Fuzzy control system for regulation of integrated shading and ventilation

M. Košir, Ž. Kristl*, A. Krainer
University of Ljubljana, Slovenia

ABSTRACT

Automated living and working environment is becoming a commonly used service. The present paper deals with a dynamically automated control of shading in buildings during mid-seasons. In addition to shading the controller also regulates illuminance levels, internal temperatures and their harmonization. The system is designed as fuzzy controller that functions in real time and under real environmental conditions. For this purpose a test chamber with an opening on the southern side was built. Changeable geometry of the opening was realized with the automated external roller blind. Proper functioning as well as fine-tuning of the regulator was achieved through a series of tests conducted during spring time. The experiments justified the use of automated shading for the control of internal temperatures during mid-seasons.

1. INTRODUCTION

Regulation of internal living conditions in temperate climate during mid-seasons can be in most cases attained by properly positioned external shading devices. Because during this period the amount of available solar radiation is high and the external ambient temperatures are relatively low, the impact of shading on the internal temperature is important. Additional positive effects can be attained by implementing natural ventilation and radiative cooling during night time. The system presented in this paper was designed according to the above described presumptions.

In temperate climate weather during spring and autumn is exceptionally varied and prone to rapid changes. Because of these conditions the control of shading devices has to be automated. Automated control of shading devices incorporated in the building envelope has to assure optimum balance between aspects of energy consumption and internal user conditions (Krainer, 1993, Kladnik et al., 1997). Best results can be obtained by applying advanced control systems based on the developments in the field of "artificial intelligence" technologies. One of the possibilities is a system based on fuzzy logic, which is vastly superior to manual or ON-OFF control as well as less complicated to execute and more intuitive to the designer and to the user than the classical PID or PI controllers.

The presented fuzzy system was realised as a thermal and illuminace fuzzy controller for the internal living environment. The basic controller architecture was built around two fuzzy control loops, the first for thermal conditions and the second for illuminance. Controller operated in real-time conditions as well as in real environment. The whole system was tested on a test cell with south oriented window. Dimensions of the cell were 1 m x 1 m x 1 m and the south oriented window was 1 m x 1 m double glazed float glass with air fill and wooden frame. The whole cell was constructed from 20 cm thick aerated concrete blocks with ventilated roof and ground to prevent influences of the immediate surfaces on the interior.

In this paper experiments carried out on the test cell during mid-season months are presented.

2. DESCRIPTION OF THE SYSTEM

As mentioned above, the control system was installed and tested in an experimental test cell with a south facing glazed surface. The changeable geometry of the window was achieved with an externally fixed PVC roller blind controlled by a programmable logic controller (PLC) connected to a PC and an operator panel. The control algorithm for the thermal and illumination processes was developed in the IDR BLOCK environment and was loaded on the PLC (Trobec-Lah, 2003, Trobec-Lah et al., 2005). A remote PC and control panel were used for the process supervision and for the visualization of experiments. The obtained values and process variables were collected and stored in the PC, with an application in Factory Link environment developed for this purpose. The framework of the system is presented in Fig. 1. The control algorithm is composed of two general loops, which can function separately or can be linked to work simultaneously. The first loop is the "illumination loop" comprised of elements or blocks, which make the roller blind alternations possible in such a way that the indoor set-point illumination is followed. The second is the "thermal loop" which is comprised of two separate controllers, one for the summer season and the other for the winter season. The thermal loop also includes the controlled functioning of heater and ventilator. Both control loops are designed as a cascade control system where fuzzy controller is used as the main controller and PID/V type controller as the auxiliary one (Trobec-Lah et al., 2005). In this way the main fuzzy controller defines roller blind position according to the external conditions and the set point values. The PID/V controller then executes the appropriate change.

