DEVELOPMENT OF A SMART SENSOR FOR CONTROLLING ARTIFICIAL LIGHTS AND VENETIAN BLINDS

Pantelis Foutrakis [1], Sotiris Papantoniou [2], Kostas Kalaitzakis [1], and Denia Kolokotsa [2]

1 Technical University of Crete
Department of Electronics and Computer Engineering
Chania, Greece

2 Technical University of Crete
Department of Environmental Engineering
Chania, Greece

ABSTRACT

Cooling loads in office buildings with large glazing facades are increase due to solar radiation penetrating the windows and over-heating the rooms. Moreover solar radiation provides natural lighting in the rooms, which might be higher than expected in the summer months and causes glare problems. In order to balance optimally between the reduction of cooling loads and natural lighting a controller can be applied to select the best combination between the position of blinds and whether the artificial lights will operate or not.
The developed controller, arduino based, is applied in an office building and is controlling the level of venetian blinds and their angle. The application is using as input an indoor and outdoor illuminance sensor, and an occupancy sensor. The controller is based on fuzzy rules and the fuzzification parameters are optimized offline using matlab's optimization algorithms.

KEYWORDS

Energy Saving, smart sensors, Control, Arduino, Matlab

1 INTRODUCTION

Energy efficiency in buildings is becoming a crucial issue nowadays as it contributes simultaneously to conventional fuels consumption reduction, energy costs cut for building owners and decrease in global warming gas release to the atmosphere. Buildings consume 40% of the energy used worldwide, and it is widely accepted that measures and changes in the buildings operation can achieve substantial savings. Moreover buildings are expected to meet very high standards in the near future. They should be created in a sustainable way, achieve zero-net energy equilibrium, be healthy, comfortable, responsive to the power grid, and economical to build and maintain (Kolokotsa et al. 2010).
In a typical office building, the energy-saving of lighting is an important problem because the lighting accounts for 40% of the total electric power consumption in the entire building. However, the lighting affects the amenity of an office space, and inappropriate energy-saving

of the lighting decreases the productivity of office workers. Therefore, a lighting control system for the office building must achieve the appropriate energy-saving based on careful and accurate control of light. In any case, energy efficiency must never compromise indoor comfort for building users. Lack or poor indoor comfort has a direct affect on users' productivity and an indirect effect to actual buildings' energy efficiency. Unreasonable users' reaction is proved to be disastrous for energy efficiency, i.e. heating greenhouse extensions to buildings, using internal blinds during the day to cut daylight and keeping electric lights on. Building energy management systems (BEMS) contribute to energy efficiency, maintaining indoor and visual comfort. Most BEMS applied in buildings store measured data for energy analysis, control and optimization of energy management, preserve indoor and visual comfort. Although the implementation of BEMS used to be cost effective only in new buildings due to extended wiring required for the communication demands, recent developments in the building automation and control sector by the introduction of various transmission media, helped considerably the feasibility of energy management in existing buildings. Moreover the requirement for a global interoperability in heterogeneous building automation environment consisting of different fieldbuses and data networks is recently a field of continuous research that is still far from being satisfied. Generally, interoperability is achieved when heterogeneous operating entities can communicate transparently and work together for a common scope. One major scope of BEMS is to satisfy the thermal and visual comfort, the air quality demands as well as reduce the energy consumption. Factors that influence the users' comfort are the indoor thermal comfort, the indoor visual comfort and the indoor air quality.

Artificial Intelligence (AI) has been applied to advanced building environmental controls such as thermal-, lighting-, and air-quality controls. With the substantial advantage of applicability in non-linear systems or systems with unclear dynamics, AI-based control methods incorporating Fuzzy Logic (FL), Adaptive Neuro-Fuzzy Inference System (ANFIS), and Artificial Neural Network (ANN) successfully have created more comfortable environments in buildings. In visual comfort, advanced logics using AI models are being investigated for optimal control of lighting conditions with improved energy efficiency.

In research, the field of modeling the behavior of occupants in a building and the field of developing smart controllers (especially for lighting and blinds) are evolving alongside each other. So on one hand, there is a large variety of control algorithms for blinds and lighting, on the other hand, multiple stochastic models have been developed to mimic the behavior of an occupant regarding the use of blinds, light, and ventilation. By combining stochastic models with control algorithms for lighting and blinds, higher simulation accuracy can be reached, and additionally, the saving potential of a controller can be better estimated. Controlling blinds and lighting not only changes the consumption of electric energy for lighting but also that of heating and cooling. Interior venetian blinds are widely used in office spaces to control solar heat gain and prevent visual discomfort. Their properties have significant impact on office daylight availability, and hence on energy demand for office lighting, heating and cooling. Recent studies on automated operation of shading devices have shown great potential for energy savings.

