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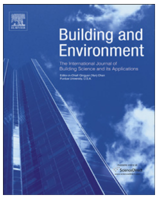

Indoor-environment simulator for control design purposes

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ABSTRACT

Building-management systems (BMSs) are becoming increasingly important as they are an efficient means to having buildings that consume less energy as well as for improving the indoor working and living environments. On the other hand, implementing automated control and monitoring systems in buildings is still relatively new, and one of the obstacles for their wider implementation is the ease of setting up the appropriate parameters for the controllers. During our work on an experimental controller for an indoor environment that is installed in an occupied office in the building of the Faculty of Civil and Geodetic Engineering, University of Ljubljana, Slovenia, it has become evident that a computer simulator of the system would be a welcome aid for the optimization of its functioning. In this paper we present a simulator application developed in a combined Matlab/Simulink and Dymola/Modelica environment. The simulator mirrors the functioning of the control system and the dynamics of the indoor environment, where the thermal model of the simulator was developed in the Dymola/Modelica environment, while the illuminance model was developed and parameterized as a black-box model on the basis of measurements in the Matlab environment. The simulator can emulate the response of conventional ON/OFF controllers as well as fuzzy controllers. The paper presents the design of the simulator with all of the key elements described. The underlying models for the thermal and illuminance control are also separately described. Finally, the performance of the simulator is presented for a selected day.

1. Introduction

The use of automated control in buildings has been shown to have a great deal of potential for reducing the energy consumption of HVAC systems as well as for artificial illumination [1,2]. Building automation can also greatly enhance the quality of the indoor environment and in this way increase the performance and enhance the comfort of the occupants. Recent developments in building-management systems (BMSs) have been predominantly driven by the advances in computers and telecommunications technology. The possibilities of using wireless-communication technologies as well as a reduction in prices have enabled their wider application in the construction industry. Despite this it needs to be stressed that the primary focus in the development was not on new control concepts, but on the application of existing technologies [3], although advanced control methods have been used in numerous experimental systems. The use of fuzzy-logic in the field of indoor-environment control was presented by Kolokotsa et al. [4] and Kristl et al. [5] for the regulation of thermal and visual environments as well as for the control of ventilation, while Guillemin [6] supplemented fuzzy-logic controllers with genetic algorithms for the optimization of the decision matrix. Neural networks are also used. Argiriou et al. [7] employed them for the control of hydronic solar heating, while Castilla et al. [8] used them for thermal-comfort models of HVAC systems. Široky et al. [9], Castilla et al. [10] and Ma et al. [11] showed through their work that model predictive control (MPC) was well suited for the control of an indoor environment. An upgrade of the conventional MPC, the adaptive multiple model MPC, was implemented by Kim [12] for the optimization of thermal storage in buildings. Another point that is also very evident in the field of "smart buildings" is that in many building applications the primary goal is just a reduction of the energy being consumed. Other benefits that could be reached with a holistic control system for the indoor environment [13] (e.g., enhanced daylighting [14], user comfort [15], indoor-air quality [16]) are neglected or ignored [17]. Such an approach contradicts the basic philosophy of bioclimatic design, where the higher efficiency of buildings does not only mean the use of less energy for

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heating and cooling, but primarily better working and living conditions for the occupants [18]. With an integrated treatment of the buildings and installed systems, better results can be achieved simultaneously in terms of occupant comfort as well as energy use.

The Integral Control system of Indoor Environment (ICsIE) presented and described by Košir et al. [17] is based on the above-stated basic presumption of bioclimatic design. The system regulates the indoor workplace illuminance, heating, cooling and natural ventilation, linked to the indoor CO_2 concentration. The ICsIE is installed in an occupied office of the main building of the Faculty for Civil and Geodetic Engineering in Ljubljana, Slovenia. The indoor environmental conditions are regulated via available actuators that consist of external motorized venetian blinds, ceiling-suspended radiant heating and cooling panels, conventional office fluorescent lights and an automated window. The control and monitoring of the environmental conditions are achieved through an elaborate array of internal and external sensors. These sensors record the internal and external illuminance, the temperature, the relative humidity, the internal CO_2 concentration, the global and reflected solar radiation, the precipitation detection, the wind speed, the wind direction and the consumption of energy for heating and cooling. Further information regarding the control logic and the structure of the system is available in the above reference.

