SIMALATION AND CONTROL SYSTEM DESIGN OF THERMAL CONDITIONS IN BUILDING USING ACTIVE AND PASSIVE RESOURCES

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ABSTRACT

The paper deals with a systematic approach to the control system design with a final goal to efficiently control some living conditions in a test chamber. The mathematical model was implemented in MATLAB Simulink environment. The structure is modular, the robust numerical algorithms give accurate results and fast simulation runs. The developed simulator gives an ideal environment for the design and validation of different control structures. Four fuzzy logic controllers were proposed for efficient control of indoor temperature: for heating, for cooling, for coordination of both subsystems and for roller blind positioning. Simulation gave applicable information for control system implementation with industrial hardware..

KEYWORDS

Mathematical modeling, simulation, fuzzy control

1 INTRODUCTION

From prehistoric times bioclimatic conditions in buildings were of extreme importance for pleasant and healthy feeling. As such they represent a process with inexhaustible possibilities for the studying of new control design approaches. Recent outcomes of the control engineering area are more and more applicable on different areas due an incredible development of software and hardware technologies. Beside traditional PID algorithms which are implemented in industrial hardware for many years, it is also possible to use more advanced techniques, e.g. fuzzy logic, neural nets, expert systems, genetic algorithms, adaptive and multivariable control etc. However an efficient control design procedure always demands the development of simulation model.

2 MODELLING AND SIMULATION

The designed building simulator (entitled KAMRA) is based on theoretical mathematical modelling approach (Matko et al, 1992). The theoretical modelling of heat dynamics of a room was based on the analyse of thermal conduction, thermal convection and solar radiation and on appropriate energy balance equations (Kladnik, 1987, 1995, Zupančič et al, 1998a, Furlan et al, 1998). The properties of the envelope are treated as time-varying parameters as they are variable by their own nature. The variable nature is especially worth for the openings in the building envelope.

Simulator KAMRA can be used for different purposes. In this case it was used for control system design purpose, so only input/output relations will be presented in more detail. The inputs of the simulation model are the outside conditions as well as dynamical parameters of envelope:

Variable outdoor (weather) conditions:

- the outdoor air temperature,
- the temperature of the terrain,
- global solar radiation,
- level of cloudiness and
- ratio of diffuse/direct radiation.

Changeable properties of the building's envelope are:

- the opaque elements: thermal capacity and resistance of these elements can be changeable,
- the transparent elements (windows): geometry of openings, optical characteristics of glass and resistance of fill between glass panes are variable,
- interior properties: absorption, emission coefficients of walls and thermal capacity of furnishing are variable,
- other characteristic: changeable orientation,

Additional heating and cooling: the power of heater and ventilator.

The outputs of the simulation model are:

- the indoor air temperature and interior heat flow
- the walls, windows and surface temperatures

After the development of the mathematical model and the simulator concept the appropriate programming tool was selected with regard to the following requirements:

- Modular and transparent syntax. Model can easily be understand and modified as well.
- Modern graphic user interface should enable that modelling and simulation unskilled users can efficiently experiment with the model.
- High numerical accuracy and robustness.
- Fast simulation.
- Portable models. The selected environment should be a widely spread one, used not only on academic institutions but also in industry.
- With regard to the developed simulation concept the capability for the inclusion of continuous and discrete submodels into the simulation model must be presented.
- In the chosen environment different toolboxes must give powerful possibilities not only for simulation but also for analysis, design, graphical results presentation etc.
- If possible, control structures obtained by off line simulation and design can be automatically coded for appropriate target hardware giving efficient real time implementations (Zupančič, 1998b).

Having in mind the itemised requirements the mathematical programming environment MATLAB-Simulink with appropriate Toolboxes (for control, fuzzy logic, ...) was used. Fig. 1 shows the highest hierarchical level of the modularly constructed simulation model, which is already prepared to serve as a test cell for control system development and validation.

