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Functions of fuzzy logic based controllers used in smart building

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ABSTRACT

The main aim of this study is to support design and development processes of advanced fuzzy-logic-based controller for smart buildings e.g., heating, ventilation and air conditioning, heating, ventilation and air conditioning (HVAC) and indoor lighting control systems. Moreover, the proposed methodology can be used to assess systems energy and environmental performances, also compare energy usages of fuzzy control systems with the performances of conventional on/off and proportional integral derivative controller (PID). The main objective and purpose of using fuzzy-logic-based model and control is to precisely control indoor thermal comfort e.g., temperature, humidity, air quality, air velocity, thermal comfort, and energy balance. Moreover, this article present and highlight mathematical models of indoor temperature and humidity transfer matrix, uncertainties of users' comfort preference set-points and a fuzzy algorithm.

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1. INTRODUCTION

The integration of real-time events with indoor air temperature, humidity, the level of carbon dioxide (CO_2) and indoor illuminance level are not a straightforward task using proportional integral derivative (PID) controllers. Thus, a multi-agent control system, are designed and reconfigured in this paper rather than using one multi controllers of each separate control signal. In addition, it is quite difficult to apply and design model free controller to real-time indoor environment control system based on surrounding real life event and real time thus modifying adaptability is included in this study in order to increase controller feasibility. Consequently, suitable mathematical models of controlled goals are essential throughout the design and testing phase, the proposed control strategies. Accordingly, this chapter discusses the mathematical models of the building's indoor atmosphere including the model of indoor temperature, humidity, the concentration of CO_2 level and the indoor illuminance level. The chapter also discusses the mathematical models of lighting and heating, ventilation and air conditioning (HVAC) system and systems' energy usage and savings. The recent control methods that extensively employed in indoor thermal comfort control mathematical models. The current research, a fuzzy-logic-based controller is designed and modelled in order to control indoor temperature, indoor humidity, indoor air quality and indoor illuminances by integrating real life events such as the usage of ambient air and natural light (day-lighting) into the existing artificial indoor environment while using minimum energy.

The mathematical models have been investigated heavily throughout literature such as [1] have modelled and experimentally investigate indoor thermal comfort. Also, same authors have highlighted indoor comfort parameters and its effect on indoor air quality [2]. Lately [2]–[6] have introduced necessary parameters in considering indoor thermal comfort in fuzzy logic controllers. However, the most of those research activities lack of accurate mathematical models. Accordingly, this article presents and highlight mathematical models of indoor temperature and humidity transfer matrix, uncertainties of users' comfort preference set-points and a fuzzy algorithm and the integration of daylight with existing artificial light.

2. INDOOR ENVIRONMENT MATHEMATICAL MODEL

Here, the controller's modelling representing indoor climate level containing building's inner space temperature, building's indoor humidity, building's indoor air quality (IAQ) and comfort index is presented. The proposed control system which is based on add on multi-agent fuzzy based control system into existing PID controller algorithms are detailed and presented in the following sub-sections.

2.1. Modelling of space indoor temperature

Inner spaces' temperature of a building is a very important factor in indoor environment monitoring. The models of in space air temperature is able to predict the daily change of indoor temperature with time. According to [7], the in-space temperature is influenced by the atmosphere temperatures in inside climatic conditions. The modelling process of inner air temperature is built using the regression analysis method by evaluating conduction, radiant and convection heat transfer. Accordingly, indoor temperature can be evaluated based on (1) taking into account energy conservation principle:

$$\rho_a . C_P . V_i \frac{dt}{d\tau} = Q_{h1} - U_w A_w (T_i - T_o) \tag{1}$$

where ρ_a is air density in (kg / m^3), C_p represents heat capacity of air in (J/kg·C°), Vi is room volume in (m^3), Ti is inner doors temperature in C°, τ is time in (s), Q_{h1} is HVAC work rate, To is outdoor temperature in C°, Aw (m^2) is the area of walls, Uw is overall heat transfer coefficient in (W/m^2 ·C°). Uw can be calculated using (2).

$$U_w = \frac{1}{\frac{1}{h_a} + \frac{dw}{kb} + \frac{1}{hB}} \tag{2}$$

Here K_b represents the walls heat conductivity, units is (W/m · k), d_w is walls thickness in (m), h_A and h_B are convection heat transfer coefficients on the side of each wall in (W/m^2 · k). Hence Laplace transform is used to transform (3) into (3) and then into (6) taking into account the convection heat transfer coefficient is constant [8].

$$T(s).S = \frac{1}{\rho_{a.} Cp.vi} Qh1(S) \tag{3}$$

$$T(s).S = \frac{1}{\rho_{a.} Cp.vi} Qh1(S) + \frac{UwAw}{\rho_{a.} Cp.vi} T_0(S) \tag{4}$$

$$\frac{UwAw}{\rho_{a.} Cp.vi} T_0(S) = 0 \tag{5}$$

Then (4) can be written as (6):

$$\frac{T_i(S)}{Qh1(S)} = \frac{K_{it}}{T_{it}(S)+1} \tag{6}$$

Here T_{it} is the time constant and heat gain is a DC gain of the transfer function is K_a.

