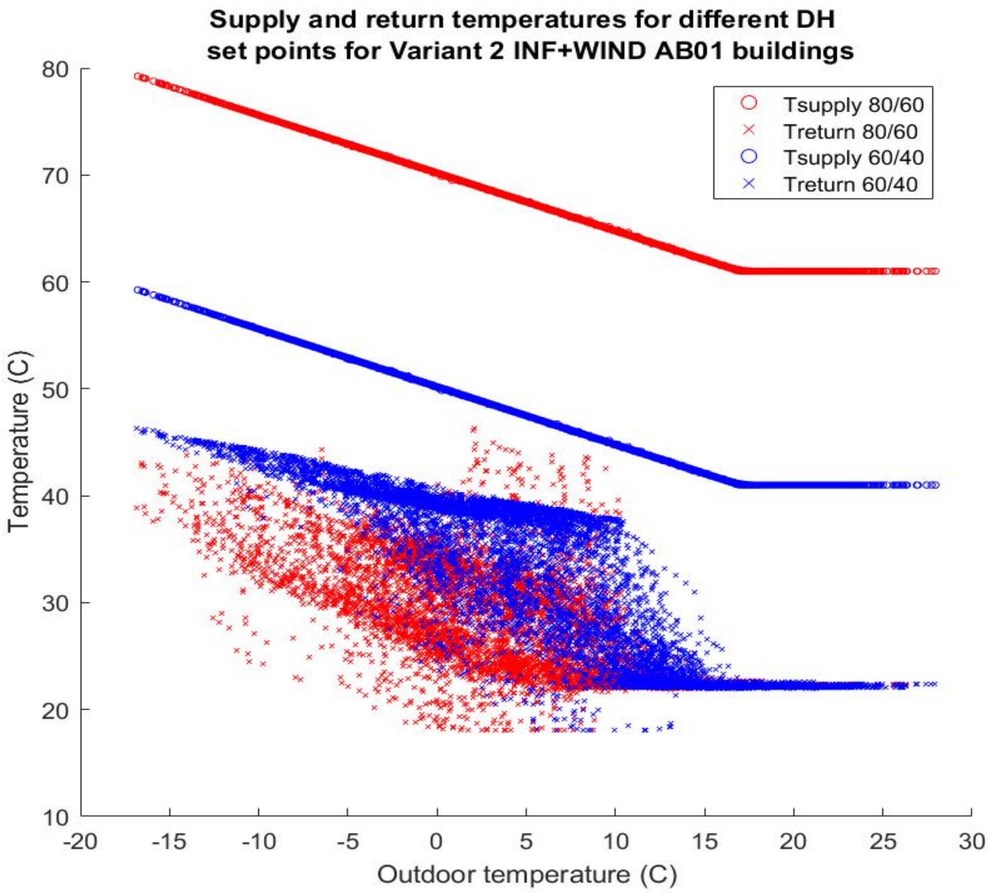
Component	Specification	U-value initial built (W/m²K)	Specification	U-value standard renovation (W/m²K)
Roof	Concrete hollow core slab, 220 mm mineral wool	0.14	Passive house, typical roof	0.09
External wall	Frame-built timber wall, 200 mm mineral wool, 100 mm thermal bridge barrier	0.22	Passive house, typical wall	0.12
Windows	TEK 10-window	1.20	Passive house window	0.80
Floor	250 mm insulation board, 100 mm reinforced concrete	0.14	Passive house, typical floor	0.14