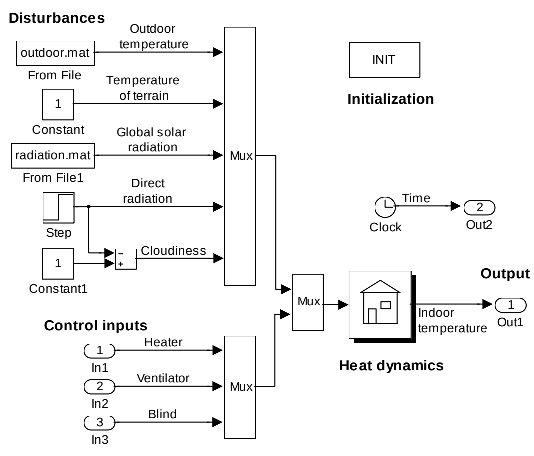

Fig. 1. Simulation scheme of the simulator in MATLAB-Simulink environment

In the block Initialization all the parameters about the materials, geometry of window, orientation, geographic location and starting simulation time are given. So the simulation of the behaviour in the case of different materials, orientations, geographic location, position and number of windows and period of the year can be performed. Outdoor temperature and Global solar radiation are defined with appropriate data files obtained from real measurements. They can easily be defined by some other signals from Simulink library. Temperature of terrain, Direct radiation and Cloudiness are prepared as constants or step signals. However in the presented model Direct radiation and Cloudiness are not independent (e.g. if the parameter of direct radiation changes from 0 to 1, the parameter of cloudiness changes from 1 to 0). Up to now described signals are treated as disturbance inputs. The last three inputs signed with Heater, Ventilator and Blind are control inputs as they will be fed by controller signals in order to assure the appropriate indoor temperature. Indoor temperature is the model output or from the point of control system the controlled variable. Of course the simulator can be easily modified so that also other variables of the model can be influenced or monitored.

The verification and validation of the simulator is one of the most important tasks in each modelling cycle. It is mainly based on the comparison of the measured and simulated results. The verification and validation of the simulator KAMRA was performed with a real system (chamber) – a testing cell built on the roof platform of the Faculty of Civil Engineering, University of Ljubljana. Fig. 2 shows the scheme of the test chamber with basic sensors and actuators used in the verification and validation of the simulator KAMRA.

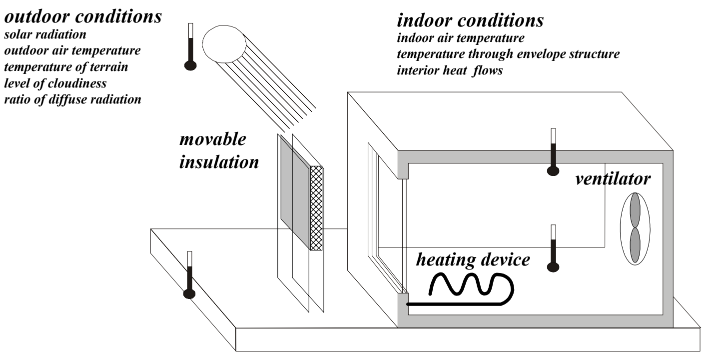

Fig. 2. Scheme of the test chamber with basic sensors and actuators used in the verification and validation of the simulator KAMRA.

The test chamber is a box with all dimensions 1m. The south wall is completely glazed, double-glazing is composed of two layers of standard clear glass and air fill, the thickness of wooden frame is 5cm. The roller blind is as external PVC blind and the alternating window geometry was realised by moving the blind to desired position. Walls, floor and ceiling are composed of dry wall panel 1cm, mineral wool 8cm dry wall panel 2cm (from outside). Internal walls are painted in light grey colour. The box is shifted off the ground and the roof is ventilated. Measured values for outdoor conditions were global and reflected solar radiation and outdoor air temperature. The temperature of indoor air defines thermal response of the object. Window size was expressed as ratio of shaded area and whole glazing area. For the purpose of collecting of different samples of the outdoor environment conditions, some series of measurements were performed in different seasons of the year. Position of blind was changed randomly in different time intervals independent of the outdoor conditions.

