Dynamic simulation and on-site monitoring of a combined solar and pellet system in a low energy house

Elisa Carlon – Bioenergy 2020+ GmbH / Free University of Bozen-Bolzano – elisa.carlon@natec.unibz.it
Alessandro Prada – Free University of Bozen-Bolzano – alessandro.prada@unibz.it
Markus Schwarz – Bioenergy 2020+ GmbH – markus.schwarz@bioenergy2020.eu
Christoph Schmidl – Bioenergy 2020+ GmbH – christoph.schmidl@bioenergy2020.eu
Marco Baratieri – Free University of Bozen-Bolzano – marco.baratieri@unibz.it
Andrea Gasparella – Free University of Bozen-Bolzano – andrea.gasparella@unibz.it
Walter Haslinger – Bioenergy 2020+ GmbH – walter.haslinger@bionergy2020.eu

Abstract

This study focuses on the dynamic building simulation of a low energy house, situated in the region of Lower Austria. The pre-fabricated single family house has highly insulated lightweight walls and triple glazed windows. The house is heated by a 6 kW pellet boiler supplying hot water to a floor heating system. The boiler is also used for domestic hot water production, in combination with solar collectors, thus forming a combined solar-pellet system. The house was monitored in the frame of the BioMaxEff project (funded by FP 7), aiming at the demonstration of biomass boilers in real life conditions. Parameters describing the boiler operation as well as outdoor and indoor temperatures were monitored continuously for one year. The aim of this study is to develop a coupled simulation of the house and its heating and hot water supply systems has been set up in the TRNSYS simulation suite. System components have been simulated using both standard and non-standard TRNSYS Types. A new component was developed within this study to simulate the system's control unit. The comparison of monitoring data of the year 2013 and simulation results showed that the boiler operation in field conditions was accurately reproduced in the simulation environment.

1. Introduction

Nowadays pre-fabricated single-family houses are becoming increasingly popular in Austria, thanks to their high-energy performance. In Austria, houses having an annual heat demand below 50 $kWh \cdot m^{-2}$ are certified as "Low Energy Houses" (Oberösterreich Energiesparverband, 2013).

The building under study is a pre-fabricated single-family house (Figure 1), whose envelope has highly insulated lightweight walls (U_{value} 0.14 $W \cdot m^{-2} \cdot K^{-1}$) and triple glazed windows (U_{value} 0.90 $W \cdot m^{-2} \cdot K^{-1}$). The house is heated by a 6 kW pellet boiler supplying hot water to a floor heating system. The boiler, manufactured by the Austrian company Windhager Zentralheizung Technik GmbH, is also used for domestic hot water (DHW) production, in combination with the solar collectors installed on the roof, thus forming a combined solar-pellet system, as shown in Figure 2. Additional details about the building and its heating and DHW supply system can be found in a previous paper (Carlon et al., 2014). Since November 2012, the house has been monitored in the frame of a FP7 project (BioMaxEff), aiming at the demonstration of biomass boilers under real life conditions.

The aim of this study is to supplement the monitoring activity with a coupled simulation of the house and its heating and DHW supply system, allowing to closely investigate the system's response to the heating and hot water demand. The main objective of the simulation was to accurately simulate the boiler operation in field conditions. The simulation has been conducted by means of the TRNSYS simulation suite. The main system components have been simulated using appropriate TRNSYS Types or developing new Types specifically designed for the devices installed in the house.

Part of
Baratieri, M., Corrado, V., Gasparella, A. & Patuzzi, F. (Eds.). 2015.
Building simulation applications BSA 2015. bu,press.
https://doi.org/10.13124/9788860460745

Fig. 1 – Monitored house

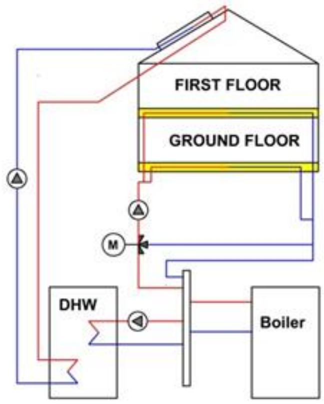

Fig. 2 – Scheme of the heating and DHW supply system

2. Method

2.1 On-Site Monitoring

The house has been monitored since November 2012. Parameters describing the boiler operation as well as outdoor and indoor temperatures provided a data set suitable to characterise the boiler's performance in different seasons.

A heat meter installed at the boiler outlet measured the hot water production and an electricity meter measured the boiler's electricity consumption. The weight measurement of a calibrated balance, placed under the pellet storage, was used to determine the pellet consumption. The outdoor temperature was measured by a NTC thermistor installed on the north wall of the house. Concerning the indoor environment, the temperature and relative humidity was measured in four different rooms using ASH 2200-1 wireless temperature and humidity sensors. Data were logged every 10 seconds by means of a PC-based data acquisition system connected to the boiler's-internal data transmission system. Monitoring data of the year 2013 revealed that the house had an insufficient thermal comfort, as the indoor temperature was very often below the set value chosen by the inhabitants (Carlon et al., 2014).

