Model and Validation of a Multi-family Building ‘Haus M’ Using Modelica

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Abstract

Haus M is a multi-family building composed of twenty-nine dwellings and a kindergarten. The building and its energy systems have been modelled in Modelica considering a typical occupancy profile based on the habits of the tenants and questionnaires.

The limited information about the building combined with its highly-unpredictable use and the simplistic controls of the systems in Haus M conducted to a shallow validation of the model. The results of simulations show an energy use for heating of about the 77% of measured energy.

The building is heated using an underfloor heating system that is coupled to a geothermal heat pump. After validation of the model, the estimated energy use was compared with the energy use of a baseline heating system composed of a natural gas boiler and radiators for all heated zones.

Introduction

One important part of the global energy is used in buildings where people develop their lives. In this area, the present and future pass through the reduction and optimization of the energy at the building and energy systems level. Any building, described as an energy system, is the result of a combination of many different parameters and many connections between them. Even if the equations that rule the system are relatively simple, the amount of different parameters involved and their relationship produces a complex system that cannot be easily analysed without computer calculations. That is why simulations became very handy tools to calculate the energy loads of buildings and, later, to optimize the energy systems to determine the optimal level of efficiency.

The use of simulations for building energy analysis is becoming more popular, but there are still some counterparts that need to be minimized to spread their use in the industry. One of the most important handicaps is the lack of information to compare the energy behaviour of a building and the results of a simulated model under the same conditions. Some parameters have to be estimated, which leads to mismatches, increases the uncertainty and, consequently, results in a poor model that cannot give good enough results. The problem is to identify how good or poor the model is and to determine whether a model can be used or not. In other words, in order to promote the use of simulations, it is a must to give ways to raise trust in

them. To reach this point it is necessary to develop validated models. (Strachan et al.) The information obtained from them would be helpful to estimate the errors of future modellers and it would be valuable to determine the estimated parameters in a better way.

Having validated models gives the possibility to develop and improve advanced HVAC-technologies that, without simulations, would be impossible to manage. For example, hybridGEOTABS is such a technology. It consists of the combination of geothermal heat pumps, and Thermally Activated Building Systems (TABS). The combination of both parts gives the acronym GEOTABS. TABS are the structural components of the building, such as floors, walls or ceilings, that contain conditioned water pipes in their cores and therefore act as emission system. The energy flows between the geothermal heat pump and the building zones through the materials of the structural components. Moreover, the TABS have a high thermal mass and can be considered as an intermediate energy repository. This property allows the use of lower temperature gradients in the components, which increase the efficiency of the system. On the other hand, the thermal inertia of TABS causes a slow reacting system and it cannot accommodate to high and sudden changes in the energy demand. To avoid the consequent discomfort periods, a fast reacting secondary system can compensate the gap between the energy demand and the energy covered by the GEOTABS system. hybridGEOTABS are governed by a Model Predictive Control (MPC) that decides in every instant the share of the demanded power between TABS and secondary system. The MPC tries to maximize the baseload and minimize the use of the secondary system, while maintaining thermal comfort (Himpe et al. (2018)).

The aim of the hybridGEOTABS project is to maximize the baseload (the share of the energy demand covered efficiently by GEOTABS) without compromising comfort and by minimizing the energy use in the building. Then, it is necessary to determine how good the performance of this technology is in comparison to other HVAC solutions under the same conditions. This process would be extremely difficult to carry out without simulations, which is where validated models are an important tool.

In context of the hybridGEOTABS project, several case-study buildings were selected around Europe to demonstrate the technology using real-life data and validated

models. The selected buildings are equipped with a GEOTABS or similar technology. One of those is the multi-family building Haus M, in which underfloor heating is combined with geothermal heat pumps, a system close to the GEOTABS solution. In particular, the use of the building is interesting: GEOTABS is typically applied in buildings with an easily predictable building use (e.g. office buildings), while residential buildings have a more irregular occupation. For this building, and the other case-study buildings, the hybridGEOTABS system is compared to a 'baseline' HVAC-solution, in order to show its performance. The 'baseline' HVAC solution is a more traditional system concept that is relevant and applicable for heating and/or cooling in all climates in Europe and for all building typologies investigated (offices, schools, elderly homes and multi-family buildings). For Haus M, it basically consists of radiators and a natural gas boiler with the same power as the actual heating system. The results of the comparison between several models of buildings and their respective baselines are going to be published in the deliverable 4.5 of the hybridGEOTABS project and they will be public accessible from the website of the project.