The scientific and the political communities have been aware for several years of the global warming problem. By consequence, a European target is the reduction of greenhouse gases by 20% until 2020 while allowing economic and demographic growths. This can be reached only if the energy consumption is optimized. According to, in 2007 the services and households sectors use 40% of the total final European (EU-27) energy. Within the buildings, the heating systems consume more than 50% which means about 23% of total energy consumption. Even if the trends are to construct new energy-efficient buildings, an overall energy consumption reduction cannot be achieved without an optimization in the existing buildings. As renovations and isolations have high costs and are time demanding, in this context, an advanced control system is the optimal solution. The challenges of indoor lighting system control are to find a compromise between the user visual comfort and the energy consumption.

2 EXISTING LIGHTING AND BLIND CONTROL MODELS

Blind controllers have either been time dependent or have been based on a threshold value, for example, solar radiation. Over the years, more input variables have been added and the outcome was no longer linearly dependent on input variables. In recent years, automatic adaptation to the occupant and acceptance by the occupant has attracted the attention of researchers and developers in this field. In the early approaches, blinds were adjusted based on one input variable, for example, (Inoue et al. 1988) or (Leslie et al. 2005). In (Newsham et al. 1994) model, the blinds were lowered if the intensity of the sunlight, which fell on the occupants, exceeded 233W/m2. With this rather simple rule, it was already possible to lower the mean PPD (predicted percentage of occupants dissatisfied with the thermal environment) from 22% to 13%. More sophisticated controllers include more than one variable and are closed-loop algorithms. (Trobec Lah et al. 2006) built a fuzzy logic system for managing a roller blind with respect to lighting levels inside the building. The inputs for the system are internal illuminance, global and reflected solar radiation, as well as the current position of the roller blind. The system was applied to a test chamber where it showed a solid performance in controlling the inside illuminance in correlation with the available solar radiation. Thermal comfort is not controlled by the system.

Another improvement is the adaptation of the system according to the needs of the occupants. In (Guillemin and Morel 2002), an integrated self-adaptive controller for heating, shading, and lighting is proposed. The inputs for the controller are current time, indoor and outdoor temperature, solar radiation, presence or absence of occupants in the room, and, additionally, set points (concerning lighting and temperature) expressed by the user. The controller consists of two artificial neural networks (ANN) for the prediction of room temperature and weather, a fuzzy logic for controlling heat and a fuzzy logic for controlling artificial lighting and blinds, which also controls the blinds. To continuously optimize the system, each night, a self-adaption process, using Genetic Algorithms, looks for the most efficient set of parameters for the controllers.

The process and controller are described in separate papers ((Guillemin and Morel 2001), (Guillemin and Molteni 2002)). (Kolokotsa et al. 2006) presents a fuzzy logic controller for indoor thermal and visual comfort and air quality based on the EIB (European Installation Bus) and Matlab. The system was tested and implemented in an experimental chamber (size: 1 m x 1 m x 2 m) equipped with sensors for outdoor and indoor temperature, humidity, illuminance, airflow, and CO2 concentration. The fuzzy controller is fed the following parameters: Predicted Mean Vote (PMV), outdoor temperature, heating or cooling requirements, window opening, indoor illuminance, level of electric lighting, and shading. This produces the following outputs: artificial lighting level and shading position. The system was tested for a period of 3 days, which is short, and showed a good performance in terms of keeping the target values (temperature, PMV index, and illuminance) in the defined range. There is no information given about energy savings resulting from the system. In most publications, it has been shown that the proposed controllers in terms of energy consumption are superior to an on-off controlled counterpart ((Kolokotsa et al. 2001), (Kolokotsa 2003), (Galasiu, Atif, and MacDonald 2004)). Thus, it would generally seem that blind controller development has maintained the focus on providing a comfortable environment and saving energy. However, the adaptation to, and the acceptance of, the occupant is increasingly the centre of interest. Another trend is that more input variables are used for the controller. This

