Combining the Daylight and Artificial Light Based on Fuzzy Logic

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Abstract. The paper present a strategy of artificial lighting control to respond the natural state of daylight based on fuzzy logic control. After building the fuzzy logic controller, the simulations using Matlab program in two scenarios are built. For each scenario, the output responses were surveyed with the whole range of daylight corresponding to each of input statement. The simulation results show that the output of the fuzzy controller is good responsive the equilibrium when the input illumination changes, while the 4 zones scenario have more sensitive result than the 3 zones scenario.

Keywords: intelligent lighting, daylight strategy, fuzzy logic.

1 Introduction

As economies and populations grow, so will energy needs, the overall energy demand in buildings is considered and optimized in order to minimize energy requirements. Although lighting system is a very small part of energy consumption in buildings, it plays an important role in making workplaces more comfortable. Thus the lighting system needed to be studied seriously. In addition to the technical solutions are currently being used such as high performance lights, taking advantage of the natural light should be considered because of the continuous and available properties during working hours.

A controller which meets the constantly changing of the natural light during the day is required to combine the daylight with artificial light. Due to the flexibility of the control system based on the knowledge base, the fuzzy controller is proposed to meet the changes of daylight which changing with time of day. In addition, because of nonlinear output function, the fuzzy controller is capable of reducing environmental noise such as cloud-shading effect.

2 Combining the Daylight and Artificial Light in Buildings

The daylight illumination diagram (Fig. 1) shows the intensity of solar radiation increases from morning to noon, and decreases from noon to night. We could use this

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chart to determine the potential time for daylight and artificial lighting in buildings. In particular, the Limit Outdoor Illumination (E_{LOI}) is illumination in which the indoor lighting must be provided, i.e. the limit illumination exceeds 85% [5] in working time from 9am to 5pm on all days of the year.

In Fig. 1, when choosing E_{LOI} = 5.000 lux corresponds to the period from 7am to 5pm, the condition is satisfied in:

- During 8 months in Northern.
- During 9 to 10 months in Central.
- Almost all year round in Southern.

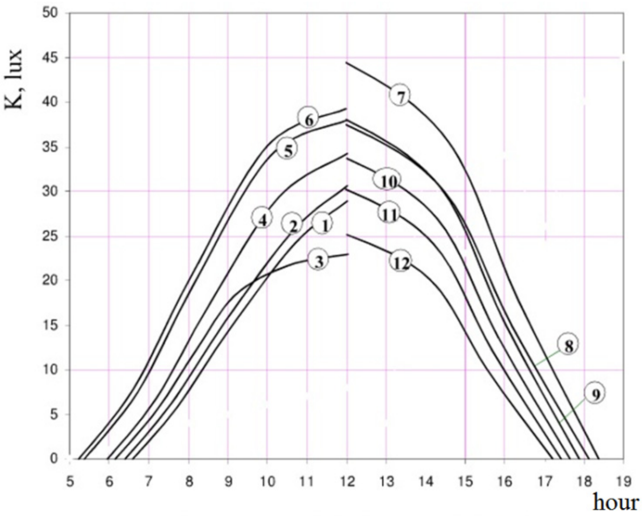


Fig. 1. Daylight illumination diagram on a horizontal surface in Hanoi [1]

When choosing E_{LOI} = 3.000 lux corresponds to the period from 7am to 5pm this condition is satisfied in:

- Almost all year round in the area from Quang Nam province to Southern.
- During 11 months in the area from Thanh Hoa province to Da Nang city (except Dec or Jan).
- During 10 months in the remaining local in Northern.

With daylight, the control system cannot adjust the intensity in the direction of increasing, it can only adjust the receiving point to decrease received light. Therefore, it’s very passive and ineffective if you only rely on the natural light. Combining the daylight and artificial light will complement each other and increase the initiative in controlling the lighting system, take it easy response the different activities in buildings at various times.

The combination of natural lighting and artificial lighting must ensure lighting performance index, illumination and luminance according to requirements and used function in buildings.