2.2. Modelling of inner space humidity

The mathematical model of indoor humidity can be obtained in a similar way to the of indoor temperature modelling. The humidity of a conditioned space room is considered to be equal to the mean humidity that are provided by sensors. The humidity of a space depends on the humidity of the provided air from the inlet air and HVAC ducts, room temperature, and occupant's number. Using energy conservation principles, indoor air humidity can be expressed using (7) [9]:

$$\rho_a.V_iH.\frac{dhi}{d\tau} = Qh2 - fH\rho_a(hi - ho) \quad (7)$$

where vapor enthalpy of vapor in H (kJ/ kg), f is the flow rate volume in (m3/s), hi is the inner space humidity in (g /kg), ho is the outdoor humidity in (g/kg) and Qh2; work rates in (W) and dτ is time constant.

The (8) is resulted using Laplace transform in order to solve the previous differential (7).

$$H_i(S).S = \frac{1}{\rho_a.V_{i.}H}Qh2(S) - \frac{f}{V_i}(H_i(S) - Ho(S)) \quad (8)$$

Here, (9) is resulted from rearranging (8).

$$\left(S + \frac{f}{V_i}\right)H_i(S) = \frac{1}{\rho_a.V_{i.}H}Qh2(S) + \frac{f}{V_i}(H_o(S) \quad (9)$$

Taking into account that $\frac{f}{V_i}(H_o(S) = 0$ as the change in indoor enthalpy is neglected due to its' little effect and, then the transfer function is given in (10):

$$\frac{H_i(S)}{Qh2(S)} = \frac{K}{T_{ih}.(S+1)} \quad (10)$$

where $T_{ih=}\frac{V_{i.}}{f}$ is the time-constant and $k_{ih=}\frac{1}{\rho_a.V_{i.}H}$ is the heat gain transfers function.

2.3. Modelling of indoor thermal comfort conditions

The modelling of indoor thermal comfort conditions and environment is defined by ASHRAE 55 and ISO 7730. In addition, comfort in an indoor environment, indices also the way of measurement methods are presented here. This section also shows most of parameters that affects local thermal comfort level such as air speed, thermal radiant gain, and vertical temperature difference as shown in Figure 1. There are a few research activities available concerning the mathematical model of thermal comfort [10], [11]. These authors have investigated the implementation of mathematical models in the control process of smart buildings and thus improving the thermal prediction level of pivot mean value (PMV) model in buildings.

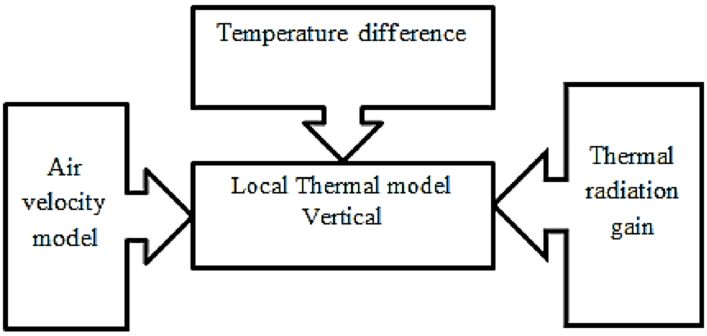

Figure 1. Indoor standards model

2.4. Mathematical model of thermal comfort

Air speed is linked to air sensible heat gain caused by convection heat transfer and latent heat gain caused by evaporation and, thus, the sensation of thermal comfort is affected by air current. For example, occupants expose a more indoor air temperature the moment indoor air velocity is decreased. Accordingly, throughout hot season, ventilation is increased to cool the conditioned space rather than running the cooling system which means the cooling energy consumption is decreased. Throughout cold season, a higher air velocity is required for operating heating system which means heating energy consumption is higher. In order to control air velocity influence, air velocity limitation is applied as indoor air velocity ranging between 0.6-0.90 m/s in hot season and under 0.150 m/s throughout the cold season taking into account temperature fluctuation. Simultaneously, in two different situations, occupants encounter the same heat loss and thus the feeling of higher temperature unsatisfactory where air temperature encounters high varying in respect to time, which is known as air turbulence [10], [11]. The pressure in duct percentage PD% can be obtained based on (11) which defines the draft risk (DR) which expresses the percent of people dissatisfied due to draught. The implied set point temperature is in the range of 22–26 °C, Air speed velocity varies between 0.050 m/s and 0.40 m/s, and winds concentration is ranged from 0% to 70% [12].