may not be a problem in a laboratory setting but in the real world the additional sensors often make the controller expensive, complicated to install and hence unattractive for users.
(Kurian et al. 2008) developed a combined system for controlling blinds and lighting. This system consists of three fuzzy logic controllers: glare, visual comfort, and energy effectiveness (user absent). For controlling blinds and artificial light, an adaptive neuro-fuzzy inference system (ANFIS) (Kurian et al. 2005) was implemented. The controller was compared with a base case, a simple on/off scheme that yielded energy reductions between 5% and 60%. Lighting controls should not only optimize the energy consumption but also aim to provide comfortable lighting to produce a good working environment. Additionally, it needs to be shown that daylight may have a positive influence on the body and can raise worker productivity, which is very important for office buildings (Berson, Dunn, and Takao 2002). An overview of current research regarding the affect of daylight on people is given in (Galasiu and Veitch 2006).
Although it is rather clear that lighting control systems have a positive impact on energy consumption when maintaining a high level of lighting, comparing the level of savings is rather difficult. This is due to the different profiles of setups as well the requirements of occupants.

3 DEVELOPMENT OF CONTROL MODEL

3.1 Development of fuzzy code

If we analyze a fuzzy controller, we notice that there are a couple of basic elements that describe its function, or its input-output relation. Creation of zero-order Takagi-Sugeno fuzzy system implies the defining of input and output, their respective domains, input membership function, values of output constants and a rule base.

In order to control both blinds and lights in an office using Takagi-Sugeno fuzzy system two models were created with 2 inputs and 1 output, one for blinds and the other for lights.

For inputs the illuminance sensors are used. The indoor sensor value minus a constant of 500 lux is called error and the outdoor sensor value in lux is the second input called outside. We used trapezoidal continuous membership functions for the inputs of the system and they have 4 parameters. The range for error is [-500 2000] and for outside is [0 1000]. The parameters of membership functions are stored as a matrix in a memory card in two separate files one for each input.

Output membership functions of the zero order Takagi-Sugeno system are constants and are stored in a file in memory card as a column-vector.

Rule base is one of the basic elements of the fuzzy system. One rule can be represented by four elements. This way for a system with n rules, a matrix with nx4 dimension is formed.
Rules applied in this fuzzy system have the following form:

If error is A1 and outside is B1 then Y1
If error is A2 and outside is B1 then Y2
If error is A3 and outside is B1 then Y3

For a system with two inputs and one output, this is a general format of rules. So, membership functions linked with both inputs, operator which links the inputs in premises (AND or OR), value of output in the consequence, which is also called a membership function although in zero-order Takagi-Sugeno system it is a constant, are important. In order to create a numerical representation of the rules, each function is marked with a number, for instance the value of its index. That way, three elements of a row-vector for this rule are specified. It remains to find a number to represent the AND or OR operation. That can be solved by marking AND with 1 and OR with 2. Membership function of the first input is the first element in the row, the second is the membership function of the second input, the third is a membership function of the output, and the fourth is the value defining AND or OR operation. So the first rule can be presented with the following vector [1 1 1 1], the second is [2 1 2 1] and the third is [3 1 3 1].

This way there are two files in memory card for the rule base, one for blinds and another for lights.

The rule base for lights and shades are shown in the following figures:

1. If (error is ZERO) then (lights is stable) (1)
2. If (error is NE) and (outside is low) then (lights is up) (1)
3. If (error is NE) and (outside is normal) then (lights is up) (1)
4. If (error is NE) and (outside is high) then (lights is lup) (1)
5. If (error is SNE) and (outside is low) then (lights is lup) (1)
6. If (error is SNE) and (outside is normal) then (lights is stable) (1)
7. If (error is SNE) and (outside is high) then (lights is ldown) (1)
8. If (error is SPE) and (outside is low) then (lights is ldown) (1)
9. If (error is SPE) and (outside is normal) then (lights is ldown) (1)
10. If (error is SPE) and (outside is high) then (lights is ldown) (1)
11. If (error is PE) and (outside is low) then (lights is down) (1)
12. If (error is PE) and (outside is normal) then (lights is down) (1)
13. If (error is PE) and (outside is high) then (lights is down) (1)