3 Optimal Control Zoning Strategy

The depth of the optimal lighting zone depends on the shape, the height and the physical properties of window materials, direction of the window or outdoor illumination. Natural illumination is very high, but it will decrease quickly and be unevenly distributed on the working plane from the window position when going through the window. The positions which are near the window will have a very high illumination, and the illumination of the positions which are away from the window will decrease rapidly. Natural light is only significant influence in the optimal lighting zones. Depending on the feature of the buildings such as shading or no shading, the depth of the optimal lighting zone will range from 1.5 to 2.5 times height of the window. For this reason, control zoning strategy in the room is very important.

Because the positions which are near the window are affected by the rapid and significant impact of the natural light while the positions which are away from the window hardly change, control strategy will be applied in each region are different. The border zones of the room match on – off control while the central regions are more in line with dimming control [4]. The result of paper is the simulations based on scenarios of three zones scenario and four zones scenario.

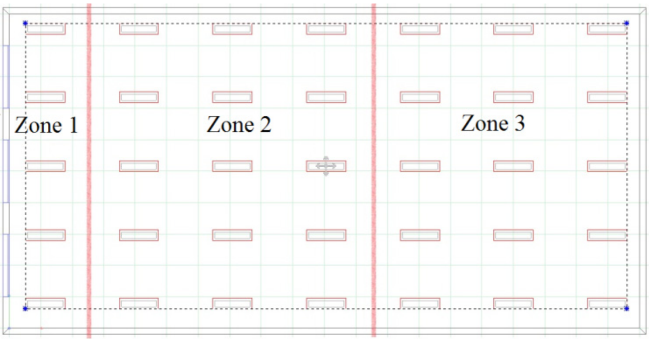


Fig. 2. The three zones scenario

The simulation performed on the model of "standard room", in which, the size of the room is chosen 10m x 20m to consider the depth of natural lighting to 20m. The room receives the light from one direction with windows located in zone 1. The artificial lighting system is designed based on DIAlux software with artificial light illumination (Eal) requires 500 lux and 35 fluorescent lamps 54W. Due to the depth of optimal lighting is about 1.5 to 2.5 times of the window height, zone 1 is selected is the first array near the window. The remaining zone is divided into 2 control zones to match with the strategy of on – off and dimming control [3].

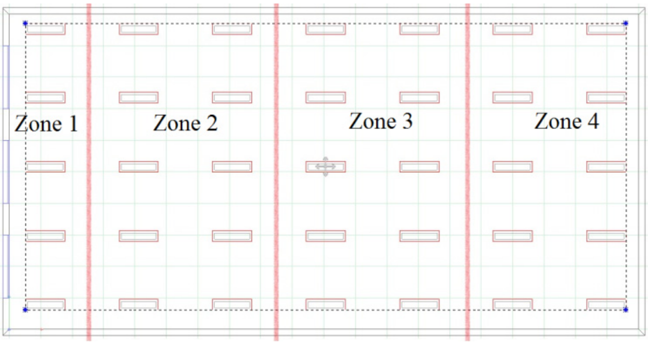


Fig. 3. The four zones scenario

The four zones scenario is built by dividing one more control zone to observe responses between zone 2 and 3. Splitting control zones allows the system response to meet closer to the influence of input [2].

4 Building Fuzzy Algorithm

4.1 The Model of Control Subject

System response is controlled by open – loop fuzzy controller. Controller input receive the signal from photo sensor which measure natural lighting illumination outside. After going through fuzzy controller, the signal is sent to dimmer which control lamps. After building control model, the knowledge base which is formed based on the results of specific states is solved by Matlab [2]. These results are the base to form the inference.

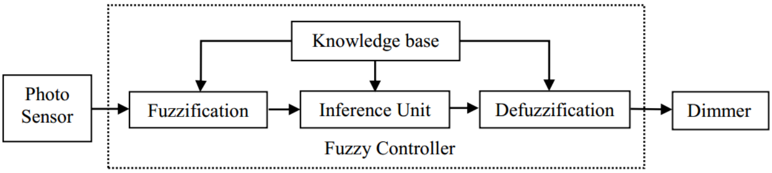


Fig. 4. Block diagram of fuzzy control system

Fuzzification and defuzzification are made by building input and output statements.