$$DR = (34 - t)(v - 0.05)^{0.62}(.37v.T_U + 3.14) \quad (11)$$

3. THERMAL RADIATION AND VERTICAL TEMPERATURE DIFFERENCES MODEL

Thermal radiation is defined as the heat energy gained by the mean of emission of electromagnetic waves. Asymmetric thermal radiation occurs when residents of an inner space environment are indorsed in to a heat source on one part of their body for substantial time, leading to a certain level of un-satisfactions or discomfort. The effect of current thermal radiation is obtained by two techniques.

Measuring in 2 opposite directions and utilizing transducer to record radiation that affects a tinny point from the matching hemisphere and measuring surroundings surface temperature in indoor environments and evaluate the increase of radiant temperature. Consequently, (12) shows the percent of PID caused by warm ceiling [13].

$$PD = \frac{100}{1+e^{(2.84-0.174.\Delta t_{pr})}} - 5.5 \quad (12)$$

In addition, the percentage of PD caused by a cold ceiling is given by (13).

$$PD = \frac{100}{1+e^{(9.93-0.5\Delta t_{pr})}} \quad (13)$$

In a similar way, the percentage of PD caused by cold and hot walls are given in (14) and (15) respectively [13]:

$$PD = \frac{100}{1+e^{(6.61-0.345\Delta t_{pr})}} \quad (14)$$

$$PD = \frac{100}{1+e^{(3.72-0.0525\Delta t_{pr})}} - 3.5 \quad (15)$$

where Δt_{pr} is the increment of radiant temperature in °C. The vertical temperature differences affect PD for various increments of temperature, as shown in (16):

$$PD = \frac{100}{1+e^{(5.76-0.856\Delta t_{pr})}} \quad (16)$$

were Δt is the vertical temperature difference in °C.

3.1. Thermal comfort index

American Society of Heating, Refrigeration and Air Conditioning Standards (55) have outlined the influences of tinner space temperate and inner environment on residents' satisfaction under hot and humid atmosphere also under misty atmosphere based to the model of humans' metabolism enhanced by that human's thermal behavior which is influenced by different environmental conditions and several sole conditions as there is a definite difference between the PMV model and the thermal sensation, as presented by (metabolic rate and clothing) [14]. The difference, compared to the neutral temperature (comfort level) is nearly 1.4 °C due to heat sensing is acquired from occupants' survey located in certain environment taking into account that, PMV method utilize heat transfer as demonstrate in (17):

$$PMV = at + b_{pv} - c \quad (17)$$

where a, b and c are coefficients representing occupants' gender and their function of spent time as shown in Table 1. Meanwhile the error in evaluating the body neutral temperature is related to a PMV issue in determining the metabolic rate and the clothing factor (clo) which represents the insulation of the body [15].

Environments' researches of Kansas's State University helped developing a model of PMV that is able to evaluate inner thermal comforting an institutional building in order to quantify the parameters of PMV [15]. This research project developed different regressions and consequently, the thermal sensational value T_{sens} which is presented in Table 2 as in (18):

$$T_{sens} = 0.305T + 0.99clo - 8.08 \tag{18}$$

where T_{sens} the sensational temperature in °C, T represents inner temperatures in °C also *clo* is clothing factor in *clo*.

Table 1. Coefficients (a, b and c and gender of the resident)

Time s / Genders	a	b	c
1 h/Males	0.2190	0.2330	5.670
Females	0.2719	0.24890	7.240
Both (male sand females)	0.2445	0.2490	6.470
2 h/Males	0.2220	0.2690	6.020
Females	0.2820	0.2990	7.690
Both (male and females)	0.2510	0.2390	6.850
3 h/Males	0.2130	0.2990	5.940
Females	0.27560	0.2560	8.6219

Table 2. Coefficient a-b-c and genders

Thermal sensation	Thermal sensations
3.0	Warmth
2.0	Hot
1.0	Near hot
0.0	Neutralth
-1.0	Fresh
-2.0	A bit mist cold
-3.0	Coldth