In this paper, the modelling and validation of the multi-family building Haus M is described, considering all available parameters. The use of the building represents one of the most difficult scenarios for the modeller. Some assumptions related to the people have to be taken into account to represent a reliable behaviour influenced by the daily habits of all of them. Nevertheless, most of the buildings in the world have the same use as the modelled one, so the interest in this model is also important.

The second part of the paper is about the implementation of the 'baseline' heating system and its comparison with the model of the actual one in terms of energy efficiency.

hybridGEOTABS project

The model, validation and comparison with the baseline scenario of the multi-family Building 'Haus M' is part of the EU Horizon project hybridGEOTABS. The challenge of the project is to demonstrate the performance of the hybridGEOTABS system and develop a design methodology and MPC-solution. The final objective is to probe the efficiency of GEOTABS and to improve and promote that technology in the industry and in the society. More information about the project can be found at <http://www.hybridgeotabs.eu>.

Description of the building "Haus M"

Haus M is a multi-family building located in Zürich, Switzerland. The weather in that region corresponds to a temperate climate (oceanic in particular) with four seasons. The maximum temperatures in the year are around 24 °C in July and the minimum are around -2 °C in January.

The gross floor area of the building is around 950 m² per floor. Its shape is an irregular quadrilateral which largest facades have east-west orientation. There is not any relevant element in front of its eastern and southern façades that can project shadows in any moment of the year. The shaded facades are the western and the northern ones,

which are facing to other buildings. Haus M is composed of five floors of six dwellings per floor, except for the first floor, which has five dwellings. There are 29 living units in total for 97 people. On the ground floor, there is a kindergarten for about 70 people, named KiTa. The basement is used as storing area and it is also the place where the technical room is located. The apartments are organised around a large atrium that reaches from the first to the fifth floor and has an irregular quadrilateral shape. The atrium includes the staircase and gives access to every dwelling. It is wide enough, so it can also be defined as a large air volume that connects all floors in the middle. Besides the atrium, there are four common areas per floor for storage, laundry and rooms for drying clothes. Around the 20% of the flat area is represented by the common zones and the atrium.

External surfaces of the building have the U-Values shown in Table 1:

Table 1: U values of external surfaces in Haus M

Type	U_value [W/(m ² K)]
Ground floor	0,214
Facades	[0,135-0,573]
Roof	0,135
Windows - glazing	[0,7 – 1,1]
Windows - frame	[1,3 – 1,7]

The energy systems in Haus M are only for heating and domestic hot water. There is no active system for cooling. The heating system takes the energy mainly from a 75-kW ground source heat pump (GSHP) with horizontal heat exchangers located under the building, covering an area of 885 m². The GSHP is exclusively used for floor heating both for the KiTa and for the dwellings. There are two constant-flow pumps for delivering the heating energy to the underfloor heating system. One is for the KiTa and the other one is for all the living units. All hydronic loops are based on pressure drops and they were tuned once to guarantee the right balance between them. The heating system is ruled by a heating curve that sets the return temperature of the water for the global flow. The GSHP has eight levels of modulation to adapt the power to follow the target temperature given by the heating curve.

There is another heat pump in the building. It is a 64-kW air source heat pump (ASHP) that recovers the heat from the ventilation exhaust air to produce domestic hot water (DHW) at 53 °C. It can also give support to the underfloor heating when the GSHP cannot reach the target temperature defined by the heating curve. This situation is controlled by a valve between the two major loops (DHW and floor heating) of both systems. To let the ASHP support the floor heating it is mandatory to satisfy the temperature of 53 °C for DHW. There are 31 solar collectors on the rooftop used to produce DHW as well. The total absorption area is 77,81 m². Originally, there was also a loop controlled by a valve that could connect the solar collectors to a heat exchanger for ground recovery when the temperature was not enough to heat the DHW or when

there was not any DHW production. This ground recovery loop is installed but it is not working since 2015. Consequently, solar collectors are only used for DHW production.

The emission system in Haus M is floor heating. The water pipes are embedded in the screed, about 5 cm below the floor finishing. The conditioned net areas represent 3940 m² (840 m² KiTa and 3100 m² of apartments). All levels of dwellings have similar geometry and distribution, thus there are six types of apartments and they are repeated along the five floors.