Several measurements were used for appropriate final parameters tuning of the theoretical model of the test chamber. Another set of measurements was used for simulator validation. Simulations were obtained with the measured outdoor temperature and global solar radiation as input variables taken from the experiments as well as with the signal for blind moving regime (see Fig. 3). The comparison of the simulated indoor temperature and the measured one is presented in Fig. 4. The error between calculated and measured values is acceptable in the range of 5-20%. Mainly it is caused by unexpected ventilation heat-losses through some cracks in the dry wall panels and by the influence of wind.

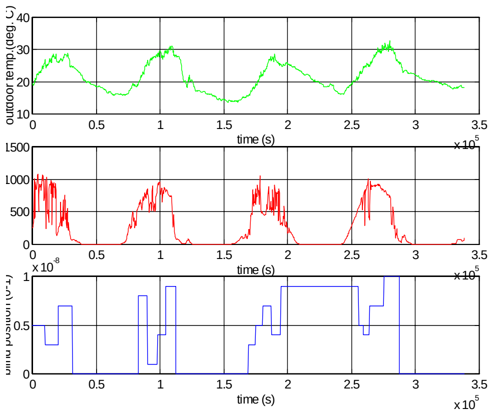

Fig. 3. Blind position, global solar radiation and outdoor temperature

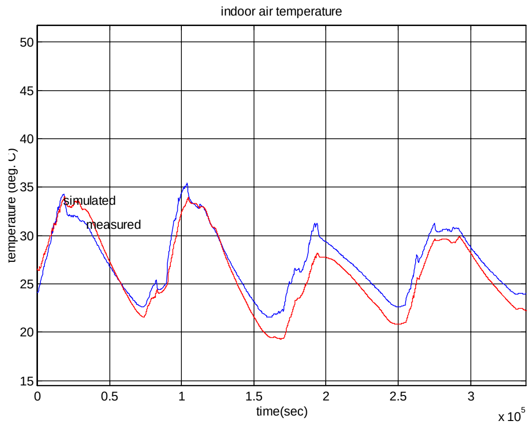

Fig. 4. Comparison of the measured and simulated indoor temperature

3 CONTROL SYSTEM DESIGN AND VALIDATION

As mentioned the final aim was to develop a control system for pleasant and comfort living conditions but also for economic energy consumption. The comfort was mainly determined with indoor temperature. However the appropriate daylight was also important as it can significantly influence comfort behaviour and energy consumption as well. It is well known that optimization of each technical system starts with different and contradictory demands so the most important step in the design procedure is to choose appropriate criterion functions. Fig. 5 depicts the Simulink simulation scheme of heat dynamic control system. The heater and ventilator are controlled by two fuzzy systems, each of them consists of two fuzzy controllers. The inputs of both fuzzy systems are control error and error derivative. With such approach a fuzzy logic controller can be treated as a dynamic controller. Obviously heating and cooling (ventilation) are not simultaneously in operation. This operation is harmonized by the third fuzzy feedforward controller entitled fuzzy logic coordinator. The output of this system is the third input of the fuzzy controllers for heating and ventilation. The blind positioning is controlled by the fourth fuzzy logic feedforward controller with the following inputs: solar radiation, direct solar radiation and day index (indication of summer and winter period respectively).