It is worth mentioning that the previous models that were endorsed to assess overall thermal comforting. Researches' activities have shown that adaptive-model could be utilized to calculate sat thermal conditions inside the space atmosphere based on functions of outer ambient climates. This model is able to utilize where occupant are in resting mode or seated activity conditions also the Met level is ranging between 1–1.3 Met. The ASHRAE proposed model is based on windows that are the medium of controlling thermal conditions as shown in (19):

$$T_s = 17.8 + 0.31T_0 \tag{19}$$

here T_c is comfort temperature in °C, T_o is outer air temperature in °C and T_i is the mean inner air temperature in °C. Percentage of dissatisfied persons with local thermal comfort (PDP) is given by (20):

$$PD = \frac{100}{1+e^{(-3.58+0.18(30-t)+0.14(42.5-0.01P))}} \tag{20}$$

here P is number of persons.

4. INNER TEMPERATURE'S AND HUMIDITY'S TRANSFER MATRIX

Generally indoor environment temperature variation and indoor humidity variation are connected, it is important to evaluate the two variables jointly and thus establishing indoor temperature and humidity transfer matrix. In this research, the system output control variables are inner temperatures humidities. The output matrix is given by (21):

$$Y = [T_i - H_i]^T \tag{21}$$

where T_i is the inner temperatures in °C and H_i is the inner humidities in g/ kg. Considering the cooling system including humidifier supply power are the inputs while the output are the controlled temperatures and humidities. Accordingly, the input matrix given by (22):

$$Y = [Qh_i - Qh_2]^T \tag{22}$$

here Q_{h1} is the cooling system power supply in kWh and Q_{h2} is the dehumidifier power supply in kWh. The model of the two input parameters and the two output parameters is shown in Figure 2 where T-controller is the temperature controller and H- controller is humidity controller.

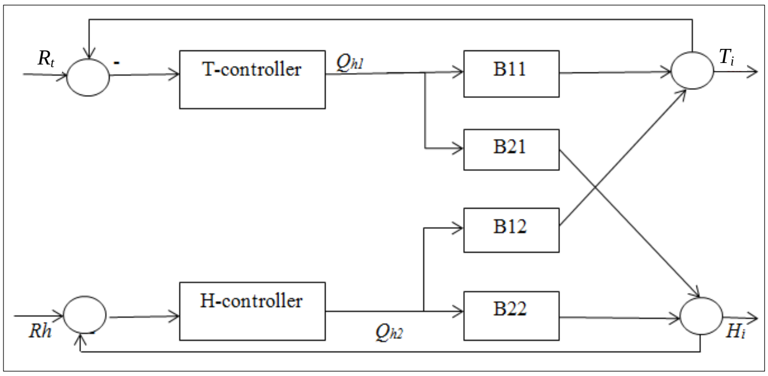

Figure 2. Inner temperatures and humidity's single input, and output model

In the previous model, the model transfer-matrix which evaluates the relationship between output Y and input X is given in (23):

$$\begin{bmatrix} T_{ic} \\ H_{ic} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} \\ B_{22} & B_{22} \end{bmatrix} \begin{bmatrix} Q_{h1} \\ Q_{h2} \end{bmatrix} \tag{23}$$

where T_{ic} is the indoor temperature controller output in °C, H_{ic} is the indoor humidity controller output in g/kg, Q_{h1} is work rate of heater in W, Q_{h2} is work rate of humidifier in W and *B's* are the matrix transfer function. Hence, the air supply flow rate is constant; the humidity is not affected by air cooling process power as it is influenced by the dehumidifier's process power. In short, the mathematical description of the previous paragraph means that G_{22}=0. Simplifying (26) will give (24).

$$\begin{bmatrix} T_{ic} \\ H_{ic} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} \\ 0 & B_{22} \end{bmatrix} \begin{bmatrix} u_{h1} \\ u_{h2} \end{bmatrix} \tag{24}$$