A2 Results from AB_01-02 and AB_06-08





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Treturn 60/40
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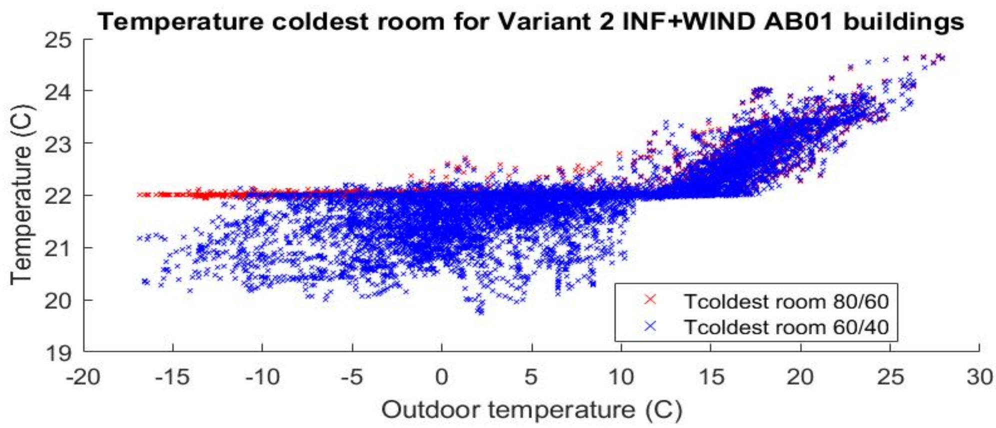
Outdoor temperature (C)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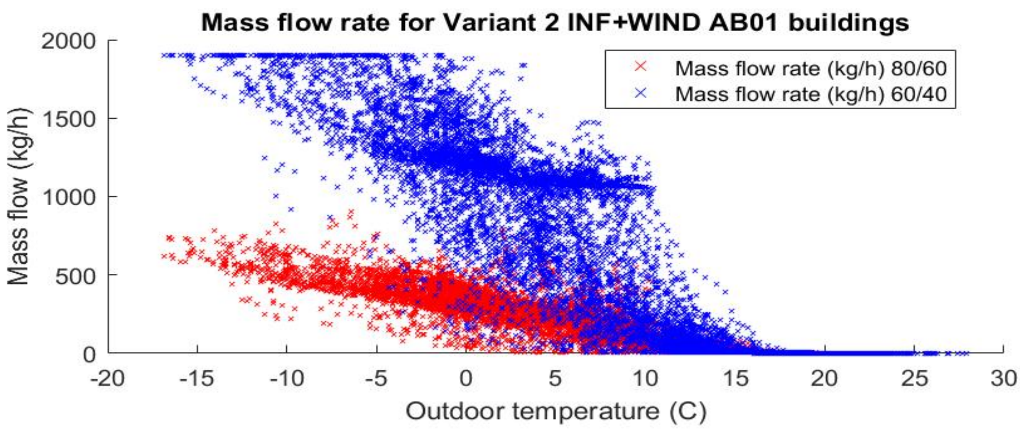
Temperature (C)
Outdoor temperature (C)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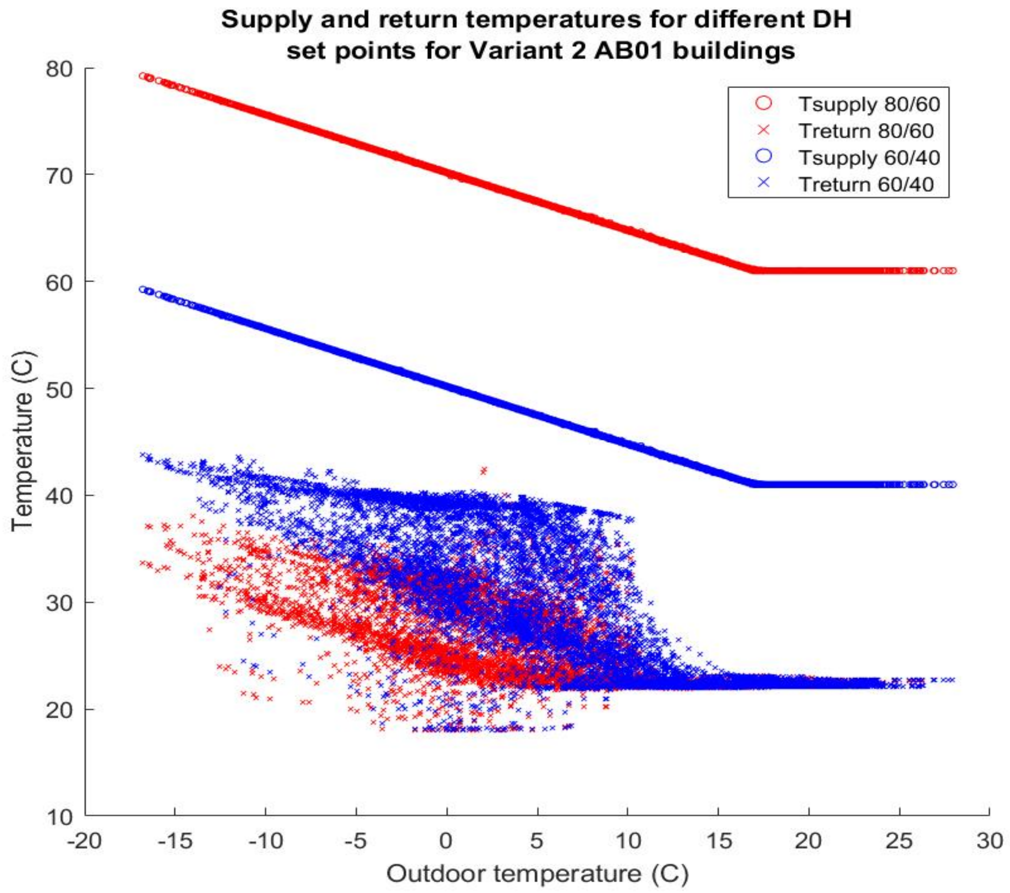
Mass flow (kg/h)
Outdoor temperature (C)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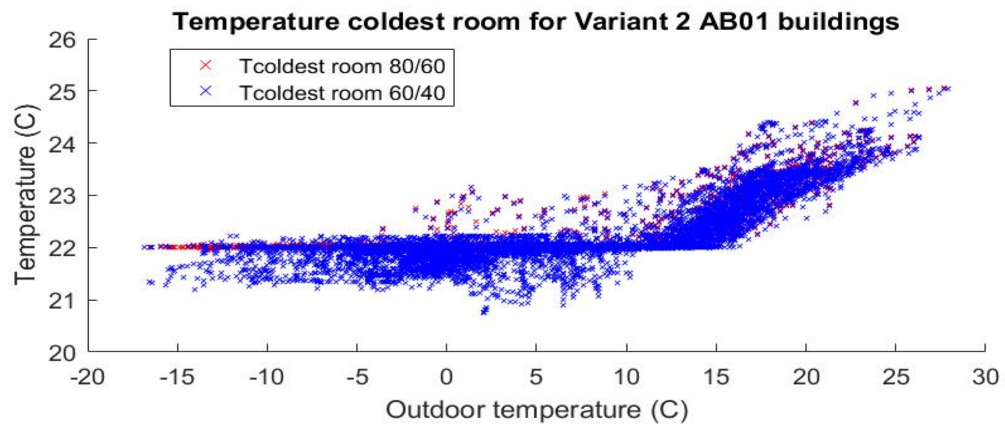