The ventilation system in Haus M is based on mechanical extraction. It consists of ventilators located on the top of the building that extract in total 6400 m³/h from all zones. The fresh air enters the building through grids located on the upper part of the outer walls of all living units and the KiTa. Fresh air comes inside the building without any treatment, but all exhaust air conducts are connected to the ASHP for DHW production.

On the rooftop, there are also photovoltaic solar panels (PV) used for self-consumption. There is not any storage system for electricity. The system is connected to the electricity grid.

Controls and monitored data

Haus M has a simple control for the heating based exclusively on a heating curve. That control is global, which means that the whole building heating system is controlled with only one parameter: the heating curve. The pumps are always working at the nominal regime during the heating period and there is not any valve that totally controls the flow of the hydronic loops. In this kind of control, the initial tuning of the hydronic loops is essential to have an acceptable thermal balance in all heated zones of the building.

The heating curve calculates a return flow temperature based on the exterior temperature, affected by a correction factor. A privative algorithm calculates that factor. Currently, the equation that rules the heating curve, according to the parameters in the BMS, is the following one:

$$T_{\text{return}} [^{\circ}\text{C}] = \frac{-7}{30} \cdot T_{\text{equivalent}} + \frac{77}{3} \quad (1)$$

Where:

$$T_{\text{equivalent}} [^{\circ}\text{C}] = T_{\text{exterior}} + F_{\text{correction}} \quad (2)$$

$F_{\text{correction}}$ varies from 0 to 15 according to the unknown privative algorithm.

Each apartment has a device to allow the users to have a certain control on the flow of one of the floor heating loops that belong to the dwelling. The number of loops in a flat varies from 3 in the studios to 9 in the biggest apartments. The user's device controls the opening of an electronic valve that changes the flow in that loop. The rest of loops do not have any regulation system and the global flow in the whole building remains constant, so the real effect of the control is the variation of the flow in all loops, including the ones that do not belong to the controlled apartment. This situation conduces to an unpre-

dictable behaviour when some users use it. In fact, the effect is not really appreciable, so it is considered by the administrators of the building as a dummy control.

For the ventilation system, the control strategy consists in extracting air at a constant flow rate all the time.

There is a web-based Building Management System (BMS) that monitors the temperature of each dwelling and the temperature of the KiTa with hourly resolution. Every apartment has a temperature sensor located in the living room and the KiTa has one located in the centre of the biggest zone. The BMS defines the equivalent temperature for the heating curve and gives the possibility to the administrator of the building to change the default parameters of the heating curve. All data can be exported with hourly resolution since 2015, but there are several periods where the data is not available due to technical problems.

Model of the building

The detailed BES-model of Haus M is a white-box model that was developed in Dymola, using validated components from IDEAS (Jorissen et al. (2018)), Buildings (Wetter et al. (2014)) and Modelica libraries.

The weather conditions for Zürich have been included in the model. The weather conditions consider more than fifteen parameters that define precisely the conditions, with hourly resolution.

The aim for the modelling the building was to include all masses of the real building.

All properties of the materials were taken from the material library included in the software Lesosai and the geometrical parameters were taken from the blueprints of Haus M. In total, there are 63 construction types using combinations of 46 different materials.

Every apartment can be considered as a single zone in the model. But it is also possible to merge all dwellings with similar geometry, orientation and boundary surfaces and conditions into one single zone (Figure 1). The reason to combine them is to reduce the complexity of the model and to improve the simulation time. It is possible to group similar zones because the accuracy in the results will not be compromised. In this case, the living units located on the fifth floor were excluded from this operation because their boundary conditions are too different than the others. By this lumping of zones the amount of them was reduced from 32 to 15. 13 of them are floor heated and the rest are unheated (passive zones).

Figure 1: Representation of the zones in the model

The building envelope was designed following all information showed in given floorplans. Also, the envelope was modelled trying to match the mass calculated from the geometries shown in floorplans and material properties. Internal walls and floors of each zone were considered using a correction factor included in the model of the zone component in IDEAS library (mSenFac) that affects the thermal capacity of the air volume in each zone. The envelope is the representation of the empty building without any furniture, but including floor and walls finishing, doors and windows. Furthermore, all external components in contact with the ambient are defined with orientation and inclination, parameters that will determinate the reaction with external conditions.