4.1. Mathematical model of thermal comfort

In this thesis, the indoor temperature and humidity is controlled by integrating outdoor ambient air into indoor once its temperature and humidity are suitable to use. In other words, if the outside air temperature is ranging from 20–25 °C and its humidity is ranging between 40%–70%, the ambient outdoor air can be pumped into the building, and, hence, less power is needed to power HVAC system. The indoor temperature and humidity are considered to be difficult as both temperature and humidity are linked together and consequently any indoor humidity changes, will endorse changes in the indoor temperature. Therefore, indoor temperature and humidity single loop control system is not able to cover the optimum control necessity and also it will produce poor control functioning. Accordingly, the design and implementation of decoupling control strategy will remove the link between indoor temperature and indoor humidity. Later, once the indoor temperature and humidity are not linked to each other, using single-loop controllers to control indoor temperature and humidity control can be satisfactory. Figure 3 represent a two input and two output control system where the input and output variables affect each other's, in the figure R_t and R_h are the system inputs (the outdoor air temperature and humidity). X_t and X_h are the controllers' temperature control outputs and humidity control outputs respectively while Y_t and Y_h are the system temperature and humidity output, respectively. The input matrix is obtained from (25) as shown in (25):

$$X_{t,h} = [Q_{h1} - Q_{h2}]^T \tag{25}$$

where Q_{h1} is the cooling system power supply in kWh and Q_{h2} is the dehumidifier power supply in kWh. Furthermore, the output matrix is given by (26):

$$X_{t,h} = [T_i - H_i]^T \tag{26}$$

where T_i is the indoor temperature in °C and H_i is the indoor humidity in g/kg and hence the matrix transfer function can be given by (27) and (28): Adding the decoupling elements; E_{11}, E_{12}, E_{21} and E_{22} as shown in Figure 4 to (30) will result a new transfer matrix as shown in (28):

$$\begin{bmatrix} Y_t \\ Y_h \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} X_t \\ X_h \end{bmatrix} \quad (27)$$

$$\begin{bmatrix} Y_t \\ Y_h \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix} \begin{bmatrix} X_t \\ X_h \end{bmatrix} \quad (28)$$

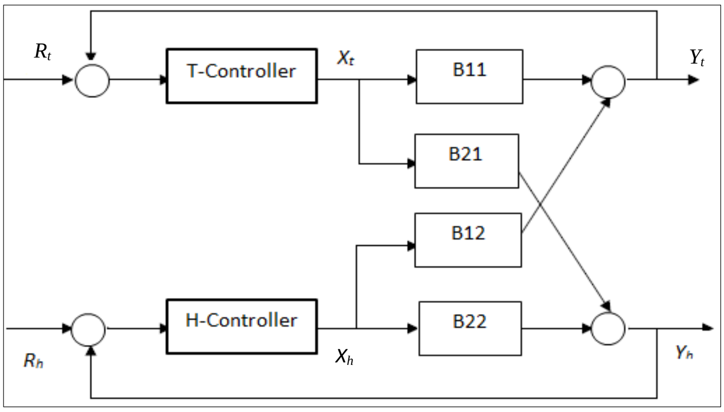

Figure 3. A two-input two-output control system

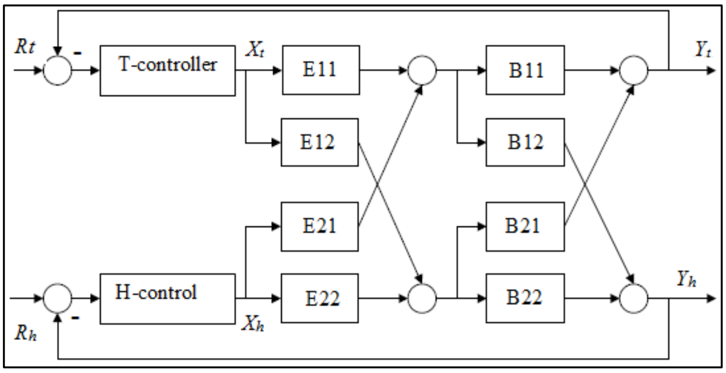

Figure 4. Two-input two-output control system with decoupling

Assuming that the decoupling elements; E_{11}, E_{12}, E_{21} and E_{22} are equal to the inverse of matrix transfer function as in (29) and (30):

$$\begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{12} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}^{-1} \quad (29)$$

$$\begin{bmatrix} Y_t \\ Y_h \end{bmatrix} = \begin{bmatrix} B_{11} & 0 \\ 0 & B_{22} \end{bmatrix} \begin{bmatrix} X_t \\ X_h \end{bmatrix} \quad (30)$$

Consequently, the two-input and two-output control system is represented by two single-input single-output control system (SISO) as demonstrated in Figure 5.

