A DEVELOPMENT OF A LIGHTING CONTROLLER USING SMART SENSORS

Sotiris Papantoniou[1], Denia Kolokotsa[1], Kostas Kalaitzakis[1], Davide Nardi Cesarini[2], Eduard Cubi[3] and Cristina Cristalli[2]

1 Technical University of Crete
Technical University of Crete Campus
Greece
**Corresponding author: spapantoniou@isc.tuc.gr*

2 Loccioni Group
Via Fiume 16
Ancona, Italy

3 Institut de Recerca en Energia de Catalunya
Jardins de les Dones de Negre 1, 2ª pl.
Barcelona, Spain

ABSTRACT

The aim of this paper is to present an advanced controller for artificial lights developed and tested using validated light models for several rooms in two European Hospitals located in Chania, Greece and Ancona, Italy respectively. Fuzzy techniques have been used for the architecture of the controller. The efficiency of the controllers has been tested using validated models of the RADIANCE back-wards ray tracing model. The input of the controller is the error between the current value of the photo sensor and the desired one, and the output is the change of the light level that should be applied (S.I.S.O). The controller has been tested on 2 different artificial light systems (On/ off switching, Dimming). Measurements and simulation indicate significant energy saving in both systems. Results are compared to the current use of the artificial lights by the users. All work has been contacted using Matlab's and RADIANCE's environment.

KEYWORDS

Fuzzy control, artificial lights, energy consumption, artificial lights dimming,

1 INTRODUCTION

Although classic passive energy saving techniques are trying to reduce energy losses from the fabric of the buildings, primary energy can also be saved from the reduction of the internal gains which affect the electricity spent and the cooling loads required to remove them. Among the most common internal gains available in most of the buildings, are those which come from artificial lights. Artificial lights in the office buildings consume significant amount of energy all around the world compared to the whole building's consumption as presented by Santamouris (Santamouris et al. 1994) and Lam (Lam et al. 2003) and increase the internal gains affecting the cooling loads of buildings as reported by Franzetti (Franzetti et al. 2004) According to Dr. Santamouris research artificial lights consume 10% of total energy consumption based on measurements in buildings of Greece. Most recent lighting systems are based on fluorescent lamps and only very recent ones allow dimming using electronic ballasts which replace the older magnetic ones. Before fluorescent lights, most buildings had incandescent lights which were very inefficient. Electronic ballasts can dim up and down the artificial lights linearly, adjusting the indoor light level to comfort levels while saving energy. Dimming of artificial lights can be combined with a recent daylight harvesting systems, which reduce furthermore the requirements for artificial lights according to Raphael (Raphael 2011). A smart controller is reading inputs from a light sensor and a presence indicator can adjust the light level automatically, maximizing the comfort level and the energy saving.

2 AVAILABLE CONTROL TECHNIQUES FOR ENERGY SAVINGS OF LIGHTING SYSTEMS

The issue of energy savings from the artificial lights, maximizing the benefits from natural daylight has been raised by many researchers for many years. Wen (Wen and Agogino 2010) estimated through a combination of measurements and simulations that a controller with a photo sensor connected to each light fixture can save up to 60% of energy or up to 23% if there is only one photo centre installed in the centre of the room. Kumaar (Nippun Kumaar et al. 2010) propose an intelligent lighting system which can save up to 40% of energy during daytime. Furthermore according to Frattari et. al. (Frattari et al. 2009) dimming of artificial lights perform much better comparing to manual on/ off or automatic on/off but the performance depends on the season of the year. According to his research dimming is performing better during the summer comparing to autumn.
Among these techniques fuzzy control techniques are also well-known for their efficiency in many controllable systems. Although fuzzy technology has been developed since 1965 their application is continuously increased due their main advantage which is the users' knowledge inserted in the form of rules. Another advantage of fuzzy control is their adaptability to actual measurements using the ANFIS (Adaptive Neuro Fuzzy Inference System) (Jang 1993) architecture, in which the fuzzification and de-fuzzification parameters are updated based on measurements. A light controller based on ANFIS is presented by Kurian et. al (Kurian et al. 2008; Kurian et al. 2006), where the controller is fuzzy based, but the parameters are adapted based on results from a model developed using RADIANCE software.