The heating system was set as described in the previous section, neglecting the non-working loop for ground recovery. The energy for heating is delivered to each zone through the surfaces that represent the floors. The heat is distributed uniformly according to the floor area of each zone. First, it goes through a heat exchanger and then it is delivered to the core of the floor component. From the floor component it flows to the zones in contact. The lumped zones consider two kinds of floors. The floor that is also a boundary receives the heat as the non-lumped zones, but the floors that are not boundaries are included as surfaces in contact to the same zone in both sides. In this case, the whole heat is flowing between the lumped zone and the surface exclusively. The heat is not delivered directly to the zone in any case. The GSHP has a modulation input controlled by the heating curve to set the return temperature. Every moment the controller is measuring the return temperature and if this is lower than the target temperature it increases the power of the heat pump to the next modulation level. If the temperature continues to be too low for 30 minutes more, the following modulation level is set. For higher temperatures than the target one, the operation is the same in times and the modulation level is decreasing until the heat pump is off. If the maximum modulation level is reached, delivering the maximum power, but the temperature is still below the target for 30 min more, a control signal is given to a valve that can redirect part of the flow from DHW loop to floor heating loop. Additionally, it is a necessary condition to open the valve that the temperature of the final DHW equals 53 °C.

Figure 2: Scheme of the systems in Haus M

The rest of the controls are simple. The domestic hot water loop is controlled by a PI controller that stabilizes the temperature at 53 ± 0.5 °C and the ventilation system has a constant extraction flow rate. The zones are connected in parallel, so all of them receive (release) air directly from (to) the exterior. The lumped zones have the same

ventilation system based on mass flow rates, but multiplied by their respective distribution factors (based on the volume of the zones). The control of the blinds is not automated in reality, but a control based on the solar radiation and occupancy profiles has been implemented in the model. A schematic view of all the systems in Haus M is shown in Figure 2.

At the moment, there is not any pressure model for the windows, so the air exchange is produced only by the ventilation system. In the next step of the model the opening of the windows will be included based on occupation profiles.

Occupancy

Although the construction parameters, the energy systems and the geometry of Haus M are well defined, other parameters are missing or they cannot be defined easily. Those parameters are related to the occupancy and the activities the tenants realize in their daily lives. For example, they can cook, open or close windows or blinds, use powerful electric devices, be or not be at their homes, etc. There are some tools to model occupancy profiles, but they are more focused on office buildings, schools and those places that occupancy level can be easily predicted, which is not the case in Haus M, except for the KiTa.

Figure 3: - Example of an occupancy profile for Apx.1. Note that this is a lumped zone composed of 4 dwellings with 6 tenants half of them and 7 tenants the other half (26 people in total).

To generate a first approach of the occupancy profile, the tenants were invited to answer a questionnaire about their habits. Based on the obtained results and the expected habits in the building, a general occupancy profile was defined for each apartment and included in the model. Lumped dwellings in the model have also a lumped occupation profile. The base occupancy profile is defined for a week. It means that there is a distinction depending on the day of the week, but not on the month or the season. An example of a weekly profile for the zone Apx.1 is shown on Figure 3.

Validation of the model

Considerations and methodology

The available information to model the building was very accurate in terms of materials and geometries. Nonetheless, the detailed information related to the heating and ventilation systems was not entirely available therefore assumptions had to be made. The controls in those systems are basic, in the sense that there are very few controlled variables. There is fixed air-extraction flow in the ventilation system and for the heating system there is just the return temperature of the water that is controlled. This

situation must be included in the model, so the modelled controls can respond in the same way as in the real building. Also, the occupation profile is not as accurate as in other buildings typologies. These circumstances provoke both in the real building and in the simulations that the temperatures in the apartments and in the KiTa may not be in the comfort band. On the other hand, that is the expected behaviour for this building, so the process of validation only has to consider that the results of the simulations have to be coherent with the real measurements of the building.

A first analysis of the measured temperatures of 2016 and 2017 showed that similar zones had considerably different temperatures. The Figure 4 shows the maximum and minimum registered temperatures of the 29 dwellings and the KiTa in every moment of the year 2017. All measured temperatures are between the shown curves. The average of the differences of both curves are around 4 °C, but it is noticeable that during summer season those differences are smaller than in the heating season.

Figure 4: Maximum and minimum registered temperatures in all zones in Haus M in 2017

As said before, the tenants practically do not have control on their part of the heating system, so these differences in measurements can be caused by the unbalance of the hydronic loops. It seems that those are not correctly tuned and the validation process cannot be based only on the temperatures of the zones. To make a validation it is necessary to compare the energy use in the building. That information is only given with monthly resolution, but is the best information available for the model validation.