4.2 Input Statements

As daylight illumination diagram, natural lighting illumination is up to 40.000 lux in Viet Nam [1], ELOI is selected 5.000 lux according to Viet Nam Building Code (VNBC). In this way, input statements are presented in the Table 1.

Table 1. The Input/ Output Statements

Input Statements				Output Statements			
Statements	**Min**	**Values**	**Max**	**Statements**	**Min**	**Values**	**Max**
VL (very low)	0 (0)	5.000 (0.125)	5.000 (0.125)	VL (very low)	0.0	0.2	0.2
L (low)	5.000 (0.125)	13.000 (0.325)	20.000 (0.5)	L (low)	0.2	0.35	0.5
M (medium)	13.000 (0.325)	20.000 (0.5)	27.000 (0.675)	M (medium)	0.35	0.5	0.65
H (high)	20.000 (0.5)	27.000 (0.675)	34.000 (0.85)	H (high)	0.5	0.65	0.8
VH (very high)	34.000 (0.85)	34.000 (0.85)	40.000 (1)	VH (very high)	0.8	0.8	1.0

The lower statement (5.000 lux) and the upper statement (40.000 lux) are defined by Trapmf functions corresponding to VL and VH levels. The statements in the range of 5.000 lux and 40.000 lux are defined by Trimf function corresponding to L, M and H levels. Thus, the lighting system could be controlled by on – off controller when illumination is beyond control zone and by dimmer when illumination is located in control zone.

4.3 Output Statements

The output is divided into 5 state levels are: VL (very low), L (low), M (medium), H (high), and VH (very high). Output statements are identical for zone 1, zone 2 and zone 3.

The VL and VH statements are defined by Trapmf functions because the system will be turned off if control level is under 20% and be turned on if control level is over 80%. The lamp life will be improved since the system is not too sensitive to VL and VH levels. These values are selected as Table 1.

4.4 Building Rules

Building identification of membership functions for output Ui is to identify C1, C2, C3, C4, and C5. Fuzzy rules are made based on lighting scenarios which is built based on “knowledge base”. These scenarios are the basis for fuzzy logic infer based on the centroid method.

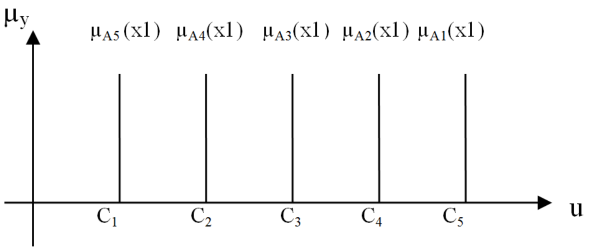


Fig. 5. The fuzzy coefficients

Defuzzifying by using centroid method:

$$u1 = \frac{c_5\mu_{A_1}(x_1) + c_4\mu_{A2}(x_1) + c_3\mu_{A_3}(x_1) + c_2\mu_{A_4}(x_1) + c_1\mu_{A_5}(x_1)}{\mu_{A_1}(x_1) + \mu_{A2}(x_1) + \mu_{A_3}(x_1) + \mu_{A_4}(x_1) + \mu_{A_5}(x_1)} \tag{1}$$