Figure 1: Rules for the fuzzy controller of the artificial lights

1. If (error is ZERO) then (shades is stable) (1)
2. If (error is NE) and (outside is low) then (shades is stable) (1)
3. If (error is NE) and (outside is normal) then (shades is up) (1)
4. If (error is NE) and (outside is high) then (shades is up) (1)
5. If (error is SNE) and (outside is low) then (shades is stable) (1)
6. If (error is SNE) and (outside is normal) then (shades is lup) (1)
7. If (error is SNE) and (outside is high) then (shades is lup) (1)
8. If (error is SPE) and (outside is low) then (shades is stable) (1)
9. If (error is SPE) and (outside is normal) then (shades is stable) (1)
10. If (error is SPE) and (outside is high) then (shades is ldown) (1)
11. If (error is PE) and (outside is low) then (shades is stable) (1)
12. If (error is PE) and (outside is normal) then (shades is down) (1)
13. If (error is PE) and (outside is high) then (shades is down) (1)

Figure 2: Rules for the fuzzy controller of the shades

The membership functions for inputs and outputs can be seen in Table 1 and Table 2:

Table 1: Architecture of the fuzzy controller for lights

Type of fuzzy controller	'Sugeno'
N. of inputs	2: error between current and desired light level, outside light level
N. of outputs	1: change in the artificial lights state

Fuzzification parameters error('trapmf')	'NE':	[-1000 -550 -400 -300]
	'ZERO':	[-200 -100 100 250]
	'PE':	[400 550 2200 2500]
	'SNE':	[-400 -300 -200 -100]
	'SPE':	[100 250 400 550]
Fuzzification parameters outside('trapmf')	'low':	[-450 0 250 450]
	'normal':	[250 450 550 950]
	'high':	[550 950 1050 1450]
De-fuzzification parameters (constant)	'down':	[-100]
	'ldown':	[-50]
	'stable':	[0]
	'lup':	[50]
	'up':	[100]

Table 2: Architecture of the fuzzy controller for shades

Type of fuzzy controller	'Sugeno'	
N. of inputs	2: error between current and desired light level, outside light level	
N. of outputs	1: change in the venetian blinds level	
Fuzzification parameters error('trapmf')	'NE':	[-1000 -550 -400 -300]
	'ZERO':	[-200 -100 100 250]
	'PE':	[400 550 2200 2500]
	'SNE':	[-400 -300 -200 -100]
	'SPE':	[100 250 400 550]
Fuzzification parameters outside('trapmf')	'low':	[-450 0 250 450]
	'normal':	[250 450 550 950]
	'high':	[550 950 1050 1450]
De-fuzzification parameters (constant)	'down':	[-100]
	'ldown':	[-50]
	'stable':	[0]
	'lup':	[50]
	'up':	[100]

The structure of the fuzzy controller for shades and lights can be seen in Figure 3:

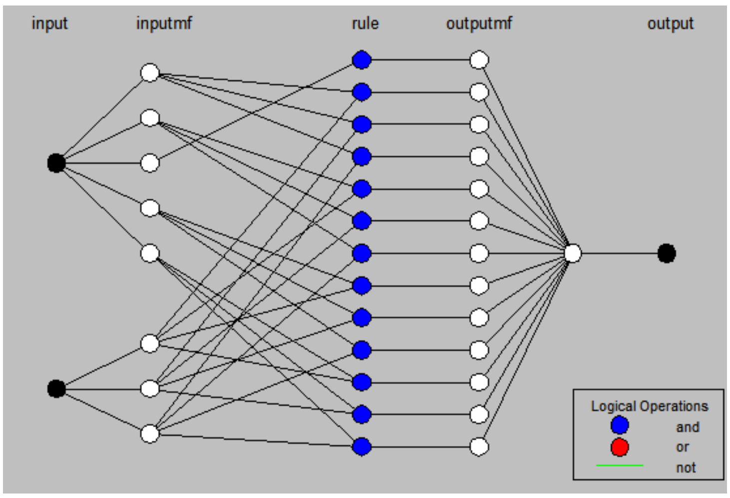

Figure 3: Structure for shades and art. lights

3.2 Sensor arrangement in building

The arduino is placed on the ceiling in the office. The PIR sensor (presence sensor), the inside illuminance sensor, the memory card module (for storing files and writing sensor values, fuzzy outputs and arduino outputs in a txt file) and the xbee module (for wireless communications) are placed on a detachable shield properly designed to attach on arduino and for use with this system. The outdoors illuminance sensor is placed outside the office window and is connected with cable to our arduino system. The system can be both battery and mains powered.