Validation results

The first approach for the validation was the comparison of the simulated and measured temperatures in all the zones. The lumped zones are compared to the mean values of the temperature in the lumped apartments. Two simulations were run, one for 2016 and another one for 2017. The reason is that in 2016 there was a large period without measurements in many zones. The measured temperatures of lumped zones, such as Apx.1, are considered as the average temperature of the affected real apartments in the building.

The first analysis was to compare the maximum and minimum measured temperatures with the results of the simulations. The idea is to see whether the simulated temper-

atures are in the range of the limits of the real measurements and whether the behaviour of the curves are similar. For 2016 the results fit almost all the time in the band, but in 2017 there are some periods where the behaviour of the results is not the same as in the reality (Figure 5). The reason is that the heating curve was changed several times during those periods (for example, in December 2016 and January 2017). There is not any log to check the right values of the heating curve for those periods, so it is not possible to adjust the model to fit the measurements properly.

Regarding the temperatures, the weighted average of the temperatures (weight defined by the volume of the zones) were compared for both years, showing differences below 2 °C (Figure 6).

In terms of temperatures, it is possible to say that the behaviour of the model is pretty similar to the reality, taking into account the circumstances previously explained.

Regarding the energy use for heating of the building (KiTa and dwellings together), the measured energy use for 2016 was about 262.000 kWh. The simulated heating use is about 77% of this measured energy use (see Table 2).

Table 2: Heating energy in 2016 in Haus M in kWh

Month	Measured (a)	Simulated (b)	% (b/a)
Jan	47771	36530	76%
Feb	38750	28978	75%
Mar	34404	24923	72%
Apr	12825	12365	96%
May	7163	5309	74%
Jun	1240	735	59%
Jul	1034	738	71%
Aug	1023	741	72%
Sep	1422	735	52%
Oct	24293	18693	77%
Nov	40044	30272	76%
Dec	52278	41902	80%
Total	262247	201921	77%

One reason for the higher heating energy use in the real building, when compared to the simulated building, can be the overheating of some apartments due to the imbalance in the hydronic loops. According to the questionnaires, about 35% of the tenants feel too warm and they sleep with at least one opened window during the night, specifically between October and April. The discomfort forces some people to release the heat to the exterior to reduce the temperature in their homes, since there is not any way to stop the water flow in the floor heating circuit. As a result, the emitted heat even increases to reach the thermal balance with opened windows. For now, the modelled building does not include a random window opening profile that could take this effect into account.

Another reason can be found in the internal heat gains related to occupancy. These gains include not only the heat produced by human bodies, but also an estimation of the gains by general electric appliances such as bulbs, computers or ovens. The simulated internal gains were 75550

kWh in 2016, which represents 37% of the simulated heating energy in the same year. Therefore, assumptions on the internal gains can largely affect the results.

Figure 5: Comparison between min and max values of measured and simulated temperatures in 2016 and 2017. Note the missing-measured-data period and the anomalies between December 2016 and March 2017.

Figure 6: Comparison between average temperatures in 2016 and in 2017. Light red and light green show the standard deviation for each curve. The maximum deviation is 1.5 °C for the measured values and 1.1 °C for the simulation results

Comparison to a baseline heating system

In order to demonstrate the performance of the current system, that combines underfloor heating with geothermal heat pumps, an alternative 'baseline' heating system is also modelled. For this, the actual heating system in the validated model is substituted by an alternative heating system which can give a similar comfort level than the original one. The baseline heating system includes radiators in all heated zones that emit heat provided by a natural gas boiler. All the components are included in IDEAS library, except for the gas boiler, which was taken from the Buildings library. The gas boiler also has the same power as the GSHP, which is 75 kW.

Figure 7: Weighted average of temperatures. The light green and light blue colours represent the standard deviation. The maximum deviation is 1.0 °C for the actual system and 1.2 °C for the baseline.

Every heated zone has a radiator sized according to its volume. The setpoint temperature for all the zones is 23 °C, with a bandwidth of ± 0.5 °C. The baseline considers one global setpoint based on the average indoor temperatures of the zones and an equivalent temperature calculated from the exterior temperature. This control strategy differs from the actual control strategy. Designing the same control for the baseline as for the actual building would require the calculation of that equivalent temperature, the heating curve and the right hydronic balance in the zones. Such calculations would give a system that reacts in a similar way as the actual one. However, in this case it was not possible to determine the equivalent exterior temperature because the privative algorithm involved in this calculation is unknown. Instead, a control based on the average temperature of all zones was chosen. It is a realistic one and it is also not far from the actual control. Both are based on one equivalent temperature to control the heating system.

