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Modeling and simulation of the heating circuit of a multi-functional building

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ABSTRACT

In this study, the fossil-fueled heating circuit and the corresponding automation system of a multi-functional building are simulated to lay the foundation for in-depth analysis and optimization of the building energy concept.

The considered building is the E.ON Energy Research Center main building which is equipped with a highly integrated energy generation, storage and distribution system. The thermo-hydraulic components and control units are developed in the modeling language MODELICA whereas the relevant part of the global Building Automation System is implemented in MATLAB/SIMULINK. The interaction between the two simulation environments is established using the non-commercial co-simulation platform Building Controls Virtual Test Bed (BCVTB).

Data stored in the comprehensive building monitoring system is used for the parametrization of the hydraulic model. Moreover, the data is analyzed to deduct information on the control system such as temperature set-points.

Both the single subsystems and the model as a whole are validated by comparing simulation results to monitoring data. The evaluation reveals that the behavior of the hydraulic components and the control system is successfully reproduced and deviations remain in an acceptable range. The reasons for the deviations are identified and mitigation measures are discussed.

1. Introduction

The objective of this paper is the creation and validation of a detailed model of a building energy system. The object under consideration is a 7222 m^2 floor area building located on a campus of RWTH Aachen University, Germany. Besides laboratories and conference rooms, the building mainly consists of offices for more than two hundred occupiers, mostly researchers, who expect to be provided with a comfortable working environment. Therefore, the heating and cooling demands of the building must always be fully satisfied. Consequently, changes in the currently installed control system cannot be made forthrightly. Therefore, new approaches such as new control strategies or optimization algorithms should first be tested and their performance should be evaluated prior to implementation in the building [1].

Due to the following reasons, the authors were motivated to create a simulation model of the energy system for testing and evaluation purposes. Firstly, dynamic modeling and simulation are much less cost-intensive compared to field experiments. Nevertheless, they still allow a first evaluation of the considered energy system [1]. Secondly, novel control systems can be tested conveniently as changes to the considered system can be applied quickly and without affecting the occupiers' comfort. Thirdly, by reproducing the behavior of the system, a profound understanding of the system dynamics can be achieved. This knowledge can be used in future works aimed at further analyzing and improving the energy concept [2]. Therefore, the authors are convinced that the developed model will allow further research of the energy system.

There are already a lot of publications dealing with simulation platforms and dynamic models that can be used for the analysis of HVAC control systems. In [3], a framework is proposed by means of which the building performance can be checked against the desired performance. This framework is implemented using EnergyPlus, the Building Controls Virtual Test Bed (BCVTB) and the Energy Management and Control System (EMCS). It is successfully tested in a real building. HVAC simulation frameworks can also be developed in MATLAB/SIMULINK, as shown in [4].

A review of different approaches for building modeling can be found in [5]. That review also includes an evaluation of the suitability of the single methods for model predictive control. For the

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Nomenclature

Abbreviations

BAS	Building Automation System
BCVTB	Building Controls Virtual Test Bed
ERC	E.ON Energy Research Center
HTC	high temperature circuit
LTC	low temperature circuit

Symbols

$\dot{m}$	mass flow
$\dot{Q}$	heat flow
$c_{p,w}$	specific heat capacity of liquid water
n	number of data points
$n_{Start\rightarrow Stop}$	number of shut-downs
R_n	ratio of root mean square deviation to range
S_n	root mean square deviation
T	temperature
t	time
x	considered physical quantity

Subscripts

Moni	value read from monitoring data base
MV	mean value
Simu	value obtained in simulation

purpose of supporting such control approaches, a suitable simulation tool is developed in [6].

Despite the fact these studies cover a wide range of applications of co-simulation platforms, there is still a need to fully illustrate the dynamic modeling and co-simulation process in the frame of a case study. Moreover, the reported simulation results are rarely supported by validation against measurements due to the lack of a monitoring, control and interface system. This paper aims at filling the gap by presenting the dynamic modeling and co-simulation process of a multi-functional building. The level of detail makes it possible for other researchers to model and simulate any comparable system by following the proposed procedure. Furthermore, the simulation results are compared to monitoring data to ensure the reliability of the simulation models. The models can thus be used in future control applications.