Given

$$\varphi 1 = \frac{\mu_{A_1}(x_1)}{\mu_{A_1}(x_1) + \mu_{A2}(x_1) + \mu_{A_3}(x_1) + \mu_{A_4}(x_1) + \mu_{A_5}(x_1)} \qquad \varphi 2 = \frac{\mu_{A_2}(x_1)}{\mu_{A_1}(x_1) + \mu_{A2}(x_1) + \mu_{A_3}(x_1) + \mu_{A_4}(x_1) + \mu_{A_5}(x_1)}$$

$$\varphi 3 = \frac{\mu_{A_3}(x_1)}{\mu_{A_1}(x_1) + \mu_{A2}(x_1) + \mu_{A_3}(x_1) + \mu_{A_4}(x_1) + \mu_{A_5}(x_1)} \qquad \varphi 4 = \frac{\mu_{A_4}(x_1)}{\mu_{A_1}(x_1) + \mu_{A2}(x_1) + \mu_{A_3}(x_1) + \mu_{A_4}(x_1) + \mu_{A_5}(x_1)}$$

$$\varphi 5 = \frac{\mu_{A_5}(x_1)}{\mu_{A_1}(x_1) + \mu_{A2}(x_1) + \mu_{A_3}(x_1) + \mu_{A_4}(x_1) + \mu_{A_5}(x_1)}$$

Thus

$$u1 = \begin{bmatrix} \varphi_1 & \varphi_2 & \varphi_3 & \varphi_4 & \varphi_5 \end{bmatrix} \begin{bmatrix} c_5 \\ c_4 \\ c_3 \\ c_2 \\ c_1 \end{bmatrix} = \varphi^T \theta \tag{2}$$

The formula of fuzzy sets which identify output U_i is:

$$\hat{\theta} = \left(\varphi^T \varphi\right)^{-1} \left(\varphi^T m1\right) \tag{3}$$

Rules in case of three control zones are:

If (X_1 is VL) then (U_1 is VH) (U_2 is VH) (U_3 is VH)
If (X_1 is L) then (U_1 is M) (U_2 is VH) (U_3 is VH)
If (X_1 is M) then (U_1 is M) (U_2 is H) (U_3 is VH)
If (X_1 is H) then (U_1 is VL) (U_2 is M) (U_3 is H)
If (X_1 is VH) then (U_1 is VL) (U_2 is L) (U_3 is M)

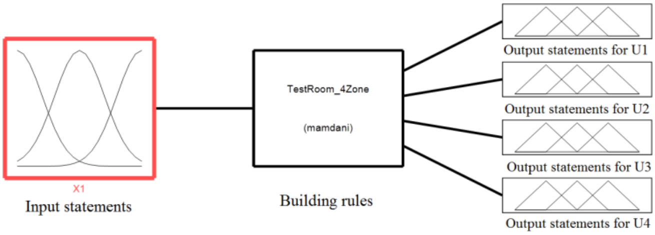


Fig. 6. Fuzzy controller in case of four zones scenarios

5 Simulation Results

5.1 Simulation Result in Case of Three Zones Scenario

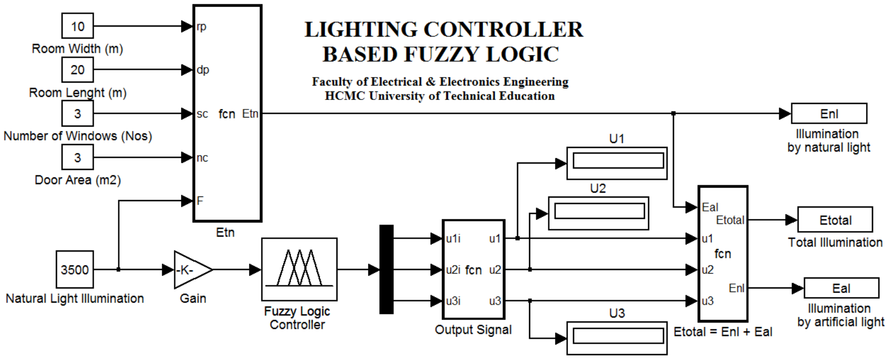


Fig. 7. Model in case of three zones scenario

Table 2. Output Results Of Lighting Controller Based On Fuzzy Logic

Case	U1	U2	U3
Case 1 (3.500 lux)	1	1	1
Case 2 (8.000 lux)	0.5	1	1
Case 3 (18.000 lux)	0.5	0.73	1
Case 4 (25.000 lux)	0.23	0.55	0.73
Case 5 (30.000 lux)	0	0.5	0.65
Case 6 (40.000 lux)	0	0.35	0.5