2.2 Dynamic simulation

A coupled simulation of the house and its heating and hot water supply systems have been set up in the TRNSYS simulation suite. The main system components have been simulated using both standard and non-standard TRNSYS Types. In particular, the pellet boiler has been simulated using the Type 869 boiler model (Haller et al., 2011) and the hot water storage tank using Type 534, available in the TRNSYS TESS library. In addition, a new component was developed within this study to simulate the heating system's control unit. Table 1 reports the lists of the TRNSYS components used in this study.

Table 1 – TRNSYS components used in this study

System component	TRNSYS Type	Source
Building envelope, thermal zones, heat gains	Type 56	Standard TRNSYS Type
Pellet boiler	Type 869	Non standard TRNSYS Type (Haller et. al.)
DHW storage tank	Type 534	TRNSYS Type (TESS Library)
Floor heating system	Type 56 (Active layer)	Standard TRNSYS Type
Three way valve	Type 11-f	Standard TRNSYS Type
Pump - DHW circuit - boiler	Type 114	Standard TRNSYS Type
Pump - DHW circuit - solar	Type 114	Standard TRNSYS Type
Pump – Floor heating system	Type 114	Standard TRNSYS Type
DHW System control unit	Type 2b	Standard TRNSYS Type
Weather data processing	Type 99-2	Standard TRNSYS Type
Solar collectors	Type 1A	Standard TRNSYS Type
Valves – heating system	Type 11 a-f	Standard TRNSYS Types
Heating system control unit	Type 251	Developed in this study

2.2.1 Heating system control unit

The heating system of the house is controlled by a thermostat placed in the living room. Whenever the room temperature drops below the set value, the boiler is switched on and the water circulation through the floor heating system is started. The boiler continues operation until the room temperature is 2 K above the set value. Hot water leaving the boiler (at approximately 55 °C) is mixed with the cold water flow returning from the floor heating system (at approximately 25 °C). The position of a three-way valve is continuously adjusted to reach a certain temperature (T_{mix}), at which the water is delivered to the floor heating system. The set value of T_{mix}, varying between 25 °C and 38°C, is calculated as a function of the outdoor temperature, by means of a heating curve (Figure 3). The limit values of the outdoor temperature, defining the slope of the line are –15°C and +15°C, according to the Austrian regulations and to the recommendations of the manufacturing company.

The considered control unit includes an optional "compensation function" which aims at maintaining the room temperature as close as possible to the set value chosen by the users. The function adjusts the water set temperature at the mixing valve from T_{mix} to $T_{mix,comp}$ according to (Eq 1).

$$\mathrm{T}_{\mathrm{mix,comp}} = \mathrm{T}_{\mathrm{mix}} + P_{comp} \cdot \left(T_{room,set} - T_{room}\right) \quad (1)$$

where P_{comp} is a control parameter, T_{room} is the actual room temperature and $T_{room,SET}$ is the room temperature setpoint. If for instance the indoor temperature is above the set value, then $T_{mix,comp}$ is lower than $T_{mix,}$ and the compensation function has the effect of moving downwards the heating curve. Consequently, water is delivered to the floor heating system at a lower temperature, thus lowering the heat transfer rate to the room and avoiding overheating.

In this study, a new TRNSYS Type (Type 251) was implemented to simulate the control unit, including the compensation function.

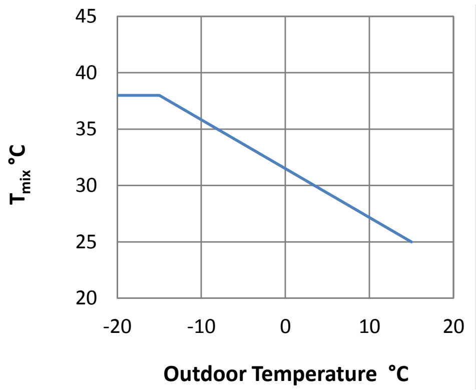

Fig. 3 – Heating curve defining the water inlet temperature to the floor heating system

2.2.2 DHW supply system control unit

In the considered system configuration, the hot water tank is used only for the storage of domestic hot water, and does not serve as a buffer for the floor heating system. The solar collectors heat the lower part of the stratified tank: when the difference between the water temperature at the outlet of the collectors and the water temperature at the bottom of the storage tank exceeds 7 K, the circulation pump of the solar circuit is activated.

If the heat production of the collectors is not sufficient to maintain a minimum temperature of 48°C inside the storage tank, then the pellet boiler starts to heat the upper part of the tank. The boiler operation continues, with priority on the heating system, until the water temperature at the top of the tank increases to 60°C.