3 DEVELOPED FUZZY CONTROLLER ANALYSIS

The current fuzzy controller developed for the lighting systems is based on the 'Sugeno' Type fuzzy model. The specific architecture is selected because it can update the fuzzification parameters using measured data. (Papantoniou et al. 2012) The controller can be trained with the specific data using the ANFIS architecture, in order to adapt it to current conditions. The architecture of the system can be seen in Figure 1. The sensors which are used are an indoor light sensor and a presence indicator. When presence is detected the controller will estimate the change of the artificial lights level in order to meet the users' requirements. When users are not detected inside the room lights will be either switched off or dim further down in order to maximize energy saving.

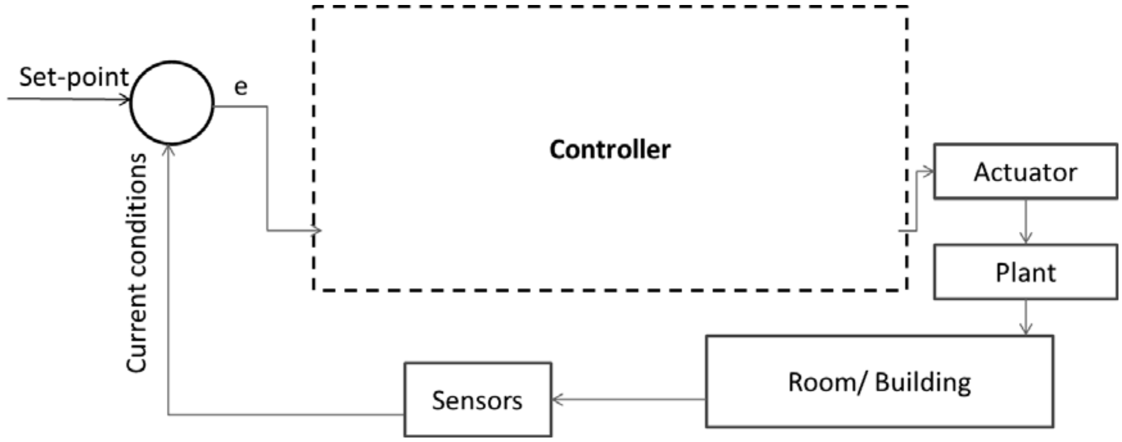

Figure 1: Architecture of the system

The controller is having as input the difference between current and desired light level (error) and as an output the new state of the artificial lights that should be applied. The architecture of the controller can be seen in Table 1.

Table 1: Architecture of the fuzzy controller

Type of fuzzy controller	'Sugeno'	
N. of inputs	1: error between current and desired light level	
N. of outputs	1: change in the artificial lights state	
Fuzzification membership functions	5	
Fuzzification parameters ('trapmf')	'NE':	[-1000 -200 -150 -50]
	'ZERO':	[-50 -25 25 50]
	'PO':	[150 200 2000 2800]
	'SNE':	[-150 -75 -25 0]
	'SPO':	[20 50 100 200]
De-fuzzification parameters (constant)	'NE':	[-1]
	'SNE':	[-0.3]
	'ZERO':	[0]
	'SPO':	[0.3]
	'PO':	[1]
User's knowledge	1, 5 (1): 1	4, 4 (1): 1
	2, 3 (1): 1	5, 2 (1): 1
	3, 1 (1): 1	
Further fuzzy parameters	AndMethod: 'prod'	OrMethod: 'probor'
	ImpMethod: 'prod'	AggMethod: 'sum'
	DefuzzMethod:'wtaver'	

3.1 Application of the controller in different lighting systems

The controller can be applied in artificial lighting systems with dimming systems or in on/off systems as long as more than 1 light fixture with different circuits are installed. In case of systems with dimming possibilities, the output of the controller should be confined to the limits of the dimming device (ex. 10% step of dimming, linear or not dimming etc.). In case of dimming systems the output of the controller has to be filtered in order to meet the requirements of the dimming system.