1.1. *Energy system description*

The building under consideration is the E.ON Energy Research Center (ERC) main building in Aachen, Germany. It is equipped with four fluid circuits used for cooling and heating energy fluxes at different temperature levels. One heating circuit is operated at 80 °C and is henceforth called High Temperature Circuit (HTC). The other one is controlled in such a way that the temperature persists at 35 °C and is thus called Low Temperature Circuit (LTC). The focus of this study lies on the HTC [7].

The building comprises multiple energy conversion and distribution technologies. Furthermore, a complex Building Automation System (BAS) is installed. Fig. 1 shows a scheme of the energy system, including consumers and storage units [1].

The HTC is supplied by a gas-fired co-generation unit (CHP) and two boilers. While the CHP system supplies base load, the boilers serve as back-up devices. The centerpiece of the LTC is a heat pump which is connected to a geothermal field (ground source) to provide cooling or heating energy, depending on the current operation mode. The transfer of excess heat to the geothermal field provides compensation for the energy extraction in heating mode. As the waste heat displacement is limited, an additional glycol cooling system can be used to further dissipate heat energy. The circuits are interconnected by means of a heat exchanger. The thermal coupling allows heat transfer from the HTC to the LTC in case the demand exceeds the generation in the LTC. Due to the large variety of distribution technologies, different fluid temperatures are required. These are included in Fig. 1. Water at 6 °C provides cooling energy for laboratory use. As concrete core activation, façade ventilation units and active chilled beams can provide both cooling and heating energy, these systems are supplied with water at 17 °C and 35 °C, respectively. Moreover, the 35 °C-flow is connected to the air handling unit of the common areas whereas the 17 °C-cooling circuit also supplies the air-cooling system of the server rooms. The HTC provides process heat at 70–87 °C for laboratories, supplies radiators in common areas and, in cooling mode, powers a sorption-supported air-conditioning unit. It is further equipped with an hydraulic separator [7].

1.2. *Modelling approach*

The dynamic model is developed by means of three different tools. The thermo-hydraulic components as well as their inner control mechanisms are modeled in the equation-based, object-oriented language MODELICA, which is a powerful language to model such systems [8]. The existence of broad and established component libraries is a further advantage [9]. In this research, the MODELICA Standard Library version 3.2 and the MODELICA libraries for building simulation developed at the Institute for Energy Efficient Buildings and Indoor Climate, E.ON Energy Research Center, RWTH University, are applied to simulate the hydraulic and thermal behavior of the system [10]. Models written in the MODELICA language cannot be executed directly, and a simulation environment is needed to translate a MODELICA model into an executable program [11]. In this study, models are developed and simulated in the MODELICA modeling and simulation environment DYMOLA, version 2013 [12]. The control strategy which the BAS is based on is deducted from building monitoring data and modeled in MATLAB/SIMULINK. BCVTB allows data exchange between DYMOLA and SIMULINK in a co-simulation [13].

Fig. 2 shows the subsystems of the HTC model and illustrates the communication structure of the entire system. At the beginning of a fixed time step, selected values of the MODELICA model are transferred to SIMULINK. In SIMULINK, the received values are included in the computation of the current time step. Certain variables are sent back to DYMOLA which, in turn, processes them in the following time step.

The parametrization and initialization of the model is based on data from the monitoring system. Monitoring data is further used for validation. Among the considered simulation results are temperatures and volume flow rates as well as operation signals and switching commands. In order to keep the number of data points in the SQL-database of the monitoring system to a minimum, the data is stored by an event-based algorithm. Triggered by significant changes of the monitored values, new data points are added to the database. Especially for rarely changing status signals, the number of stored data points can be reduced greatly [7].

2. Modeling

2.1. *Hydraulic system (MODELICA/DYMOLA)*

In the following sections, the components of the HTC and the developed models are described. These are

- CHP unit
- Boilers