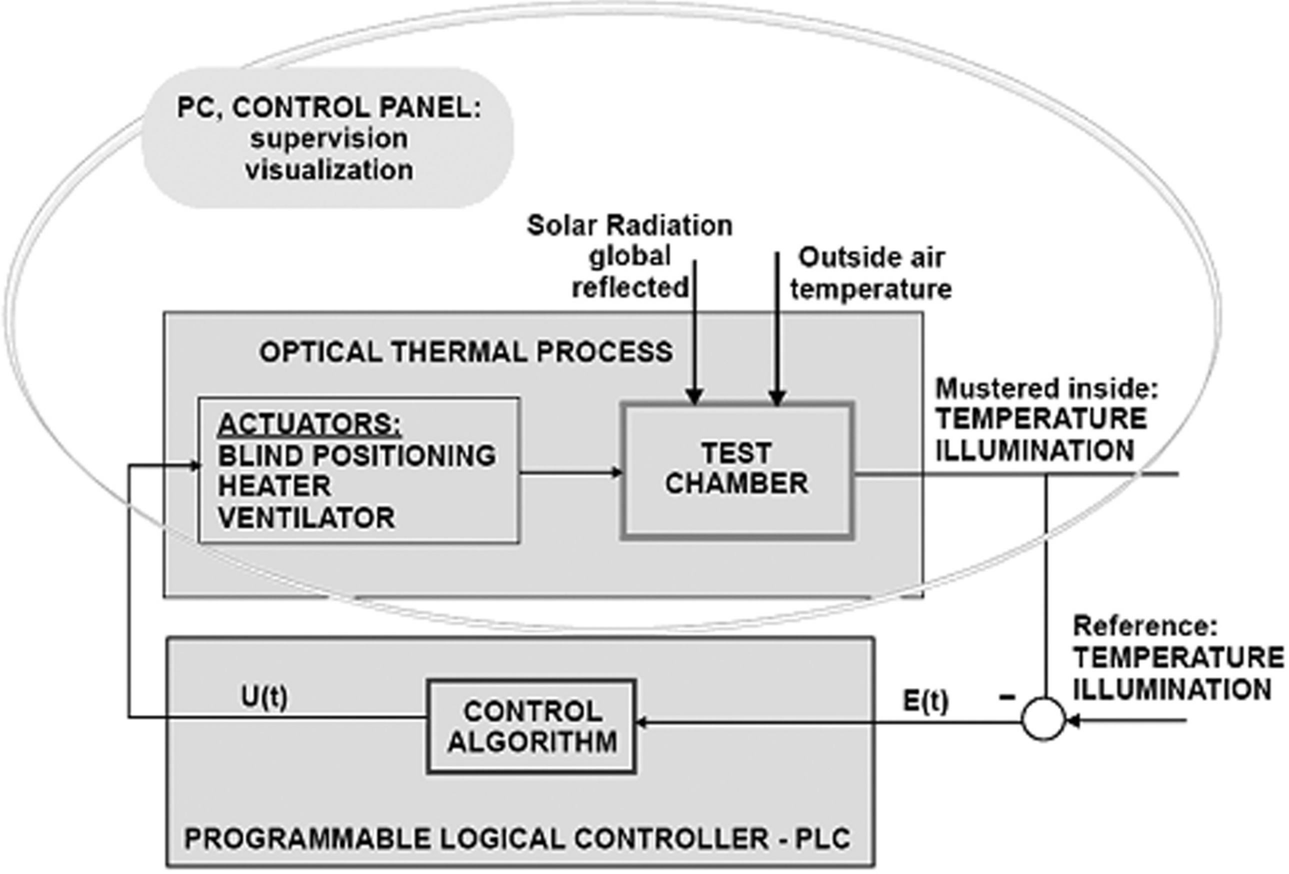

Figure 1. Basic framework of the control system for the test cell.

2.1 Thermal control loop

The thermal control loop applied in the test chamber is the result of modelling and simulation approach. It derives from the thermal theoretical mathematical model (Furlan et al., 1999, Škrjanc et al., 2001) established in the MATLAB SIMULINK environment. Later the control loop settings were fine-tuned through the experimental work on the test chamber.