In case of using on/ off with different light fixtures systems, a different approach is required in which lights are switched on or off properly. For the on/ off systems the system is initially switching on the light fixtures closer to the entrance of the room, and if the light level is not sufficient the light fixture close to the window is activated as well. Thus, daylight level is used as much as possible, since the daylight factor's value is higher close to the window comparing its value close to the entrance of the room. (Li et al. 2006)

4 APPLICATION OF THE FUZZY CONTROLLER IN HOSPITALS' WARDS

In the framework of the European Project: "Green@Hospital", measurements concerning lighting and thermal conditions is performed using smart sensors. Preliminary analysis of lighting measurements indicates that energy savings are possible if a smart lighting controller is developed and applied. A numerical estimation of the energy savings per year is presented in Table 2 and Table 3.

Table 2: Energy saving potential in artificial lights, Hospital of Ancona

Ward	Room Id	Room	Savings due to		Combined savings
			Presence detection	Dimming	
Hematology	1	Warehouse	55%	16%	62%
	2	Nurse office	34%	16%	44%
	3	Doctors office	35%	53%	70%
Oncology	4	Visitors waiting room	39%		39%
	5	Nurse office	7%	50%	54%
	6	Archives (2 rooms)	NA		
	7	Ambulatory	18%	21%	35%
	8	Patients waiting room	36%	35%	58%
	9	Day hospital room	NA		

Table 3: Energy saving potential in artificial lights, Hospital of Chania

Ward	Room Id	Room	Savings due to		Combined savings
			Presence detection	Set point	
Paediatric	1	Patients' room	65.7 %	25 %	72.60 %
	2	Doctors' room	82.17%	21.95%	88.39 %
	3	Doctors' rest room	99.65%	0.0%	99.65%

As it can be seen in Table 2 and Table 3, energy savings can be obtained by dimming down the artificial lights when the selected rooms are not occupied and dim the artificial when natural daylight is sufficient. Moreover, significant high levels of sunlight indicate possible over-heating condition during summer which could be reduced by using controllable internal or external movable shades. However, this use is not possible during the current project. For each room an annual emulation is conducted using RADIANCE Software (Ward and Shakespeare 1998) with the controller developed in the Matlab environment. The RADIANCE model is measuring the light level in a specific point selected in the room and it can also create photorealistic images to show visually the light distribution in the room. The process for developing the RADIANCE models can be seen in Figure 2. The control algorithm developed in Matlab apart from estimating the new light level is recording the selected light state in order to estimate the annual consumption and savings.