As mentioned previously, temperature and humidity are given by (24). and can be noted that $B_{21}=0$, so the flow chart of the control system can be summarized in Figure 6 which contains two control loop: temperature control loop and humidity control loop to ensure outdoor conditions are used by removing the effect of B_{21}. Consequently, the decoupling control element of the system E_{12} is configured as in (31) which can be added to the previous control system as shown in Figure 7.

$$E12(S) = \frac{B12(S)}{B11(S)} \quad (31)$$

It is may possible controlling inner temperature and inner humidifies utilizing 2 single loops controller that is capable to add outer ambient atmosphere in treated inner environment [16]–[19].

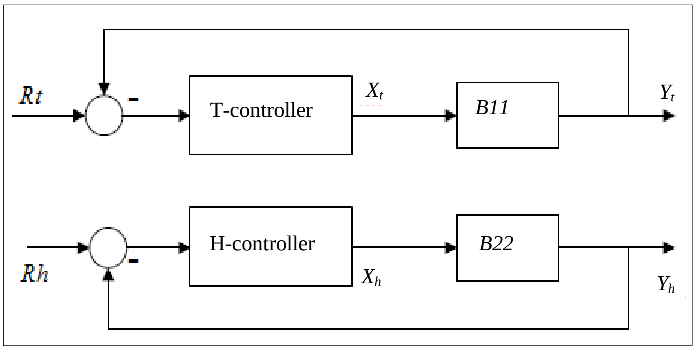

Figure 5. SISO Equivalent control system

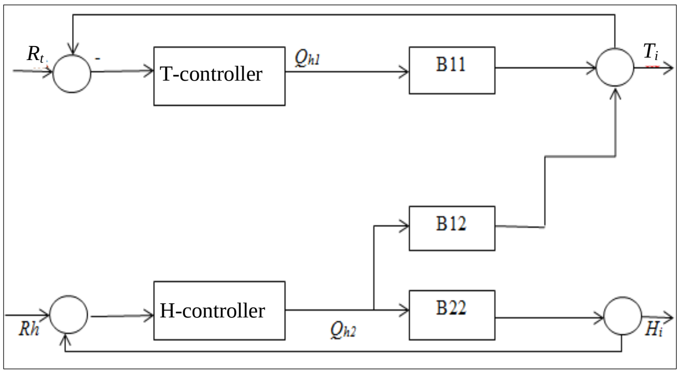

Figure 6. Temperature and humidity control system

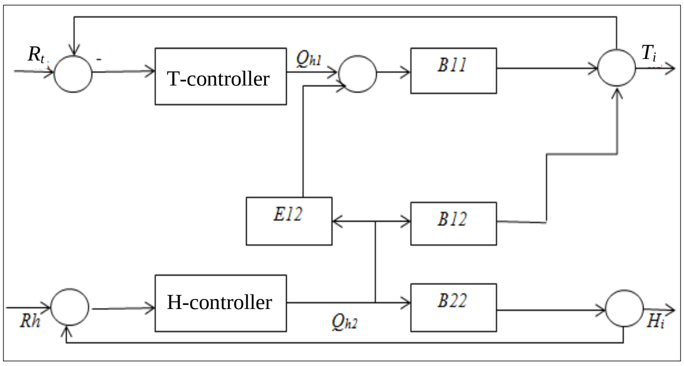

Figure 7. Temperature and humidity control system with decoupling strategy

5. RESULT AND DISCUSSION

System's simulations medium evaluated HVAC's System also the illumination systems energy usage knowing that residents' occupancy changes. ADDON fuzzy PIDs' controlling systems which readjusted so it could carry on all calculations. The fuzzies controlling input is (*eR)* also errors variation (*Δ eR)* that highlights variations of buildings former residents and building's todays residents. Additionally, memberships formations of ADDON (fuzzy PID) controlling inputs as well as outputs all show in Figure 8. The controlling input-output uses the stated functions value: negative-high (NH), negative-medium (NM), negative low (NL), zero (Z), positive low (PS), positive medium (PM) and positive high (PH) are demonstrated in Table 3. The output of

ADDON (fuzzy PID) controlling systems are basic energy variations depends on residents occupancy density that endorses keeping inner thermal-visual comforting level. The research, BMS-fuzzy logic controlling systems of institutional spaces under Australian Rockhampton campus of Central Queensland University have been evaluated, designed, and built. The performance of the proposed control system was numerically simulated and analyzed using MATLAB, DAYSIM and EnergyPlus software [20]–[22]. The study presented a comprehensive understanding and assessment of control strategies of smart buildings application using advanced fuzzy logic based control system.