It has already been mentioned that the thermal loop is split into two fuzzy controllers dedicated to guide the position of the roller blind during summer and winter. During spring both controllers are switched on and act simultaneously. The controllers are structured to closely follow the internal set point temperature parameters in correlation to the outside weather conditions. Each fuzzy controller contributes its part to the final decision on the positioning of the blind. The contributed part of the controller is determined on the basis of the difference between the internal and external air temperatures and the amount of exerted influence is derived by the evaluation function. Thermal loop also regulates the actions of additional actuators (heater and ventilator) installed in the test chamber. If these are enabled, they can be used to help regulate internal temperature, nonetheless the position of the roller blind is always the priority action.

2.2 Illumination control loop

If the internal environment in the test cell was regulated solely with the thermal loop, the illuminance loop had no effect on the regulation process. On the other hand, if both loops were harmonized to function together as a coupled controller, the priority in guiding the roller blind was given to the illuminance loop because humans are more susceptible to changes in illuminance than in temperature levels. Also the expected illumination oscillations were in the range of 1000-5000 lx and the dynamics of changes is far grater than in temperatures. All of the above reasons make illuminance a much harder quantity to regulate than temperature. When the desired levels of internal illumination are achieved, the thermal loop takes over and directs the roller blind to follow the thermal set-point profile as closely as possible within the admissible illumination set point tolerance. Because of a highly nonlinear process the illuminance control loop was not designed by using a mathematical model as in the case of the thermal loop, but rather by expert knowledge and trial and error process.

3. EXPERIMENTS

The presented tests were carried out during spring time in several sets to cover a wide range of different weather conditions. Weather during mid-seasons is prone to rapid fluctuations in temperatures as well as in the levels of solar radiation. Because of this the key part in setting up the controller is the appropriate tuning between the summer and winter components of the thermal control loop. Which controller regulates the movements of the roller is determined on the basis of the difference between the internal and the external air temperatures. In case the external temperature is lower than the internal set-point temperature, only the winter fuzzy controller affects the positioning of the roller blind, while in the reversed case (external temperature being higher than the internal) both fuzzy controllers contribute to the positioning of the roller blind. The amount of influence exerted by each controller is derived by the evaluation function. Example of the fuzzy IF-THEN setting for the summertime regime is presented below:
$Output\_signl = (fuzzy\_roll\_summer/100_{*}\ T\_error_{*}\ 0.5) + (fuzzy\_roll\_winter/100_{*}\ (100–T\_error_{*}\ 0.5),$ where the *fuzzy_roll_summer (winter)* is the output signal of the adequate fuzzy controller. *T_error* is the temperature difference between the external and the internal set-point value (Kristl et al., 2007).
The experiments presented here were conducted only with the thermal loop governing the actions of the roller blind. This means that illuminance fuzzy loop was switched off at all times and so had no effect on the results of the experiments. The input variables to the thermal controller were global solar radiation and the temperature difference between the set-point temperature and the measured indoor temperature. The output of the controller was movements of the roller blind and switching on or off the ventilator and the heater. Simultaneous functioning of these two was not allowed at any time. In the diagrams a completely exposed window is represented by 100 %, which correlates to a completely retracted roller blind. On the other hand a fully shaded window is represented by 0 % (e.g. fully extended roller blind). Similar in the case of the heater and the ventilator their functioning is represented in the fraction of operational output (e.g. 0 %=off, 100 %=full output).