5.2 Simulation Result in Case of Four Zones Scenario

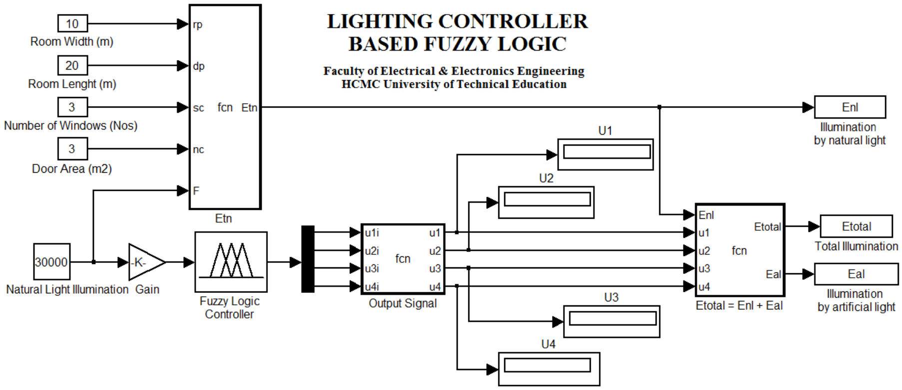


Fig. 8. Model in case of four zones scenario

Table 3. Output Results Of Lighting Controller Based On Fuzzy Logic

Case	**U1**	**U2**	**U3**	**U4**
Case 1 (3.500 lux)	1	1	1	1
Case 2 (8.000 lux)	0.5	0.65	1	1
Case 3 (18.000 lux)	0.5	0.65	0.73	1
Case 4 (25.000 lux)	0.5	0.65	0.65	1
Case 5 (30.000 lux)	0.5	0.5	0.5	0.5
Case 6 (40.000 lux)	0	0	0.35	0.43