Outdoor temperature (C)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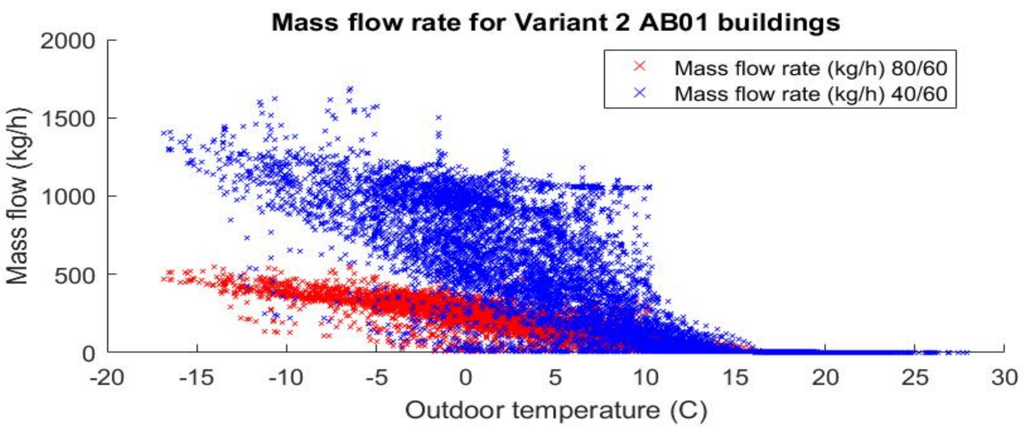
Temperature (C)
Outdoor temperature (C)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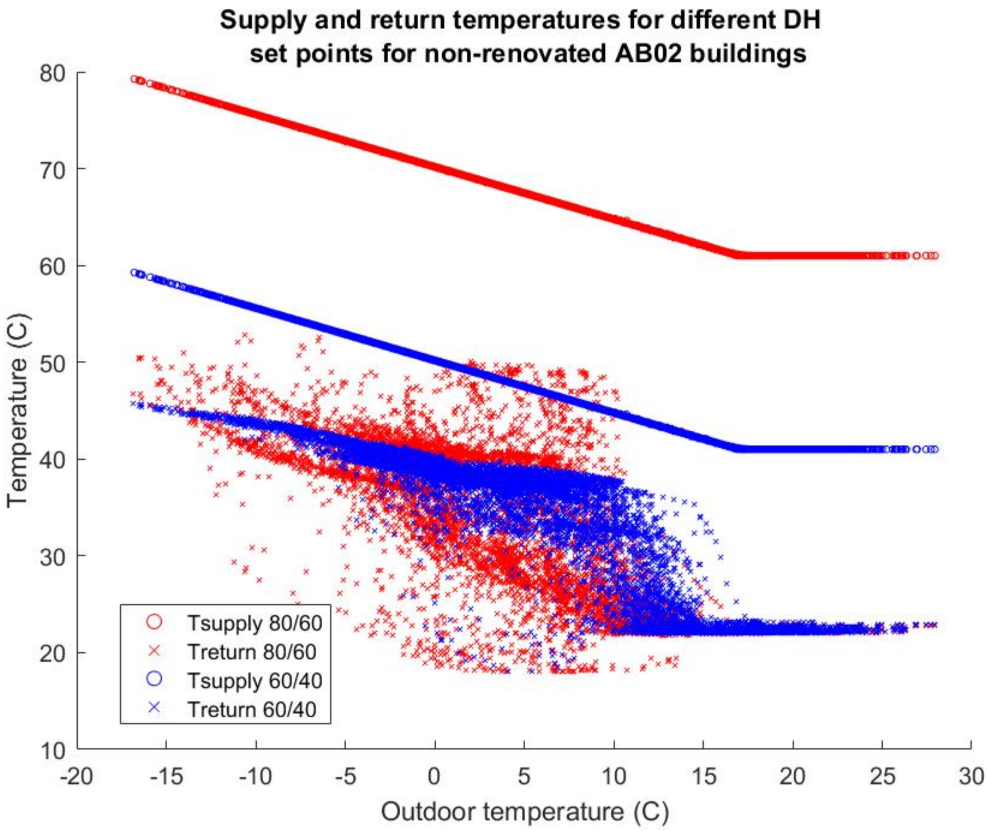
Mass flow (kg/h)
Outdoor temperature (C)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25
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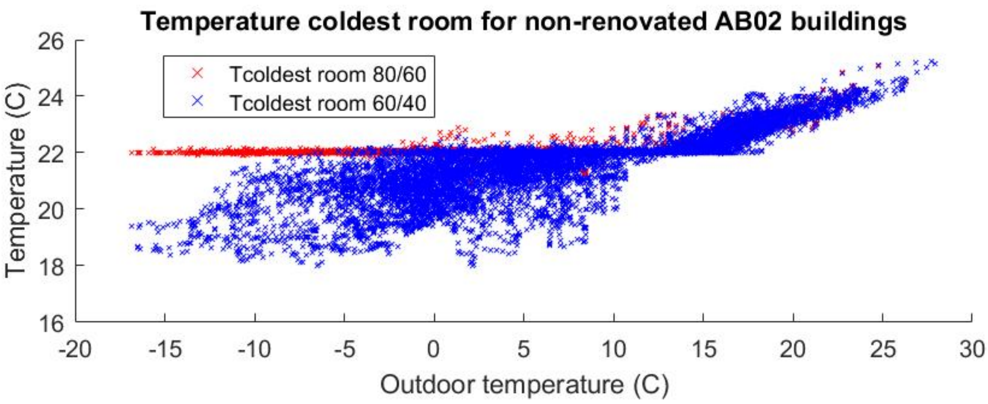
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15
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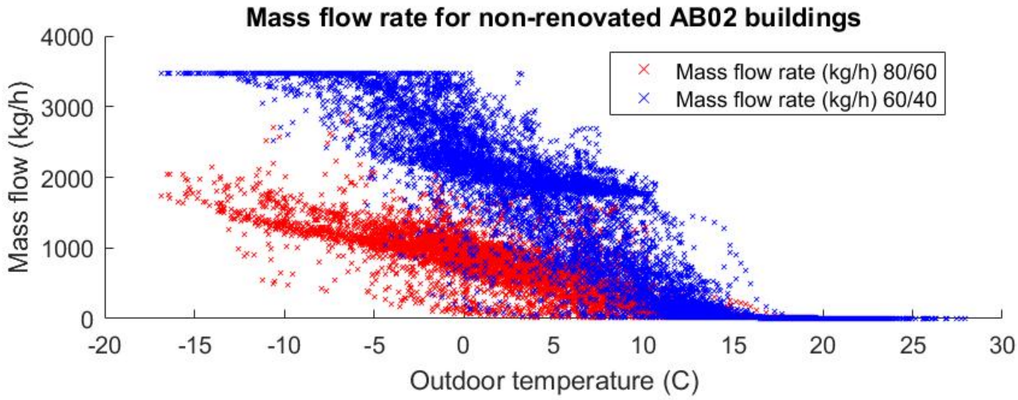
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Outdoor temperature (C)