3.1 Early mid-season experiment

Typical situation in temperate climates during early spring are represented by relatively low outdoor temperatures and moderate solar radiation, so there is no need for cooling. The test cell, however, had a tendency to overheat at relatively low external temperatures, which was the result of its small volume, lack of thermal mass and insufficient thermal insulation. Because of the above mentioned test cell characteristics the experiments were conducted during early spring to check the possibility of preventing overheating only by shading.
Fig. 2 shows the experiment conducted during three days in early-spring. Because the expected solar radiation and temperatures were low, the only active actuator was the roller blind. The main objective of the experiment was to test the effect of shading on temperature in the test chamber. Additionally we also observed the ability of the controller to follow the set-point temperature profile. The indoor set-point temperature was in the range from 3 °C to 8 °C.
During the 1st day of the experiment low external temperatures (-1 °C) and low levels of solar radiation (100 W/m^2) caused large deviations from the temperature set-point profile. As a result the roller blind was open almost all the time as the controller tried to raise the internal temperature. Because of this there was no shading induced cooling effect observed during the first day. The weather conditions changed on the 2nd day and roller blind closed during times of high solar radiation, peaking at 600 W/m^2. A delay of internal temperature amplitude compared to external temperature is clearly visible from the diagram in Fig. 2. A substantial influence of shading device was observed on the 3rd day when the set-point temperatures in the test cell were set at 4 °C. Maximum internal temperatures were 2 K lower than the external ones. Major factor affecting the internal temperatures was effective moving of the roller blind.

3.2 Late mid-season experiment

The second presented experiment was carried out on three typical late-spring days in the beginning of May. All of the system actuators were active and the set-point temperatures were in the rage from 15 °C to 25 °C, depending on the time of day. The experiment was designed to test the ability of the fuzzy controller to follow the temperature set-point profile and at the same time to prevent the test cell from overheating. Cooling of the test cell was achieved by combining the movable shading and the ventilation induced by the ventilator imbedded in the wall of the cell. The thermal control algorithm regulated the functioning of the roller blind, heater and ventilator with the aid of PID/V controllers. In the control system the roller blind positioning had a priority.

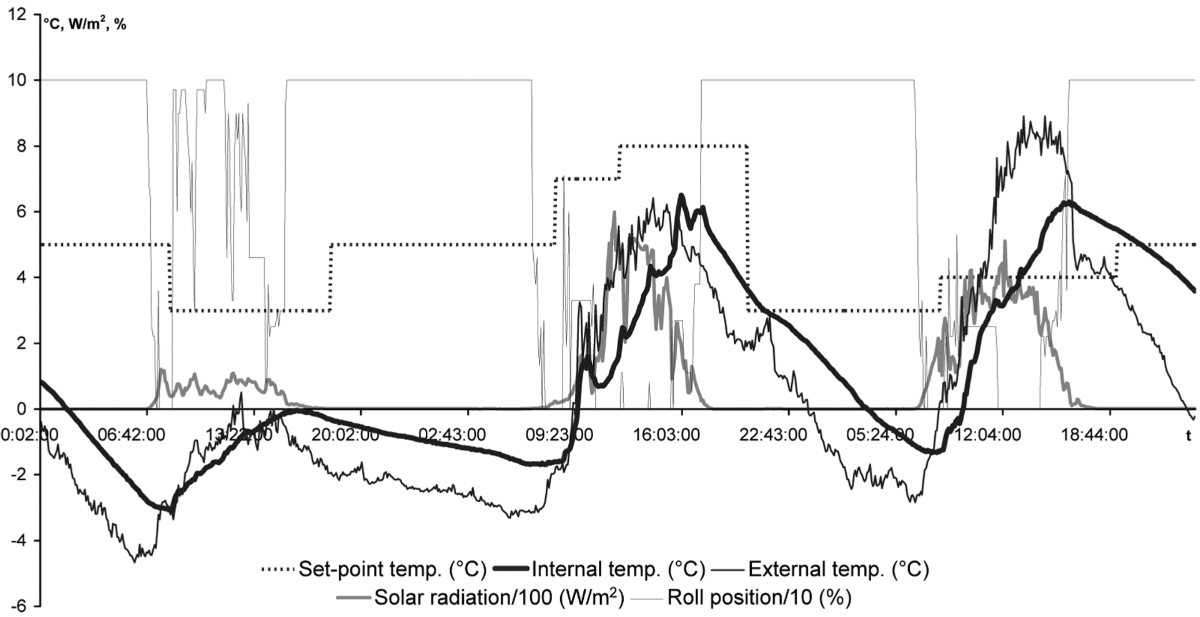

Figure 2. Test of the thermal loop conducted during 28th of February and 1st and 2nd of March. The system was influenced by the indoor set-point temperature, the global solar radiation and by the outdoor air temperature disturbances. The indoor air temperature profile exhibits the effect of cooling induced by shading the window from solar radiation – visible on the third day of the test when external temperatures peaked at around 9°C.