By using and experimenting with the ICsIE it has become evident that if appropriately tuned, the system performs satisfactorily [14,17]. Nonetheless, because at its core the ICsIE utilizes a black-box approach, the knowledge of the system operators has to be substantial in order to achieve a satisfactory control performance. Such an approach can also be tedious for the operators as they have to set-up the control parameters and wait for the experimental results. Even if the results are satisfactory, the operator cannot know if the system set-up that was used is the best possible for the given task [3] as the experiment cannot be repeated due to changes in the weather. What is missing is an underlying physical model or a simulator of the control system. Although the thermal (i.e., heating and cooling) control algorithm implemented in the ICsIE is partly based on an earlier thermal model of a building developed by Škrjanc et al. [19] and Sodja et al. [20], the illuminance control is completely based on experimentally acquired knowledge [5,21]. In order to overcome the above-described shortcomings associated with conducting real-life experiments with the ICsIE to set-up its control parameters, a simulator application has been developed. The simulator enables the testing of different set-ups of the ICsIE on a standard PC equipped with the Matlab and Simulink [22] applications. The simulations are conducted on the basis of real weather data recorded by the ICsIE for the duration of its operation since 2009. This paper presents the methodology of the simulator, the underlying models for the thermal and illuminance control as well as the user interface and functioning of the application.

1.1. *The purpose of the simulator*

The simulator was developed in order to obtain a virtual environment that would accurately imitate the real-world conditions and enable the rapid and process-safe testing of the impact of all the included parameters on the results of the simulation. Besides that, the aim was also to achieve the relatively simple use of the simulator, even for inexperienced users. For this purpose a user interface was added, through which the parameters can be adjusted and different actions can be performed with the user controls. The presented simulator has several advantages over real-system testing, for instance: the simulation runs are very fast in comparison to the real-time experiments; the simulations can be performed for any day of the year, independent of the actual day of the year; the simulation runs can be performed for several days in a row (up to ten) without having to wait for several days to get an overall insight into the results (e.g., for control design or testing purposes); a day with the desired weather conditions can be selected; and the simulation can be repeated multiple times with different control parameters. At this point, the simulator gives an immediate insight into the impact of various parameters, such as hysteresis, references, time constraints, fuzzy controllers' settings, etc., as well as the end results, which can be obtained relatively quickly and afterwards tested on a real system. Since the real-system testing, besides being slow, could also be disturbing to the occupants of the room, the use of the simulator for such purposes seems to be an optimal solution.

2. Simulator

The developed simulator is derived on the basis of an indoor environment installed in an occupied office in the building of the Faculty of Civil and Geodetic Engineering, University of Ljubljana, Slovenia. The indoor environment is on the 4th of 5 floors and consists of a room of approximately 40 m^2 area with one window of approximately 11 m^2 area and one outside wall. It is equipped with an automation system that consists of several control schemes, all the necessary sensors and actuators, automated venetian blinds with five possible positions, automated artificial illuminance (lights), automated window and heating/cooling panels.

2.1. *Parts of the simulator*

The simulator consists of three major parts, i.e., the controller, the model and the user interface, which are schematically shown in Fig. 1.

As can be seen in Fig. 1, the controller allows two different control algorithms to be executed, depending on the user's selection, i.e., ON/OFF control or fuzzy-logic control. The first algorithm consists of multiple ON/OFF controllers for illuminance, temperature, lights and CO_2 concentration, which are supported by several time and other restrictions. The fuzzy-logic algorithm consists of two separate fuzzy controllers for illuminance and temperature, and two ON/OFF controllers for the lights and for the ventilation connected to the CO_2 concentrations. Regardless of the control-algorithm selection, the controller is connected to the mathematical model of the temperature and illuminance processes in a feedback loop, which represents the second part of the simulator.

The model used in the simulator consists of two sub-models, which represent the necessary dynamic mechanisms describing the relations between the room temperature and the illuminance

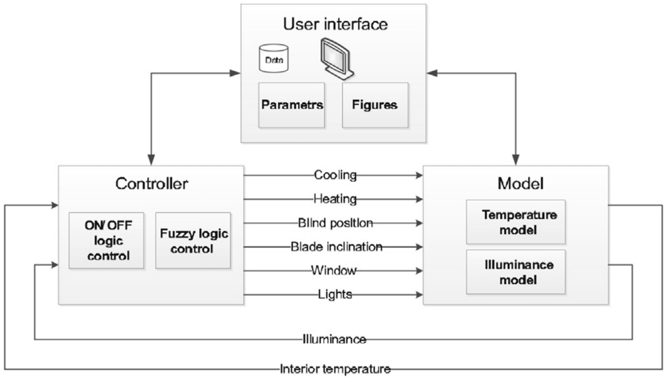

Fig. 1. Parts of the simulator.