The maximum allowable water temperature inside the storage tank is 85°C, due to safety reasons. If this value is reached, the circulation pump leading to the solar collectors is immediately stopped. The control of the hot water supply system was simulated using the TRNSYS Type 2.

2.3 Simulation parameters

The simulation developed in this study was complex and required several input parameters.

The thermal properties the building envelope were found in the Energy Performance Certificate (EPC) of the house, which was provided by the house manufacturer including all the thermal properties of the construction materials. Interviews with the house owners allowed us to define occupation schedules, internal heat gains, DHW demand profiles as well as the settings of heating system control unit. Technical documentations of the solar collector and of the DHW storage tank provided the necessary parameters to calibrate these components. In a previous study, the boiler model Type 869 was calibrated and validated by means of laboratory tests performed on the same 6 kW pellet boiler as the one installed in the monitored house (Carlon et al., 2015).

3. Results and discussion

3.1 Annual efficiency and operational behavior of the pellet boiler

The main focus of the simulation presented in this study is heating and DHW supply system, and in particular the pellet boiler, which had two different operational regimes ("Summer mode" and "Winter mode") depending on the season. Between May and September 2013, the boiler was only used to support the solar collectors for DHW supply. Hence, the boiler operation was completely independent of the building envelope ("Summer mode"). During the remaining months (from January to April and from October to December), the boiler, set to "Winter mode", heated the house and supplied DHW, together with the solar collectors. In this case, the boiler operated to fulfill both the heating and the DHW demands. The dates when the operating mode was changed from "Winter" to "Summer" (April 2013) and then again from "Summer" to "Winter" (October 2013) were specified by the house owners and used as input data for the simulation.

In Figure 4, simulation results concerning the boiler operation during 2013 are compared with the monitoring data. The deviation between the simulated and the measured annual efficiency is below 1%. For the hours of operation and for the number of ignitions, the deviations are 7.3% and 4% respectively.

Table 2 – Comparison of monitoring data and simulation results concerning the boiler operation

	Simulation	Monitoring
Hot water production [kWh]	9401	9278
Annual efficiency [%]	74.6	75.3
Annual pellet consumption [kg]	2570	2582
Number of ignitions [-]	494	516
Hours of operation [h]	1926	2077

3.2 Boiler operation in different months

The monthly pellet consumption and hot water production calculated by the simulation are compared with the monitoring data in Figure 4, on a monthly basis. Simulation results are in good agreement with the monitoring data, except for June 2013, when the simulation underestimated both the boiler heat production and pellet consumption. A deeper analysis of the monitoring data showed that the first half of June was rather cold, therefore the heating system was manually activated for some days. In the simulation, where the boiler was set to supply only DHW during the summer months, this manual start of the heating system could not be foreseen.

In June, July and September 2013, the house did not have any heat demand, and the hot water demand was almost completely covered by the solar collectors. Monitoring data show that, during these months, the boiler operated for 23 hours in total. Also the simulation results show short operation times during the summer season, resulting in a total operation time of 30 hours. The pellet consumption in the period June-September 2013 was 63 kg, representing only 2.4% of the annual pellet consumption.

4. Conclusions and future work

In this study, a coupled simulation of a low energy house and its heating and DHW supply system was set-up. The boiler operation was simulated with a good accuracy throughout the whole year of 2013. Results also showed that the simulation could not take into account all the user behaviours. Therefore, during some specific time intervals when particular conditions occurred, simulation results were less accurate. The next step of this study will be a detailed calibration of the coupled simulation, with a focus on the parameters influenced by the users' behaviour. The calibrated simulation will be used to explore new control strategies, with the aim of improving the thermal comfort in the house. Optimal control strategy shall be defined by maximising the thermal comfort and minimising the pellet consumption of the boiler.

Finally, the simulation will be used to find different system configurations to heat low energy houses by means of biomass-based system. Different system components, such as radiators, and buffer storage tanks will be tested to find optimal system solutions for pre-fabricated houses.