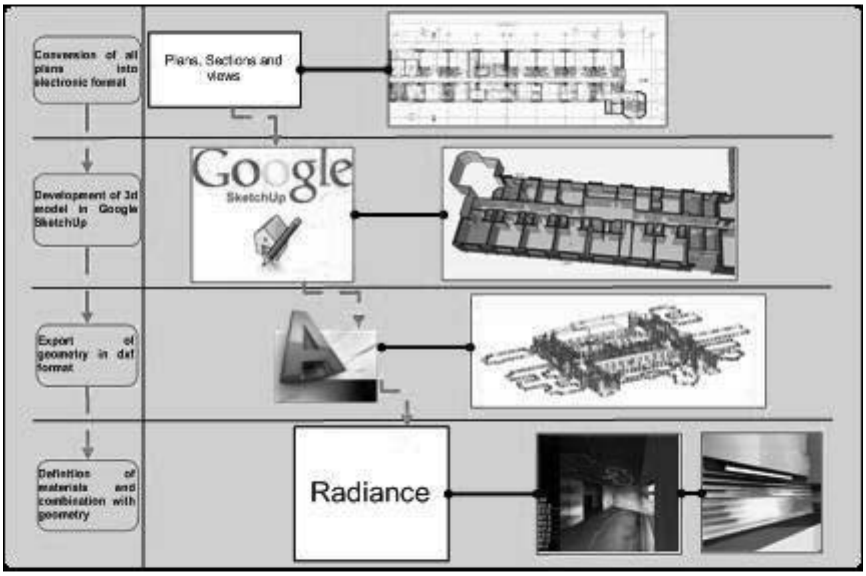

Figure 2: Schematic description of the development of the necessary geometry in RADIANCE

4.1 Application of the fuzzy controller in the Paediatric department of the Hospital of Chania

A 3D model of the hospital of Chania has been developed, enhancing the geometric details in the paediatric department as it can be seen in Figure 3 with the validation results for the Patients' room for 29th till the 31st of July 2013. The model has been validated with indoor measurements collected from the rooms and outdoor horizontal radiation measured from Technical University of Crete 7.5 km from the Hospital of Chania. The required plans and sections have been obtained by the personnel of the hospital of Chania and the technical characteristics of the light fixtures have been developed using Software Relux. (Relux Informatik AG 2012) The lighting system in the hospital is based on switching the lights on/ off.

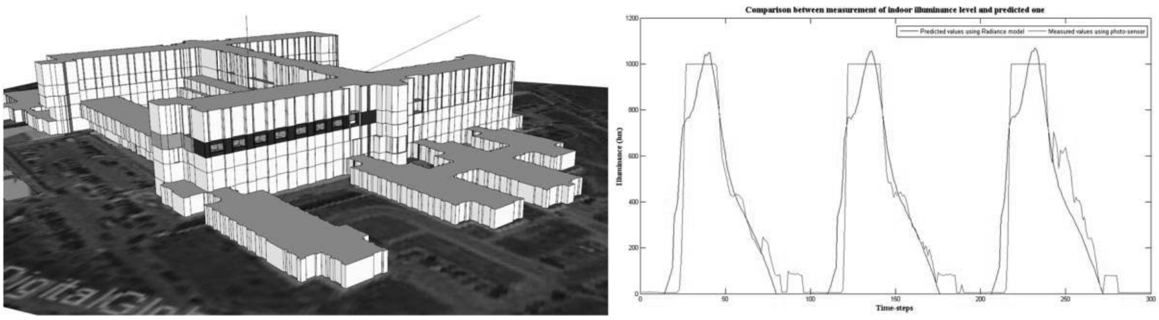

Figure 3: 3D model and validation results of the Hospital of Chania

In the 3 selected rooms where the controller will be implied 2 different light fixtures are installed. For each room, the controller selects which fixture will operate based on photo sensor and presence measurements in-situ. In Figure 4 the indoor light level can be seen under 3 different operations for 2 days.

At first the RADIANCE model is estimating light level based only on daylight (green line), with lights fully operating (red line) and with the developed fuzzy control (blue line). In the right side of Figure 4, the light level can be seen in all 3 different conditions. As it can be seen in the right part of Figure 4 the fuzzy system is switching off the second light fixture (closer to the window) saving energy while indoor light level is sufficient.