3.3 Zigbee protocol for wireless communications

The system uses xbee modules to communicate with computer through zigbee protocol. It sends the outputs, sensor values, current position of blinds and lights state to computer that monitors the system or to an arduino equipped with an LCD screen in the office room. Also the system can be programmed through zigbee from distance, send and receive files from and to memory card. The personnel of the office can bypass with zigbee the system for using their own parameters of the lighting and blinds state to match their needs.

4 RESULTS

In this chapter the results of the developed controller can be seen. At first in Figure 4, the inputs and outputs of the two developed fuzzy controllers can be seen. The hardware connection of the sensors with the arduino micro-controller can be seen in Figure 5.

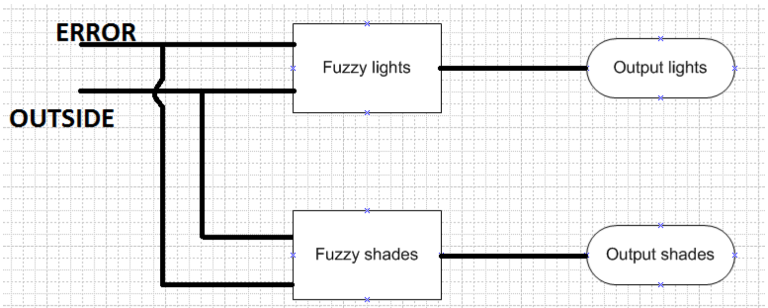

Figure 4: Fuzzy model for our system

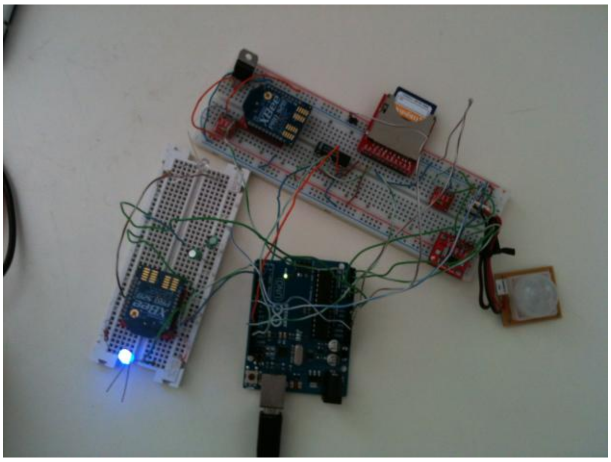

Figure 5: The developed system applied in a breadboard

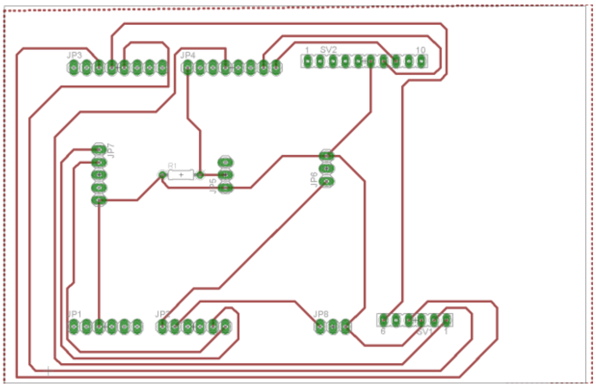

Figure 6: Designed Shield for the necessary sensors

The change in the light level due to outdoor illuminance and difference between the current and desired illuminance can be seen in Figure 8, while the change in the shades position using the same inputs can be seen in Figure 7.