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Mass flow rate (kg/h) 60/40
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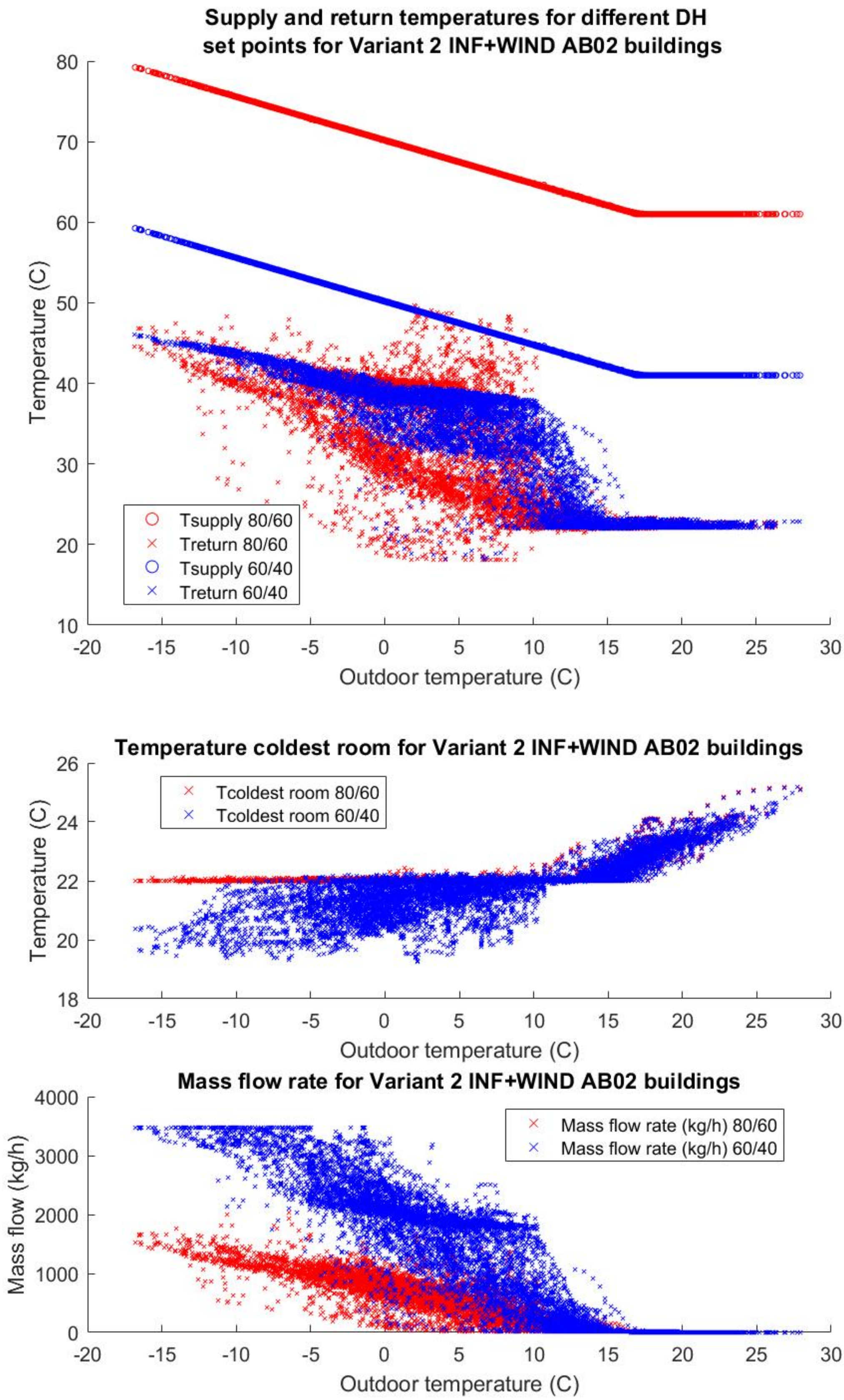
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25
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Temperature coldest room for Variant 2 INF+WIND AB02 buildings
Tcoldest room 80/60
Tcoldest room 60/40
26
24
22
20
18
Mass flow rate for Variant 2 INF+WIND AB02 buildings
Mass flow (kg/h)
Mass flow rate (kg/h) 80/60
Mass flow rate (kg/h) 60/40
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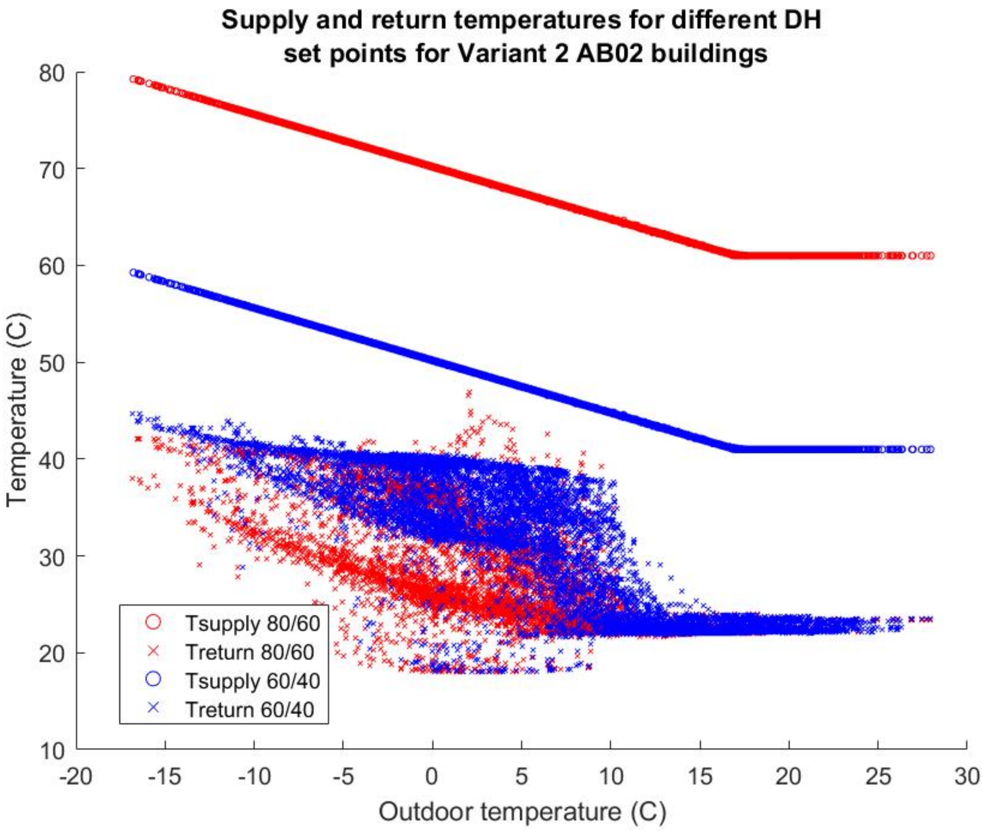
3000
2000
1000