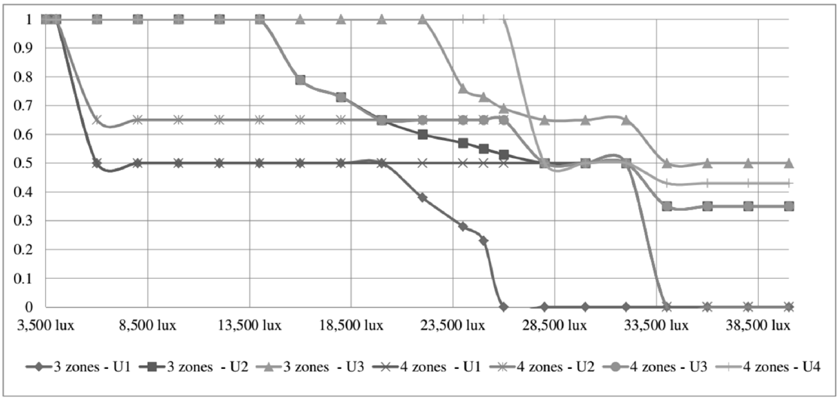
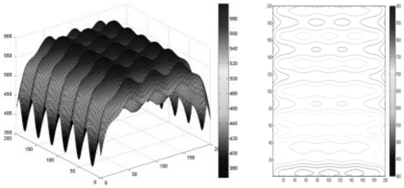
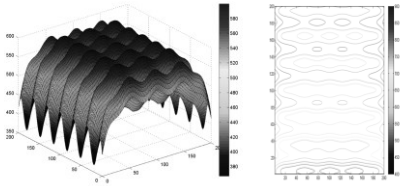
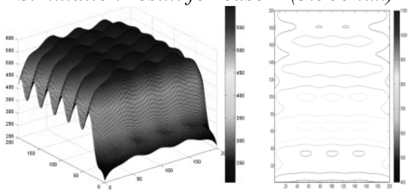
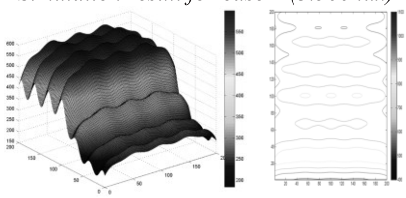
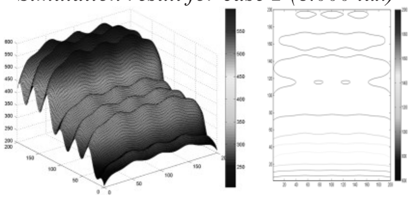
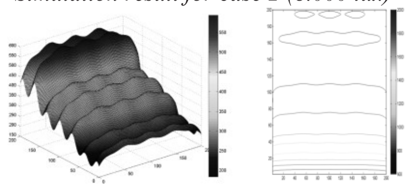
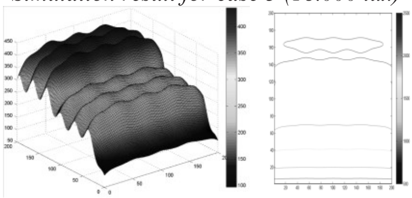
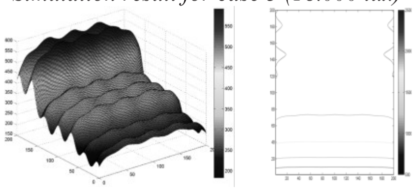
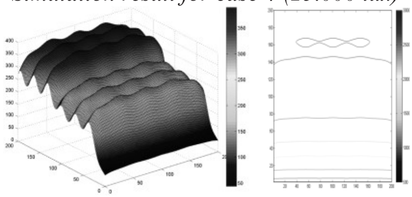
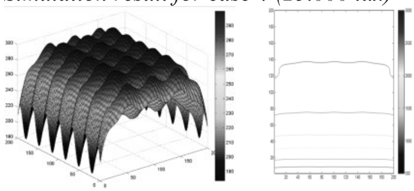
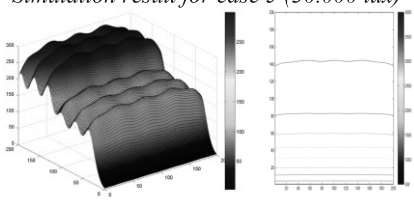
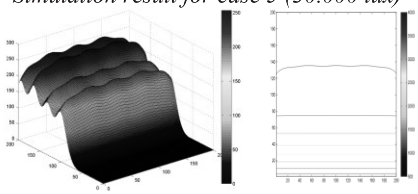


Fig. 9. System output response

The simulation results show that fuzzy controller indeed efficient in optimal lighting zone corresponding to dimming control. On other hand, on – off control is more suitable for zones which close to windows or away from windows.

Table 4. Results of artificial lighting system response and illumination plane

Three Zones Scenario	**Four Zones Scenario**
 *Simulation result for case 1 (3.500 lux)*	 *Simulation result for case 1 (3.500 lux)*
 *Simulation result for case 2 (8.000 lux)*	 *Simulation result for case 2 (8.000 lux)*
 *Simulation result for case 3 (18.000 lux)*	 *Simulation result for case 3 (18.000 lux)*
 *Simulation result for case 4 (25.000 lux)*	 *Simulation result for case 4 (25.000 lux)*
 *Simulation result for case 5 (30.000 lux)*	 *Simulation result for case 5 (30.000 lux)*
 *Simulation result for case 6 (40.000 lux)*	 *Simulation result for case 6 (40.000 lux)*

6 Conclusion

The simulation results of combining artificial lighting and natural lighting in cases show that illumination of artificial lighting system is significantly reduced in zones near window and optimal lighting zones.

The zoning method which is promoted based on the depth of natural lighting is suitable for most types of buildings that use natural lighting. Dividing lighting zones is to make artificial lighting control strategy be more suitable to natural lighting conditions.

System response is better by using fuzzy algorithm. Simulation results of combing artificial lighting and natural lighting show that this system is significantly save energy.

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