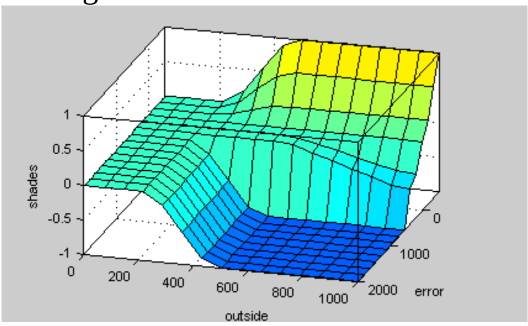

Figure 7: Structure from MATLAB for shades

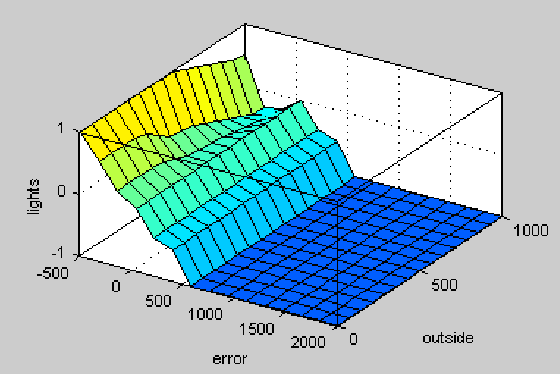

Figure 8: Structure from MATLAB for lights

5 CONCLUSIONS

This smart controller effectively uses fuzzy logic to properly control lights and venetian blinds in an office space with little power needed. It communicates with computer systems to become more accurate and flexible. It stores fuzzy rules and membership functions in memory card and this way is easily accessible to users.

6 SUGGESTIONS

Using arduino and sensors in an office control system is easy-adaptable and very flexible. More sensors can be added and with proper arduino coding, more functions can be performed with little effort. We can add to this system a CO2 sensor, a humidity sensor, a temperature sensor to entirely control an office room with one exclusive system and provide a complete controlled working environment with little to none human interference and save space because this system is very small and can pass unnoticed.

7 ACKNOWLEDGEMENTS

This work is partly funded by the EU Commission, within the research contract GREEN@Hospital (Contract Nr. 297290) a three year European Project co-funded by the ICT Policy Support Programme as part of the Competitiveness and Innovation framework Programme (CIP).

8 REFERENCES

Berson, David M., Felice A. Dunn, and Motoharu Takao. 2002. "Phototransduction by retinal ganglion cells that set the circadian clock." *Science* 295:1070–73.

Galasiu, Anca D., Morad R. Atif, and Robert A. MacDonald. 2004. "Impact of window blinds on daylight-linked dimming and automatic on/off lighting controls." *Solar Energy* 76:523–44.

Galasiu, Anca D., and Jennifer A. Veitch. 2006. "Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review." *Energy and Buildings* 38:728–42.

Guillemin, A., and S. Molteni. 2002. "An energy-efficient controller for shading devices self-adapting to the user wishes." *Building and Environment* 37:1091–97.

Guillemin, A., and N. Morel. 2001. “An innovative lighting controller integrated in a self-adaptive building control system.” *Energy and Buildings* 33:477–87.

Guillemin, A., and N. Morel. 2002. “Experimental results of a self-adaptive integrated control system in buildings: a pilot study.” *Solar Energy* 72:397–403.

Inoue, T., T. Kawase, T. Ibamoto, S. Takakusa, and Y. Matsuo. 1988. “The development of an optimal control system for window shading devices based on investigations in office buildings.” *ASHRAE Transactions* 94:1034–49.

Kolokotsa, D. 2003. “Comparison of the performance of fuzzy controllers for the management of the indoor environment.” *Building and Environment* 38:1439–50.

Kolokotsa, D., D. Rovas, E. Kosmatopoulos, and K. Kalaitzakis. 2010. “A roadmap towards intelligent net zero- and positive-energy buildings.” *Solar Energy* 85:3067–84.

Kolokotsa, D., G. Saridakis, A. Pouliezos, and G. S. Stavrakakis. 2006. “Design and installation of an advanced EIB™ fuzzy indoor comfort controller using Matlab.” *Energy and Buildings* 38:1084–92.

Kolokotsa, D., D. Tsiavos, G. S. Stavrakakis, K. Kalaitzakis, and E. Antonidakis. 2001. “Advanced fuzzy logic controllers design and evaluation for buildings’ occupants thermal-visual comfort and indoor air quality satisfaction.” *Energy and Buildings* 33:531–43.

Kurian, C., R. Aithal, J. Bhat, and V. George. 2008. “Robust control and optimisation of energy consumption in daylight--artificial light integrated schemes.” *Lighting Research and Technology* 40:7–24.

Kurian, Cp, S. Kuriachan, J. Bhat, and Rs Aithal. 2005. “An adaptive neuro-fuzzy model for the prediction and control of light in integrated lighting schemes.” *Lighting Research and Technology* 37:343–52.

Leslie, R. P., R. Raghavan, O. Howlett, and C. Eaton. 2005. “The potential of simplified concepts for daylight harvesting.” *Lighting Research and Technology* 37:21–40.

Trobec Lah, Mateja, Borut Zupančič, Jože Peternelj, and Aleš Krainer. 2006. “Daylight illuminance control with fuzzy logic.” *Solar Energy* 80:307–21.