0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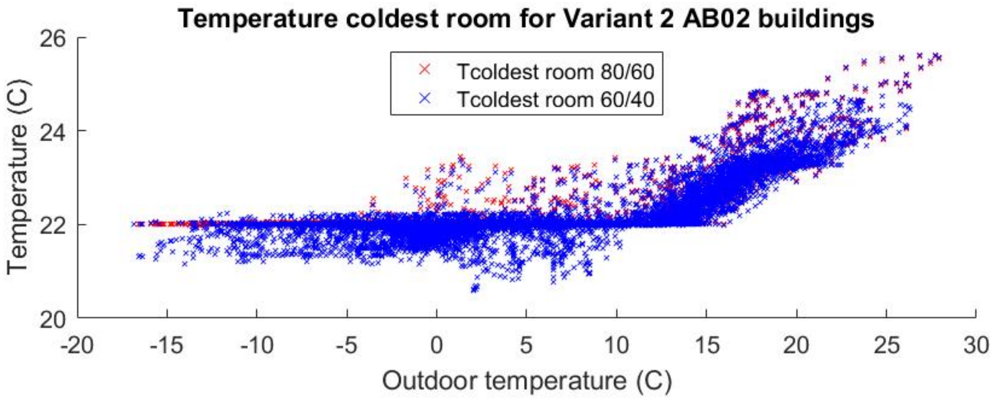
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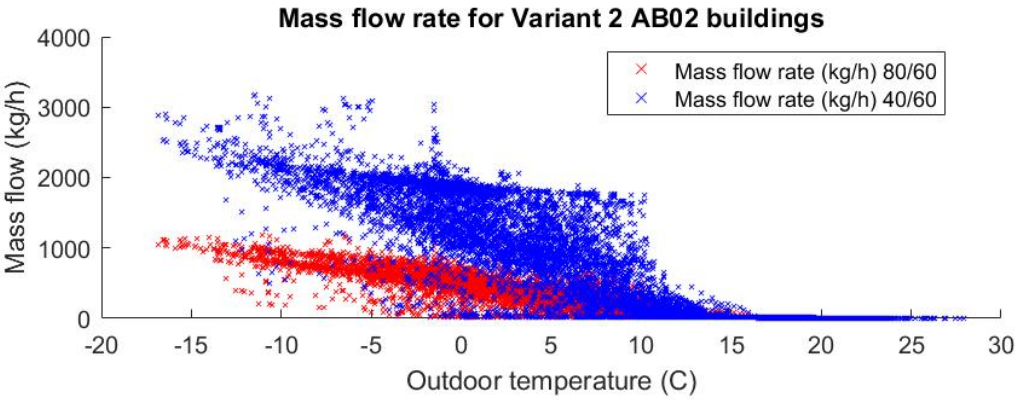
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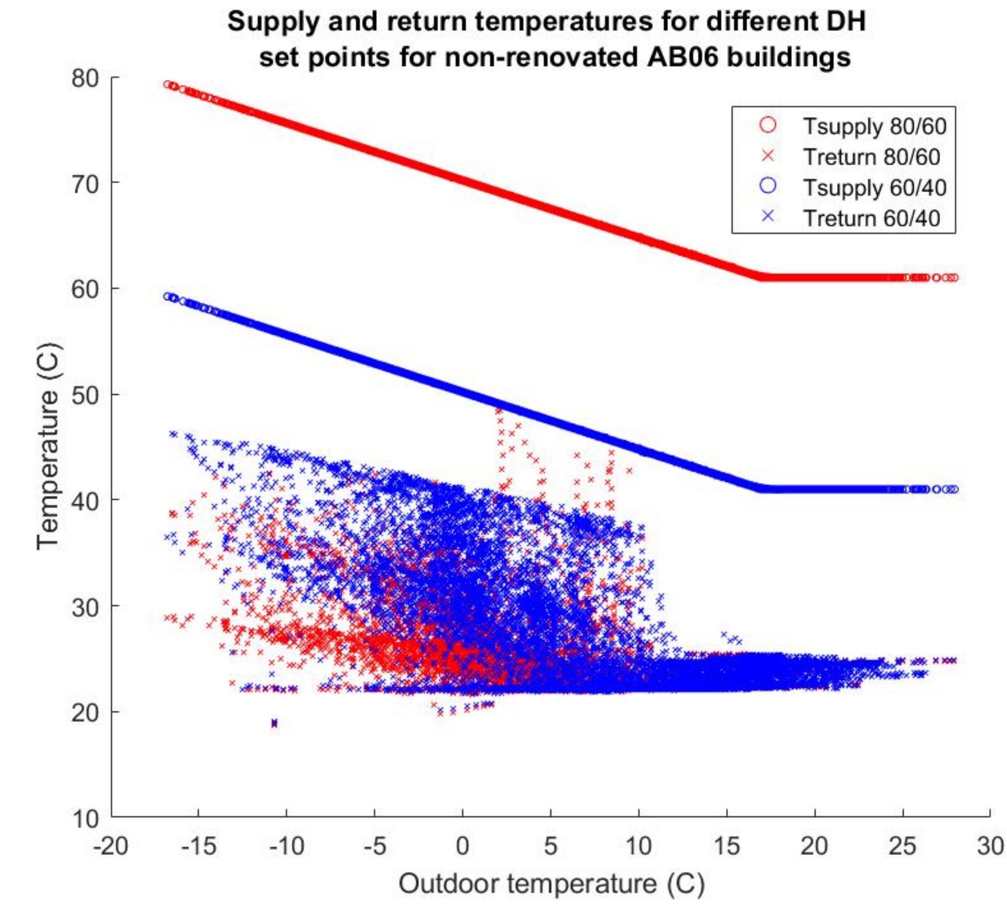
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Outdoor temperature (C)
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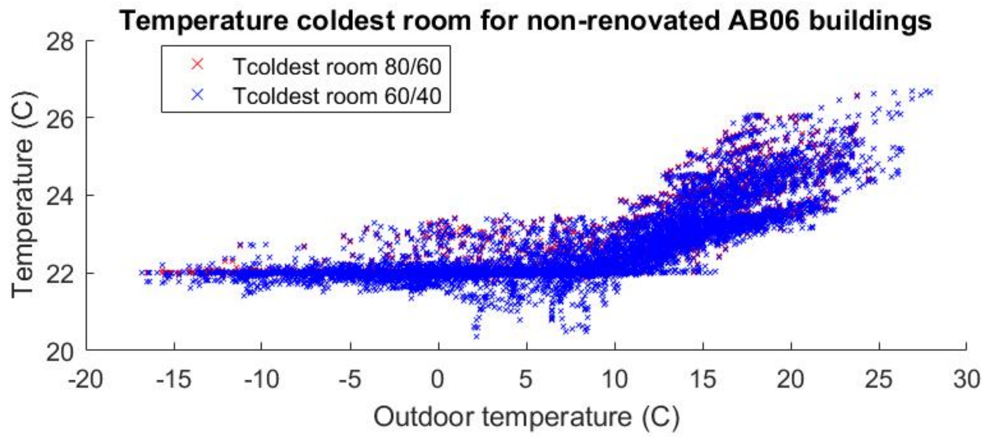
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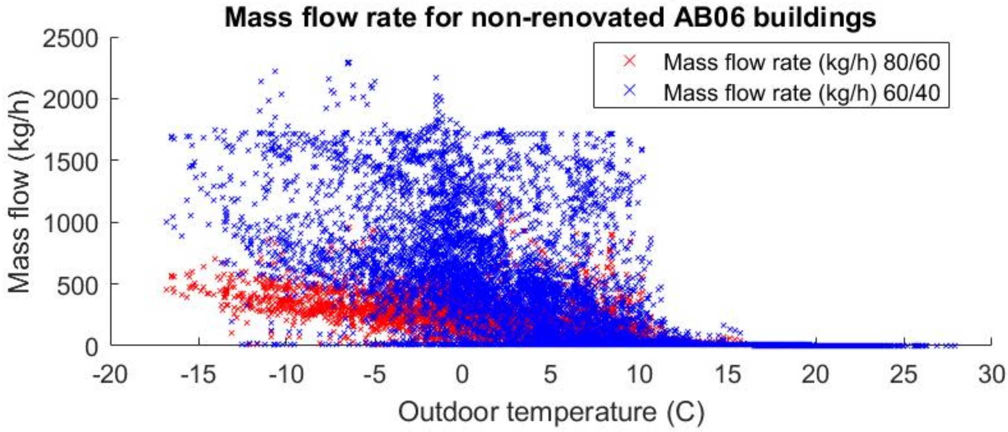
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Mass flow (kg/h)