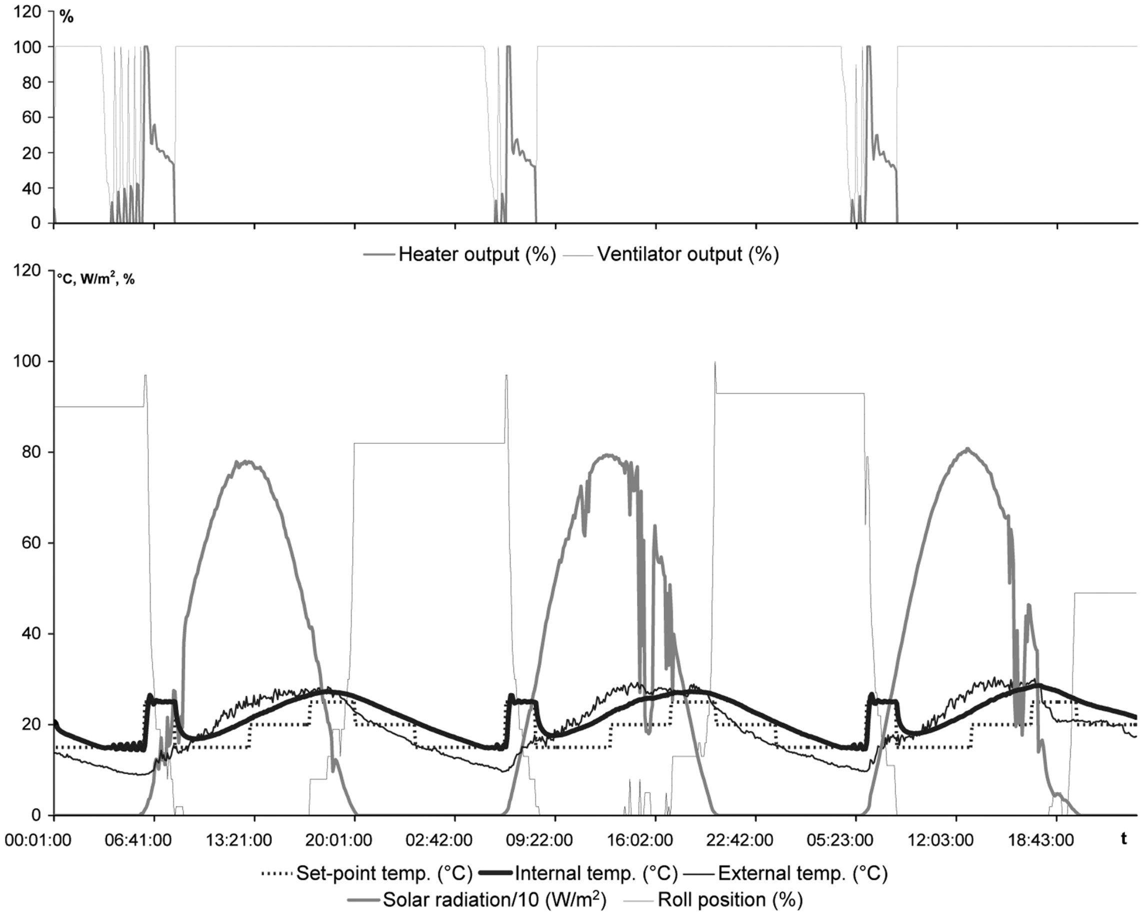

Figure 3. Test of the thermal loop conducted during 30th of April and 1st and 2nd of May. The system was influenced by the indoor set-point temperature, the global solar radiation and by the outdoor air temperature disturbances. All of the actuators were active (roller blind, ventilator and heater). The indoor air temperature profile exhibits consistent lower indoor temperatures during the day-time and higher during the night-time (which is a desirable effect in mid-seasons).