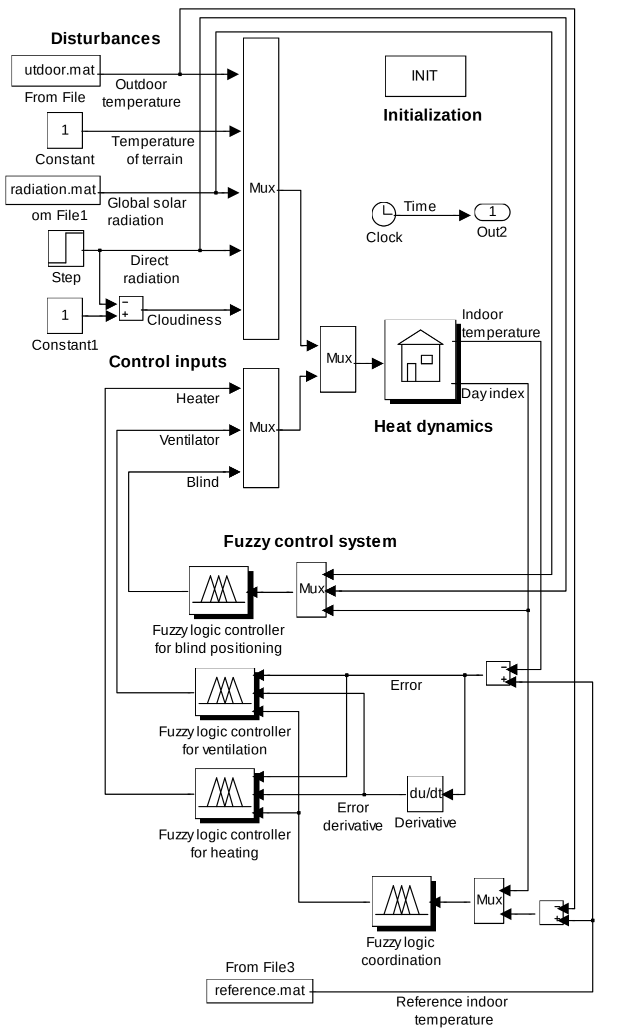

Fig. 5. MATLAB Simulink simulation scheme of the heat dynamics control system.

Fuzzy logic controller for heating consists of a parallel structure of proportional derivative (PD) and proportional integral (PI) part. It is a kind of fuzzy PID controller. PD part enables fast response and appropriate damping and PI part eliminates the steady state error. The appropriate simulation scheme is presented in Fig. 6. Appropriate membership functions and fuzzy rules were designed with many simulation experiments.

Cooling is in simulator KAMRA modelled as a negative heat flux from the ventilator. The structure of fuzzy logic controller for cooling is very similar to the heating one. It is obvious that the appropriate switching coordination is needed in order to prevent simultaneous heating and cooling actions and to assures bumpless transfers from cooling to heating phase and minimal energy costs.

It also consists of a parallel structure of PD and PI part. The membership functions are mirror images of membership functions for heating.

The described fuzzy controllers were validated with several simulation studies. Fig. 7 shows the transient response of the indoor temperature when the reference temperature is changed from 18 °C to 20 °C.

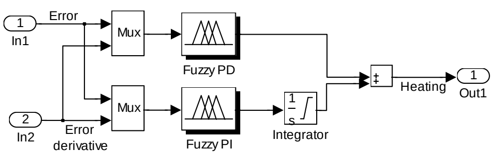

Fig. 6. Simulation scheme of the fuzzy logic controller for heating

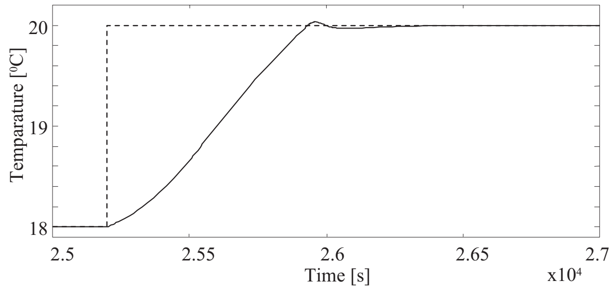

Fig. 7. Indoor temperature as the response to the reference change

The roller blind is installed in the south window of the tested chamber. As one of the important aim of the control system is also to assure the economic energy consumption, the appropriate control of the roller blind positioning is very important. The fuzzy control of the roller blind is implemented as a feedforward control as the action of the controller does not depend on the indoor temperature. The fuzzy controller has three inputs: day index, global solar radiation and direct solar radiation. The latter one is connected with cloudiness.

During observation the reference temperature is changed from 18 °C to 20 °C and back to 18. °C. In the moment t=50000s the global solar radiation is changed from 200 W/m^2 to 500 W/m^2. Fig.8 depicts the reference and indoor temperature. Fig. 9 shows the global solar radiation disturbance and the appropriate reaction of roller blind. At the beginning the roller blind is already lowered to app. 0.6 due to direct solar radiation. At the moment when the disturbance occurs the reaction of the roller blind is instantaneous as it is controlled with feed forward approach. Both diagrams in Fig. 10 illustrates however the cooling power, which is needed for appropriate control. It can be noticed, that the cooling is completely switched off for a short period after the reference changes to 20 °C. At t=50000s the fuzzy controller in the cooling system intensifies the cooling power. All these actions cause that the radiation disturbance does not effect the indoor temperature (see Fig. 8).