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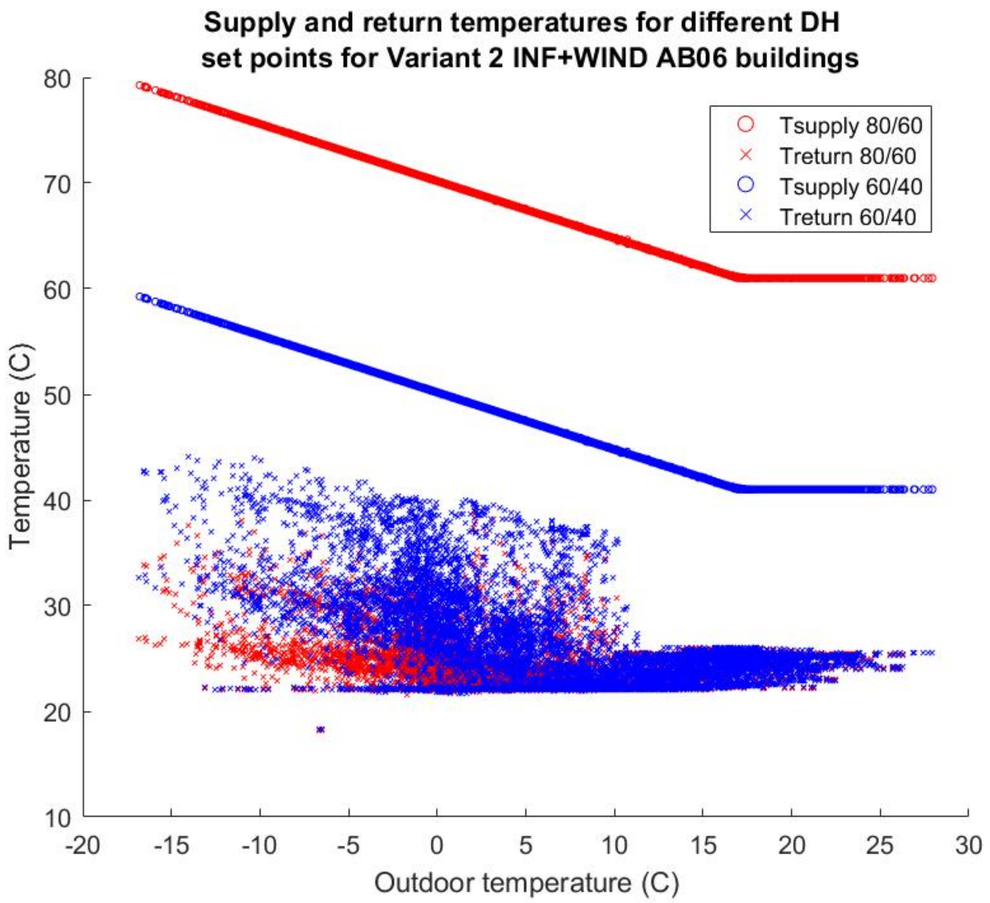
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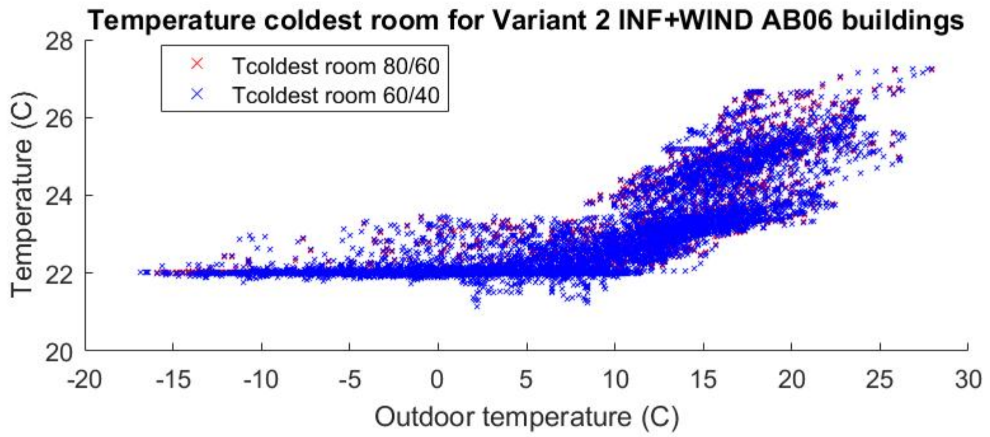
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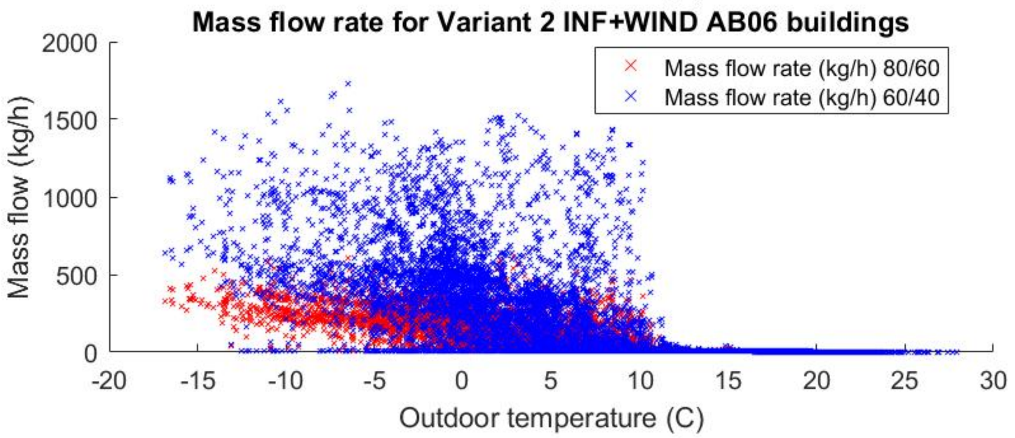
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Mass flow (kg/h)
Outdoor temperature (C)
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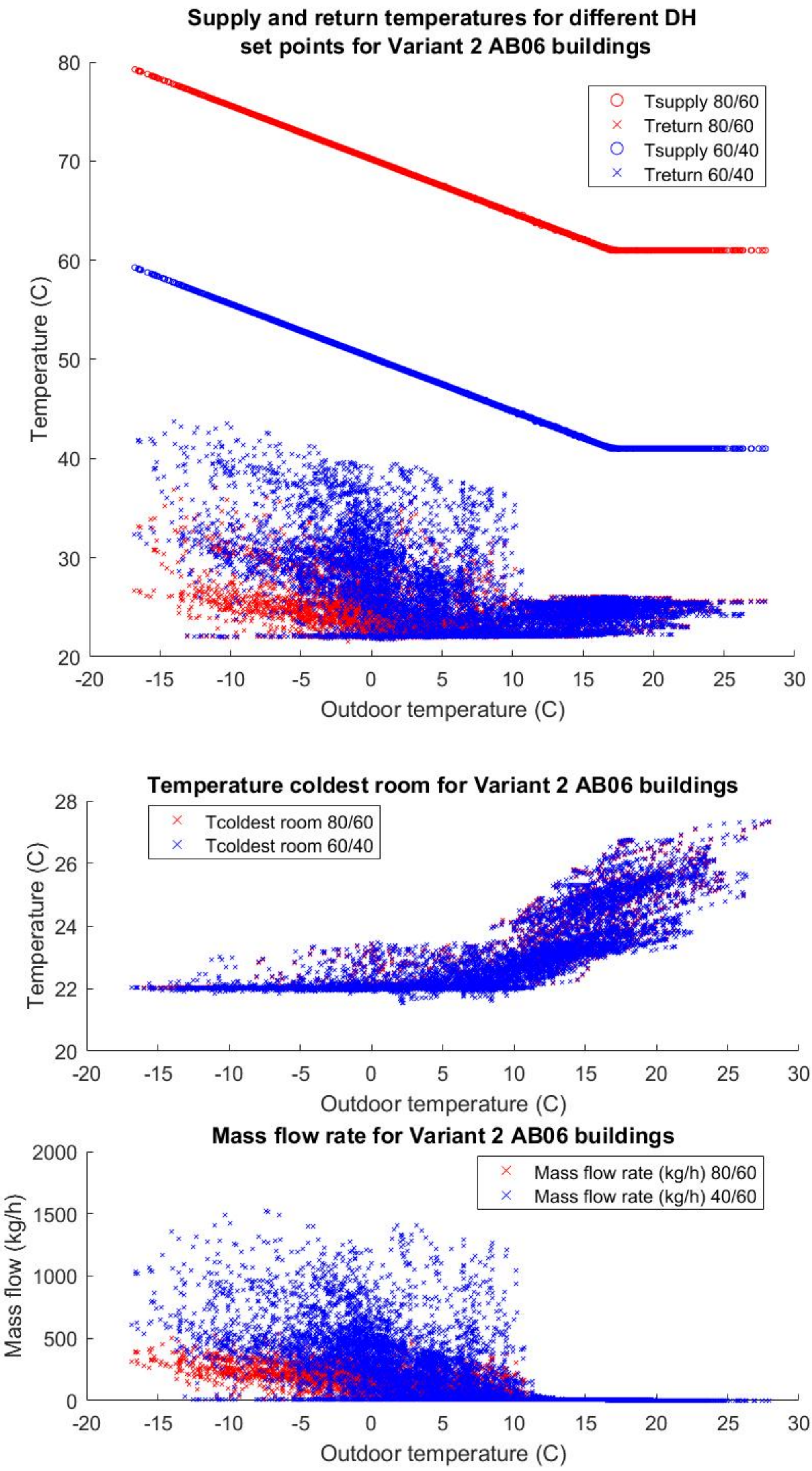
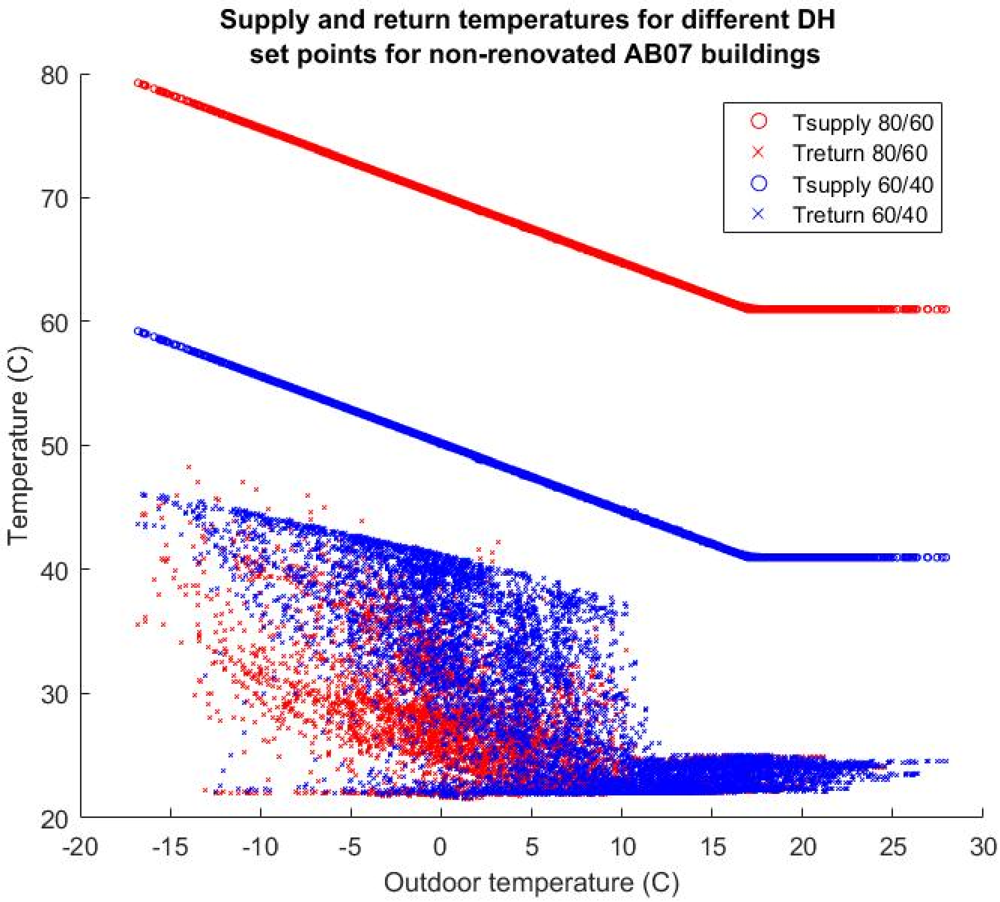
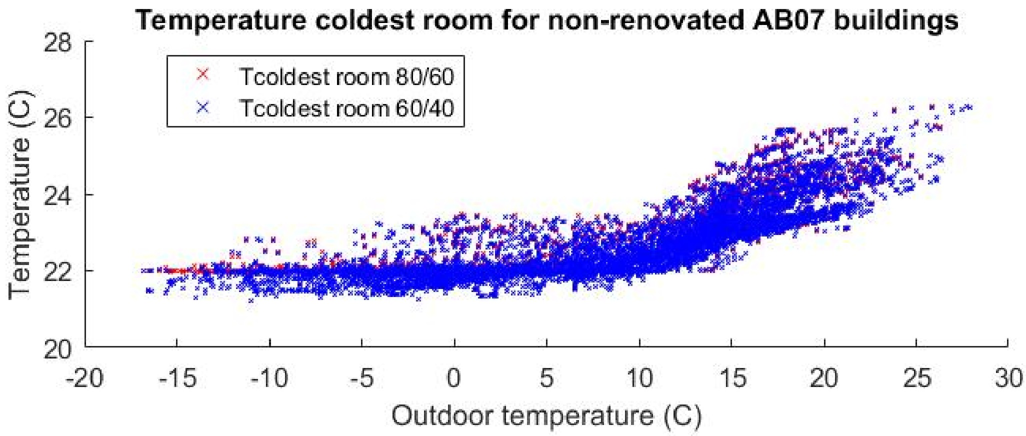
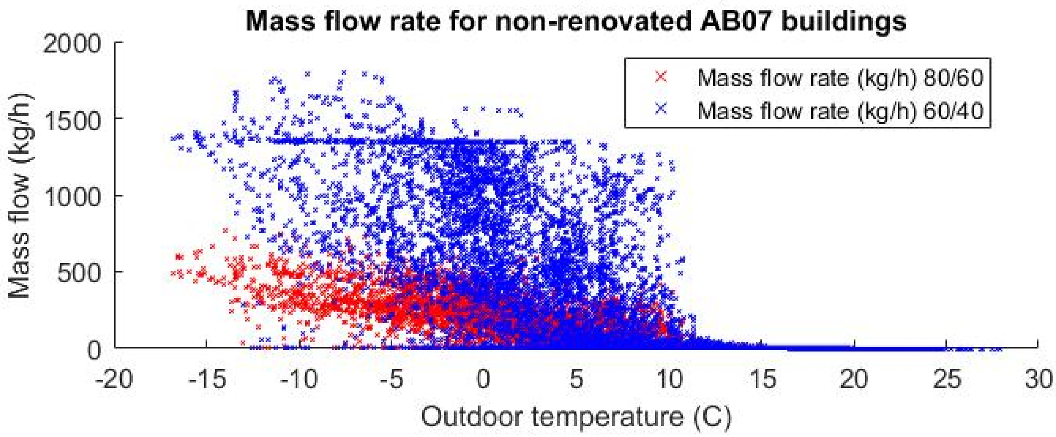
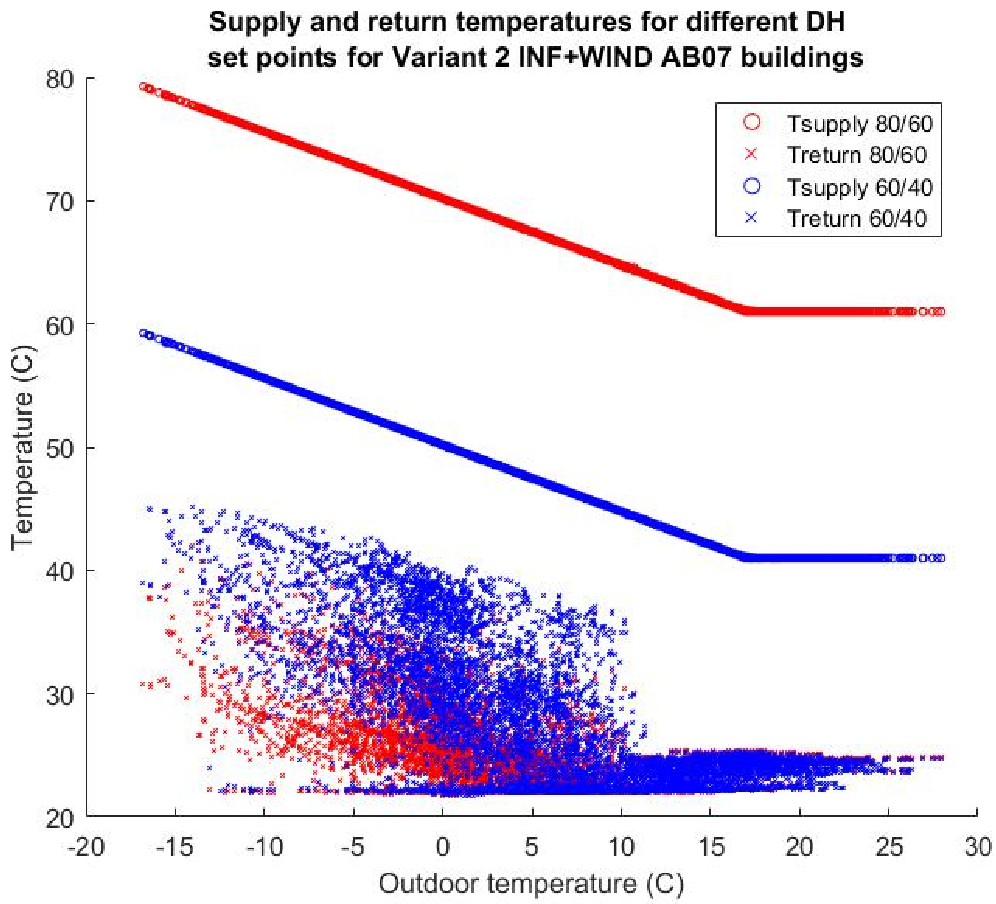
25
30