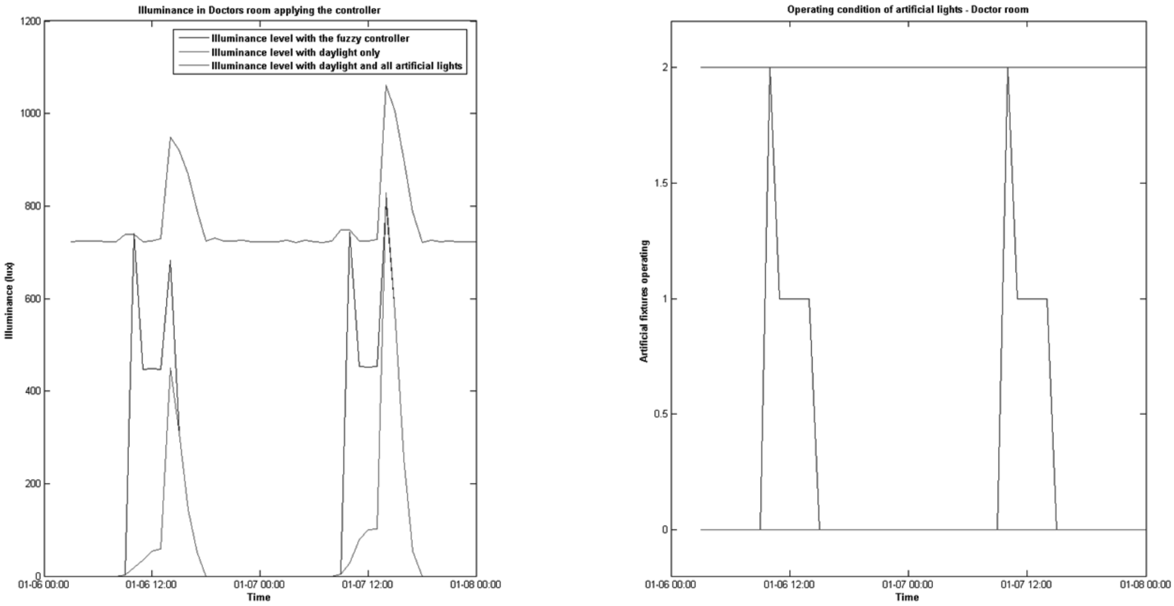

Figure 4: Indoor light level in the Doctors' room Hospital of Chania under different artificial lights conditions

Although an annual emulation has not been performed yet due to significant increased computational time (greater than a week for annual simulation), it can be seen from the results that energy can be saved during the course of the day where daylight is not sufficient but combined with partial usage of artificial lights, indoor light level can be sufficient.

4.2 Application of the fuzzy controller in the Oncology and Haematology department of the Hospital of Ancona

Similarly to the Hospital of Chania, 10 rooms have been selected in the Hospital of Ancona in order to save energy from artificial light control by dimming the artificial lights based on available daylight and presence indication. Measurements have been collect during the time period between November 2012 and January 2013, collecting 1 week data per selected room.
The developed 3D model in SketchUp can be seen in Figure 5. The required plans and sections have been obtained by the personnel of the hospital of Ancona and the technical characteristics of the light fixtures have been developed using Software Relux. (Relux Informatik AG 2012)

Figure 5: 3D model of the Ancona Hospital

In the Hospital of Ancona the artificial lights will dim based on the decisions of the fuzzy controller and presence indication. Outdoor horizontal radiation data are collected from

Loccioni Group head-quarters which are located only few kilometres from the hospital of Ancona. The application of the fuzzy controller for 2 selected day in the warehouse of the haematology department can be seen in seen in Figure 6 where the light level inside the room can be seen with the lights operating under the current system (green line), with the fuzzy controller (blue line) and only natural daylight (red line). On the right side of Figure 6 the lights operating conditions can be seen. From the dimming level of the artificial lights the energy consumption of the artificial lights can be estimated as a relation between the dimming level and the maximum consumption when lights are operating under maximum power.