If after a limited time the desired indoor temperature was not achieved, the heater or the ventilator were activated. Weather conditions during the test were constant throughout the experiment. Solar radiation reached peak levels of 800 W/m^2 on all three days and the day-time temperatures were in the range from 13 °C in the morning to 30 °C in the early afternoon. Thermal fuzzy controller was able to cool the test cell during all three days as maximum internal temperatures at any given time did not exceed 27 °C which was 2 K above the set-point temperature. The experiment also showed that only shading would not be able to achieve satisfactory results as the ventilator had to be turned on almost throughout the day and most of the night (Fig. 3.). We can speculate that if a ventilator with a lager volume capacity was installed, even beater results could be achieved.

4. CONCLUSION

The test cell with the appropriate controller and measuring equipment was built with the aim to form a fuzzy logic control system, which would enable harmonious regulation of the thermal and illumination processes in the built environment. The response of the test chamber to the illuminance and thermal conditions was regulated by an external roller blind and additional heater and ventilator. The objective of the system was optimization of the use of the available environmental conditions: the outdoor air temperature and solar radiation. The fuzzy controller's algorithm was composed of two separate loops, one for the illuminance and the other for the thermal regulation. In experiments presented in this paper only the thermal loop was active as the focus of the tests was on the study of shading induced cooling during mid-seasons.

Experimentation with the test cell during the spring time confirmed the assumption that properly regulated automatic shading can have major influence on cooling as well as on other thermal aspects of the internal living environment. Because of human adaptation to temperatures manual regulation can not provide the same precision and efficiency. The tests showed that the fuzzy controller was able to consistently keep internal temperatures substantially lower in comparison to the external thermal conditions (Fig. 3). Additionally, the thermal regulator was also able to follow the internal set-point profile within the acceptable margin of error. Best results for cooling during mid-season were attained with the combined functioning of shading device and natural ventilation, which was able to cool the cell even when external temperatures reached 30 °C or more.

Substantial reduction of overheating was recorded if automated shading control was implemented, compared to the "dry run" when no shading was applied. Fuzzy controller was capable to keep internal temperatures in the acceptable range around the set-point profile. Additional improvement of the system functioning was achieved by the integration of regulated ventilation.

REFERENCES

Furlan, B. Krainer, A. Škrjanc, I. Zupančič, B. (1999): Mathematical modelling of dynamical response of the building with variable geometry of openings, Proceedings, ISES-Europe Solar Congress, Portorož, pp.II.2.9-1-II.2.9-8

Kladnik, R. Krainer, A. Perdan, R (1997): Light and thermal energy coordination in building, Proceedings, Vol. 1., PLEA 1997 KUSHIRO: the 14th International Conference on Passive and Law Energy Architecture, Tokyo, pp.59-64

Krainer, A. (1993): Building Science and Environment-Conscious, Design Module 1: Design Principles, 7 Toward Smart Buildings, European Commission TEMPUS Joint European Project JEP-1802

Kristl, Ž. Košir, M. Trobec-Lah, M. Krainer, A. (2007): Fuzzy control system for thermal and visual comfort in building. *Renewable energy* (20): pp.1-12.

Škrjanc, I. Zupančič, B. Furlan, B. Krainer, A. (2001): Theoretical and experimental fuzzy modeling of building thermal dynamic response. *Building and Environment* (36): pp.1023-1038.

Trobec-Lah, M. (2003): Harmonizacija toplotnih in svetlobnih tokov z uporabo mehke logike. Doctors thesis. Ljubljana: University of Ljubljana, Faculty of Civil and Geodetic Engineering.

Trobec-Lah, M. Zupančič, B. Krainer, A. (2005): Fuzzy control of illumination and temperature comfort in a test chaber. *Building and Environment* (40): pp.1626-1637