The structure of the building, the ventilation system, the domestic hot water production and the occupancy profile were not changed.

Figure 8: Energy delivered to the building for heating.

The results of the simulation compared with the results from the original model for the year 2017 are shown in Figure 7. The weighted average temperatures of both scenarios differ less than 1 °C in any moment in the simulated period. The dispersion in the temperatures is a bit higher in the baseline case than in the original one. The baseline model also shows a clear band of temperatures between 22.5 and 23.5 °C during heating period, while the actual system shows a more fluctuating behaviour. The reason of this different results is directly related to the different temperatures used to control each heating system. In the baseline heating system the target is to set the weighted average temperature of the zones specifically in the mentioned band, while in the actual system the exterior temperature is used to set the return temperature of the floor heating system, which influences but does not totally determine the temperature in the zones themselves. In non-heating period, the results in temperatures differ in around 0.2 °C. This situation can be explained because the heating curve in the original model is always activated, so it is possible to have small heating power during the night in some days in summer. In those periods the baseline model would not activate the heating because its control is based on indoor temperatures.

Figure 9: Total provided energy.

Figure 8 shows the energy delivered to the building by both systems. The energy delivered by the baseline is 97.5% the energy delivered by the original GSHP by the

end of the year, motivated by the different controls of both heating systems.

The greatest differences are on the side of the primary energy. The GSHP has a COP of 3.5 and the SEER of the whole installation is 3.36. The baseline uses natural gas as primary source of energy and the boiler can transmit the 90% of the total energy released by the natural gas to the water. Figure 9 shows the provided energy for the actual heating system (electricity from the grid that is delivered to all pumps and the GSHP) and for the baseline (electricity from the grid delivered to the pumps and natural gas used in the boiler). The baseline needs 4.2 times more provided energy than the actual system the baseline. The electricity is only considered at the point of use. Transportation losses are not considered.

Conclusions and perspectives

The model of a multi-family building integrating geothermal energy and floor heating has been explained. A primary validation of the model has been accomplished considering the circumstances of the case and the available data in the real building. The model of a baseline heating system composed of a natural gas boiler and radiators has been developed as an alternative heating system for the building. Finally, the results of the simulations of both scenarios have been compared and explained. All these tasks are included as part of the hybridGEOTABS project.

Haus M multi-family building is a challenging building to model. Its simple control for ventilation and heating causes large dispersions in temperatures in all zones. The information given by the BMS is very basic and only the temperatures of the apartments and KiTa are monitored with hourly resolution. The (residential) use of the building represents an added uncertainty that causes more variability and makes more complicated to model the whole system.

Consequently, the validation process shows a weak relation between the model and the real building. The degree of accuracy of the validation cannot be easily determined taking into account the available information. There are important uncertainties that cannot be evaluated numerically due to the limitations of the available data. Nevertheless, this is an expected situation for many buildings around the world, so it is something modellers have to deal with.

Considering the limited energy measurement data for the validation, the absence of a window opening behaviour model and the uncertainty of the use of the building, the results of the validation are acceptable, but more work will be done to optimize the model and investigate the differences with the real building performance. A profile for opening windows will be implemented in the model. The expectations are to reduce the differences in energy use between the model and the reality. Also, simulations will be run for the year 2018 to check if the behaviour is similar to previous years, in which the heating control was adapted.

The baseline system results in a more stable, controlled thermal comfort in the building than the actual control in the original building. To allow a more accurate comparison of both systems, a similar control has to be implemented in the baseline system. The challenge here will be the definition of an algorithm to determine an equivalent temperature suitable for the baseline that will give similar results as the actual system. In terms of energy use, the baseline shows a reduction of 2.5% of the energy delivered for heating, but it would also have released in situ 41 tons of CO₂ to the environment in 2017. The CO₂ production is an estimation given by the model of the boiler based directly on the natural gas consumption. This value is only taking into account the emissions generated from the use of the natural gas.

The baseline will be updated with domestic hot water production (at the moment the comparison was only for space heating) and it will also be compared for the year 2018 including the opening windows profile.

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