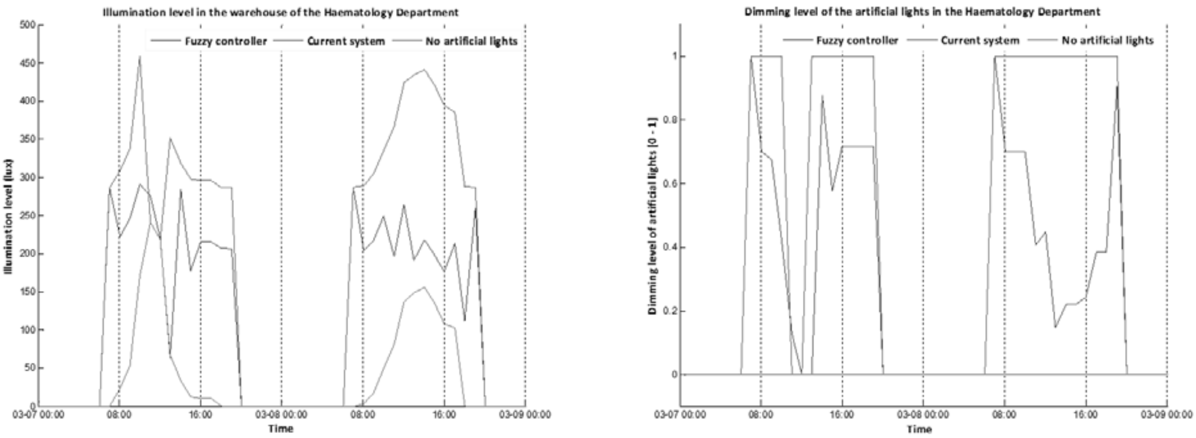

Figure 6: Indoor light level in the warehouse of the Ancona Hospital under different artificial lights conditions

As it can be seen in Figure 6, the controller is keeping the light level stable around the desired set point (200 lux) dimming the artificial lights from 0 to 1 with a step of 0.1, saving energy assuring the indoor level. Savings can be increased if the controller is applied more frequently (ex. 10 min).

An annual emulation has been performed combining the controller developed in Matlab and the RADIANCE developed model of the hospital of Chania. A representative presence schedule has been established for the selected rooms to provide the necessary inputs to the controller. The presence schedule and the necessary set points for the selected rooms are presented in Table 4.

Table 4: Provided parameters for the annual emulation

Selected rooms of AOR	**Time**	**Presence indication**	**Light set point**
Visitors waiting room (Room 7)	00:00 – 01:59 02:00 – 05:59 06:00 – 20:59 21:00 – 21:59 22:00 – 23:59	1 0 1 0 1	200 lux 50 lux 200 lux 50 lux 200 lux
Nurse office (Room 9)	00:00-06:59 07:00 – 18:59 19:00 – 23:59	0 1 0	0 lux 500 lux 0 lux
Doctors office (Room 10)	00:00-06:59 07:00 – 18:59 19:00 – 23:59	0 1 0	0 lux 500 lux 0 lux

Running the emulation the following energy savings are estimated based on the state of the artificial lights. The results from the emulation can be seen in Table 5.

Table 5: Estimated energy savings from the annual emulation

Selected rooms of AOR	Estimated energy savings
Visitors waiting room	36%
Nurse office	54%
Doctors office	45%

Comparing Table 2 and Table 5 it can be seen that the estimation of possible energy savings due to dimming are similar for the visitors' waiting room. For the other 2 rooms located in the Haematology department the emulation show that the savings are much higher comparing to initial estimation. This difference is reasonable if we assume that the initial estimations have been calculated using measurements collected during the winter. The rooms are self-shaded by hospital and thus daylight is much lower comparing to the summer.

5 CONCLUSIONS

In this paper the possibilities of primary energy savings from artificial lights operating in two hospitals of Europe have identified based on measurements. A fuzzy controller has been developed in Matlab environment and tested on validated RADIANCE models developed for the selected hospitals. The application of the controller in the RADIANCE model indicates that energy saving in the hospital of Chania and the 3 selected rooms of the hospital of Ancona can be achieved. Furthermore, running a full annual emulation combining the use of the controller and developed model in RADIANCE, energy saving based on dimming is estimated to be more than 35% in all selected rooms.

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