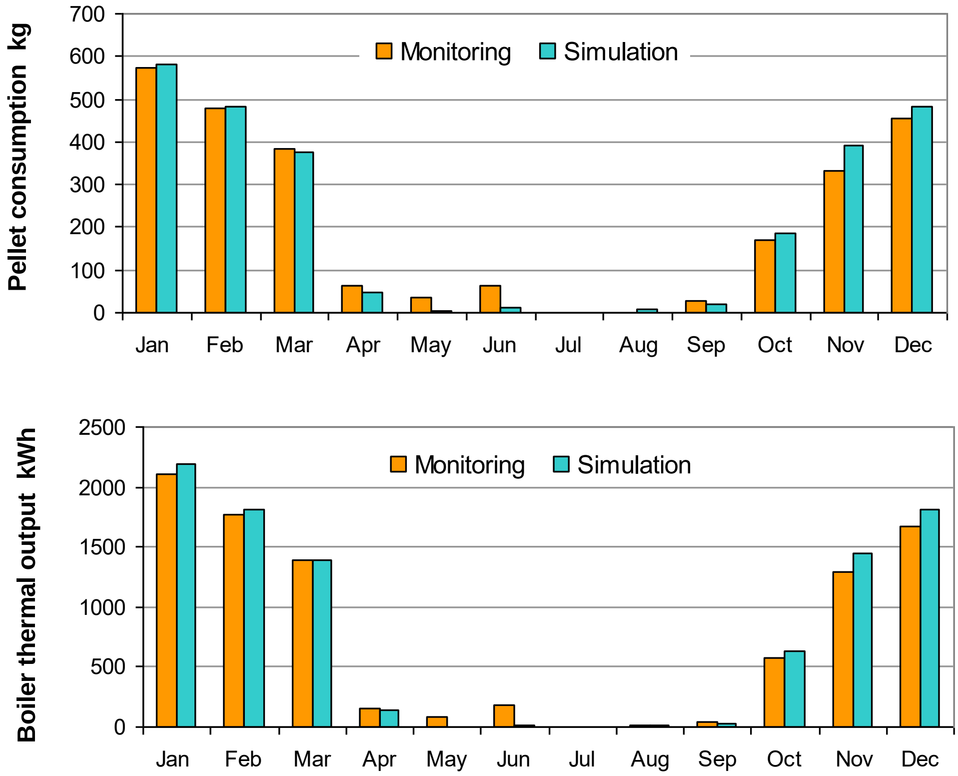

Fig. 4 Comparison of simulation results and monitoring data

5. Acknowledgement

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under Grant Agreement n° 268217. The cooperation with the Austrian company Windhager Zentralheizung Technik GmbH is also gratefully acknowledged.

6. Nomenclature

Symbols

DHW	Domestic Hot Water
EPC	Energy Performance Certificate
P_{comp}	Compensation parameter (-)
T_{mix}	Water temperature at the three-way valve (°C)
$T_{mix,comp}$	Water temperature at the three-way valve, corrected by the compensation function
T_{room}	Room temperature (°C)
$T_{room,SET}$	Room temperature set value (°C)
SHGC	Solar Heat Gain Coefficient (-)
U_{value}	Overall heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-2}$)

References

BioMaxEff project website, Accessed October 27, 2014 http://www.biomaxeff.eu

Carlon, Elisa, Markus Schwarz, Christoph Schmidl, Marco Baratieri, Andrea Gasparella, Walter Haslinger. 2014. "Low energy houses heated by biomass boilers: optimization of the heating system control strategy by means of dynamic simulation." in *Proceedings of the 3rd International High Performance Building Conference at Purdue*, 14th -17th July 2014, West Lafayette, USA, accessed November 20, 2014.

Carlon, Elisa, Vijay Kumar Verma, Markus Schwarz, Laszlo Golicza, Alessandro Prada, Marco Baratieri, Walter Haslinger, Christoph Schmidl. 2015. "Experimental validation of a thermodynamic boiler model under steady state and dynamic conditions" *Applied Energy*, 138C: 505-516. doi: 10.1016/j.apenergy.2014.10.031

Haller M.Y., J. Paavilainen, L. Konersmann, R. Haberl, A. Dröscher, E. Frank, C. Bales and W. Streicher. 2011. "A unified model for the simulation of oil, gas and biomass space heating boilers for energy estimating purposes. Part I: Model development" *Journal of Building Performance Simulation*, 4 (1): 1–18.
doi: 10.1080/19401491003671944

Oberösterreich Energiesparverband, Accessed November 20, 2014. http://www.esv.or.at/?id=2125.

TESS component libraries - General Descriptions, Accessed November 20, 2014. http://www.trnsys.com/tesslibraries/TESSLibs17_General_Descriptions.pdf

TRNSYS 16, a TRaNsient System Simulation program - Volume 6, Multizone Building modeling with Type56 and TRNBuild, Accessed November 20, 2014.
http://web.mit.edu/parmstr/Public/Documentation/06-MultizoneBuilding.pdf

Windhager Zentralheizung Technik GmbH, "Operating Manual of Windhager VarioWIN Pellet central heating boiler pneumatic + direct", accessed November 20, 2014. http://www.windhager.com/fileadmin/user_upload/VarioWIN_OP_Manual0810.pdf

Windhager Zentralheizung Technik GmbH, *"MESplus, Systemregelung für bis zu zehn Heizkreise, accessed November 20, 2014."* http://www.windhager.com/at/produkte/regelung/mesplus-47