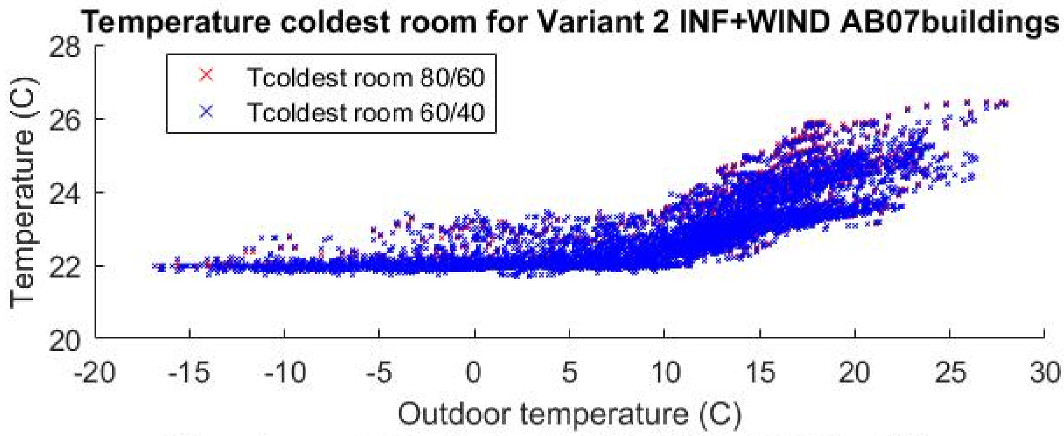

Supply and return temperatures for different DH
set points for Variant 2 AB06 buildings
Tsupply 80/60
Treturn 80/60
Tsupply 60/40
Treturn 60/40
Temperature (C)
Outdoor temperature (C)
Temperature coldest room for Variant 2 AB06 buildings
Tcoldest room 80/60
Tcoldest room 60/40
Temperature (C)
Outdoor temperature (C)
Mass flow rate for Variant 2 AB06 buildings
Mass flow rate (kg/h) 80/60
Mass flow rate (kg/h) 40/60
Mass flow (kg/h)
Outdoor temperature (C)

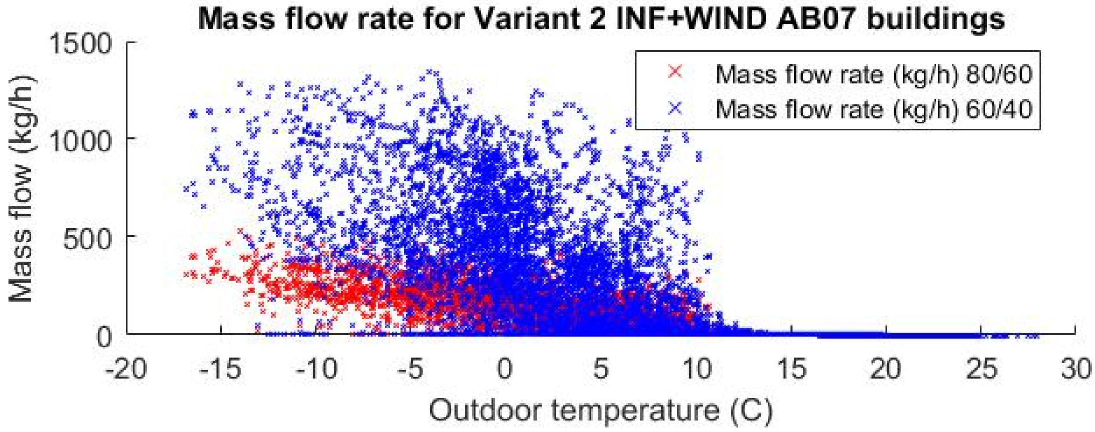

Supply and return temperatures for different DH set points for non-renovated AB07 buildings
Tsupply 80/60
Treturn 80/60
Tsupply 60/40
Treturn 60/40
Temperature (C)
Outdoor temperature (C)