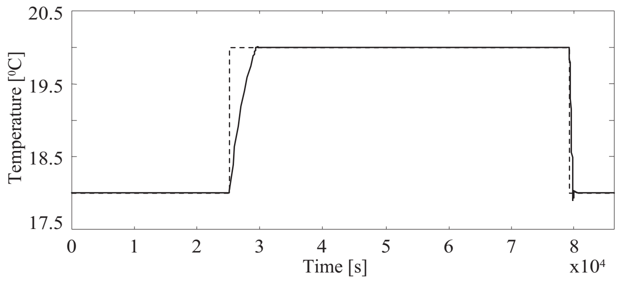

Fig. 8. Reference and indoor temperature

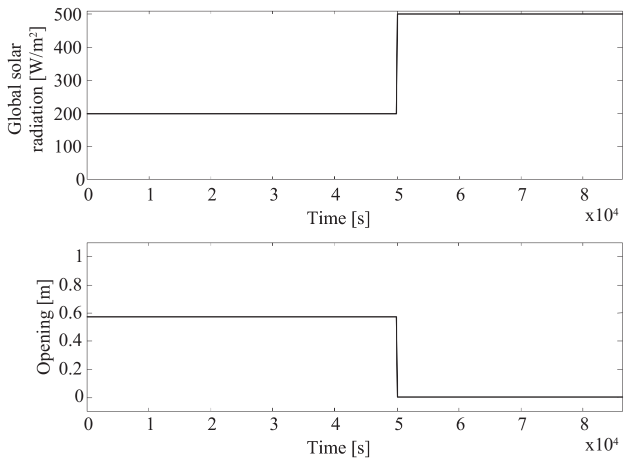

Fig. 9. Global solar radiation disturbance and the response of the roller blind.

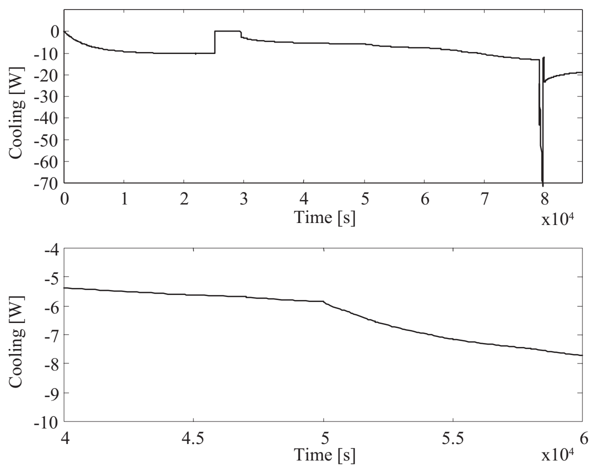

Fig. 10. Cooling power

In the presented example the disturbance was eliminated by the appropriate roller blind positioning and by increased cooling. Other simulations show that the roller blind is more effective in case of direct solar radiation disturbance. It is also worth to emphasise that criteria for good leaving conditions (e.g. good illumination) and low energy consumption are contradictory, so appropriate compromises must be considered.

4 CONCLUSIONS

The life cycle of complex control systems consists of many complicated phases. In this paper some of them, which demand high level of knowledge about modelling, simulation and control system design approaches as well as about modern software and hardware technology, were discussed and implemented. The development of mathematical modelling is probably the most crucial part. The proposed control scheme which consists of two feedback and two feedforward controllers is only the first attempt with very promising results. There are many new possibilities for new modelling and control system design approaches. Experimental modelling or the combination of theoretical and experimental modelling (e.g. with neural nets) can result in more accurate model for control design purpose. There are of course many other possibilities for control system design. It is expected that the best results will be achieved with the combination of traditional methods (e.g. PID) and methods that originate in artificial intelligence (e.g. fuzzy logic, neural nets, genetic algorithms, expert systems, …).

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