The study investigated existing conventional control systems including control for indoor temperature, humidity, air quality, HVAC system and the lighting system. Help designers to designed and developed models for fuzzy-logic based controllers of the reference building. The mathematical model of proposed fuzzy-logic-based control system was developed based on real-life events such as the utilizing un-conditioned ambient fresh air, day-lighting, and the ability of performing head count for indoor environment such as indoor temperature, humidity and thermal comfort [23]–[26]. In addition, the study will help in developing methodologies and strategies to achieve potential energy savings in the reference building taking into account of indoor environmental conditions. The existing and proposed control systems including conventional PI controller, fuzzy logic controllers and add on multi-fuzzy-logic-based controllers were simulated using energy plus, DAYSIM and MATLAB [27].

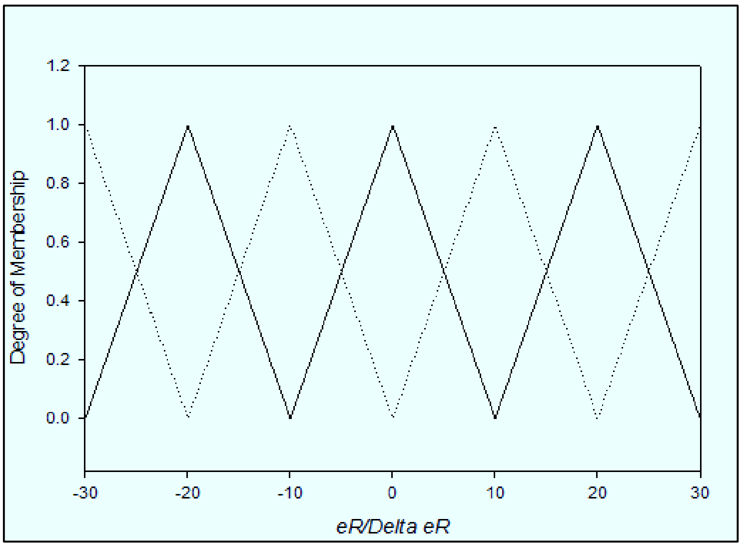

Figure 8. Membership functions of various occupancy levels

Table 3. Fuzzy control rules for local various occupancy levels

Energy changes					eR			
		NH's	NM's	NL's	Z's	PL's	PM's	PL's
(Δe R)	NH's	NH's	NH's	PH's	PH's	PH's	PH's	PH's
	NM's	NH's	NM's	Z's	PM's	PM's	PH's	PH's
	NL's	NH's	NM's	NH's	PH's	PM's	PH's	PH's
	Z	NH's	NM's	NH's	Z's	PL's	PM's	PH's
	PL	NH's	NH's	NM's	NH's	PL's	PM's	PH's
	PM	NH's	NH's	NM's	NM's	ZE's	PM's	PH's
	PL	NH's	NH's	NH's	NH's	NH's	PH's	PH's

6. CONCLUSION

Occupants spent the most of their time indoor, thus indoor environment has major effect on occupants' health and productivity. The main factors of indoor climate aspects are indoor temperature, humidity, inner illumines, and inner air quality. Nevertheless, almost inner climatic features are calibrated by utilizing regular controlling systems that its functions depends on ON/OFF controlling system and PID controlling system. As mentioned earlier, the conventional controlling system are not a suitable solution in saving energy as the functions of HVACs' systems and illuminations' systems are non-linear. Therefore, the utilization of fuzzy controlling systems in smart buildings will be energy efficient that is able in saving energy and also accordingly, able greenhouse gas emission reduction and reducing its negative impact on the environment. The structure of the newly proposed fuzzy logic based controllers contains two main segments; a market available conventional PID control which normally control indoor air temperature and an add-on fuzzy logic controller which is able to integrate the newly controlled real life events such as outdoor air temperature, humidity, and daylight usage to the PID controller based on current indoor situations.

REFERENCES

[1] A. M. Baniyounes, Y. Y. Ghadi, M. G. Rasul, and M. M. K. Khan, "An overview of solar assisted air conditioning in Queensland's subtropical regions, Australia," *Renewable and Sustainable Energy Reviews*, vol. 26, pp. 781–804, Oct. 2013, doi: 10.1016/j.rser.2013.05.053.

[2] A. M. Baniyounes, G. Liu, M. G. Rasul, and M. M. K. Khan, "Comparison study of solar cooling technologies for an institutional building in subtropical Queensland, Australia," *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 421–430, Jul. 2013, doi: 10.1016/j.rser.2013.02.044.

[3] G. A. Meehl and T. F. Stocker, "Chapter 10. Global Climate Projections," *Climate Change 2007: The Physical Science Basis*, no. November, pp. 747–846, 2007.