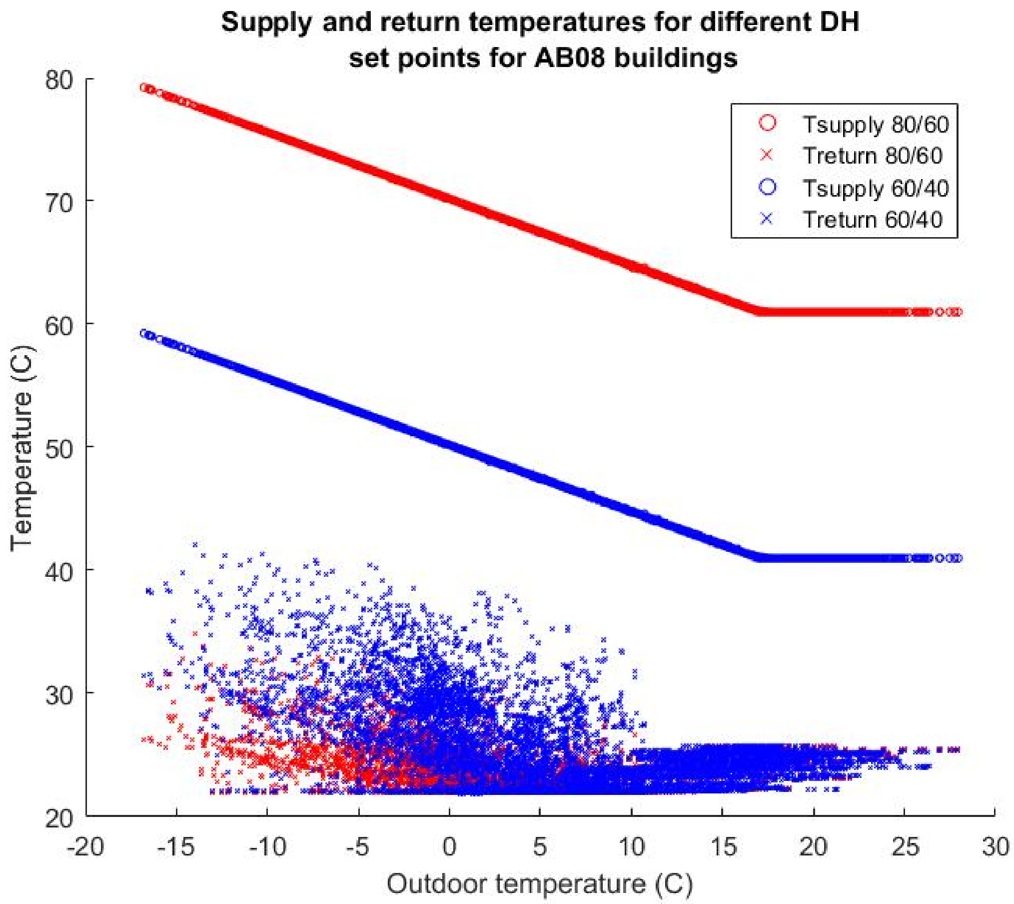

Temperature coldest room for non-renovated AB07 buildings
Tcoldest room 80/60
Tcoldest room 60/40
Temperature (C)
Outdoor temperature (C)

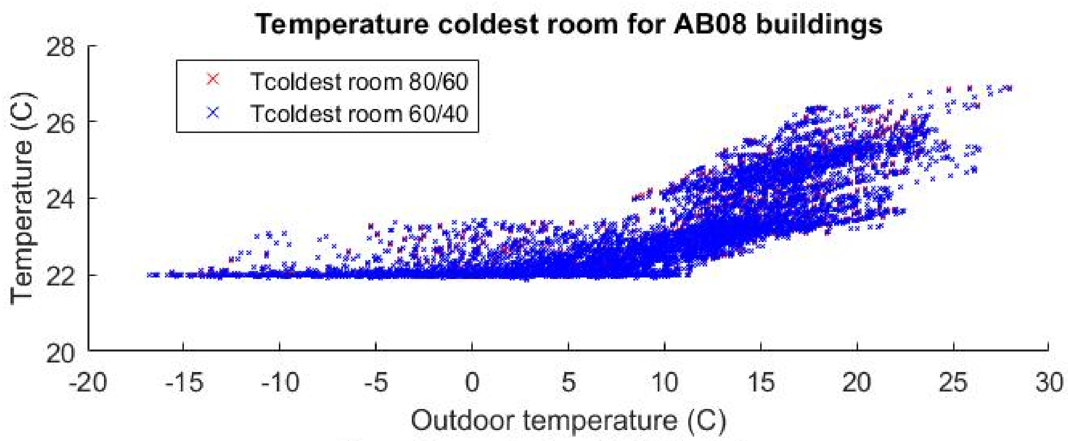

Mass flow rate for non-renovated AB07 buildings
Mass flow rate (kg/h) 80/60
Mass flow rate (kg/h) 60/40
Mass flow (kg/h)
Outdoor temperature (C)

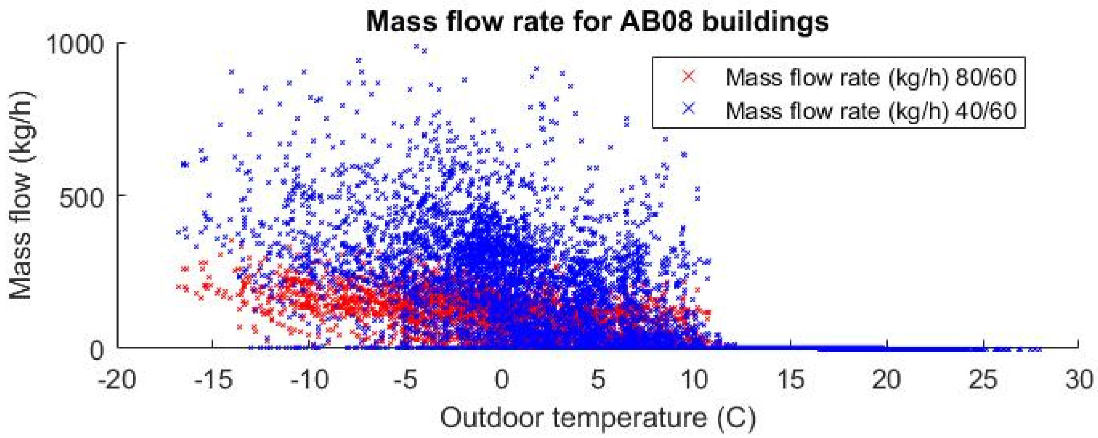

Supply and return temperatures for different DH set points for Variant 2 INF+WIND AB07 buildings
Tsupply 80/60
Treturn 80/60
Tsupply 60/40
Treturn 60/40
Temperature (C)
Outdoor temperature (C)
80
70
60
50
40
30
20
-20
-15
-10
-5
0
5
10
15
20
25
30


Temperature coldest room for Variant 2 INF+WIND AB07buildings
Tcoldest room 80/60
Tcoldest room 60/40
Temperature (C)
Outdoor temperature (C)
28
26
24
22
20
-20
-15
-10
-5
0
5
10
15
20
25
30


Mass flow rate for Variant 2 INF+WIND AB07 buildings
Mass flow rate (kg/h) 80/60
Mass flow rate (kg/h) 60/40
Mass flow (kg/h)
Outdoor temperature (C)
1500
1000
500
0
-20
-15
-10
-5
0
5
10
15
20
25
30


Supply and return temperatures for different DH set points for AB08 buildings
Tsupply 80/60
Treturn 80/60
Tsupply 60/40
Treturn 60/40
Temperature (C)
Outdoor temperature (C)


Temperature coldest room for AB08 buildings
Tcoldest room 80/60
Tcoldest room 60/40
Temperature (C)
Outdoor temperature (C)


Mass flow rate for AB08 buildings
Mass flow rate (kg/h) 80/60
Mass flow rate (kg/h) 40/60
Mass flow (kg/h)
Outdoor temperature (C)

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