[4] M. S. Rea, *The IESNA lighting handbook : reference & application*. Illuminating Engineering Society of North America, 2000.

[5] C. DiLouie, "Advanced lighting controls energy savings, productivity, technology and applications," in *Advanced Lighting Controls: Energy Savings, Productivity, Technology and Applications*, 2006, pp. i--viii.

[6] D. I. Norton, "Elementary school utilizes solar design techniques and groundwater cooling system for energy efficiency," *ASHRAE Journal*, vol. 37, no. 3, pp. 50–52, Mar. 1995, doi: 10.2172/6262018.

[7] M. Rosenbaum, "A green building on campus," *ASHRAE Journal*, vol. 44, no. 1, pp. 41–44, 2002.

[8] O. A. Seppänen, "Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings," *Indoor Air*, vol. 9, no. 4, pp. 226–252, Dec. 1999, doi: 10.1111/j.1600-0668.1999.00003.x.

[9] L. Harriman, M. Witte, M. Czachorski, and D. Kosar, "Evaluating active desiccant systems for ventilating commercial buildings," *ASHRAE Journal*, vol. 41, 1999.

[10] Smith C S, "Ventilation in the commercial environment," *ASHRAE Journal*, vol. 41, no. 10, pp. 73–76, 1999.

[11] Y. Wang and P. Dasgupta, "Designing an adaptive lighting control system for smart buildings and homes," in *ICNSC 2015 - 2015 IEEE 12th International Conference on Networking, Sensing and Control*, Apr. 2015, pp. 450–455, doi: 10.1109/ICNSC.2015.7116079.

[12] C. Beckel, L. Sadamori, S. Santini, and T. Staake, "Automated customer segmentation based on smart meter data with temperature and daylight sensitivity," in *2015 IEEE International Conference on Smart Grid Communications, SmartGridComm 2015*, Nov. 2016, pp. 653–658, doi: 10.1109/SmartGridComm.2015.7436375.

[13] L. Martirano, G. Parise, L. Parise, and M. Manganelli, "Simulation and sensitivity analysis of a fuzzy-based building automation control system," Oct. 2014, doi: 10.1109/IAS.2014.6978480.

[14] R. W. Da Fonseca, E. L. Didoné, and F. O. R. Pereira, "Using artificial neural networks to predict the impact of daylighting on building final electric energy requirements," *Energy and Buildings*, vol. 61, pp. 31–38, Jun. 2013, doi: 10.1016/j.enbuild.2013.02.009.

[15] S. Kotra and M. K. Mishra, "Energy management of hybrid microgrid with hybrid energy storage system," in *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, Nov. 2015, pp. 856–860, doi: 10.1109/ICRERA.2015.7418532.

[16] F. Maamari and M. Fontoynont, "Use of IEA-SHC task 21 C benchmarks to assess performance of lightscape 3 . 2 in daylighting calculations," vol. 2.

[17] A. Cziker, M. Chindris, and A. Miron, "Fuzzy controller for indoor lighting system with daylighting contribution," *5th international conference on electrical and electronics engineering (ELECO2007)*, 2007.

[18] C. DiLouie, "Chapter 13 good controls design key to saving energy with daylighting," in *Advanced Lighting Controls: Energy Savings, Productivity, Technology and Applications*, 2006, pp. 179–186.

[19] A. Cziker, M. Chindris, and A. Miron, "Fuzzy controller for a shaded daylighting system," in *11th International Conference on Optimization of Electrical and Electronic Equipment, OPTIM 2008*, May 2008, pp. 203–208, doi: 10.1109/OPTIM.2008.4602522.

[20] A. Cziker, M. Chindris, and A. Miron, "Implementation of a lighting control system based on fuzzy logic," *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 1, no. PART 1, pp. 135–140, 2007, doi: 10.3182/20070709-3-ro-4910.00021.

[21] J. Gwak, M. Shino, and M. Kamata, "Interaction between thermal comfort and Arousal level of drivers in relation to the changes in indoor temperature," *International Journal of Automotive Engineering*, vol. 9, no. 2, pp. 86–91, 2018, doi: 10.20485/jsaeijae.9.2_86.

[22] M. Etxebarria Mallea, L. Etxepare Igiñiz, and M. de Luxán García de Diego, "Passive hygrothermal behaviour and indoor comfort concerning the construction evolution of the traditional Basque architectural model. Lea valley case study," *Building and Environment*, vol. 143, pp. 496–512, Oct. 2018, doi: 10.1016/j.buildenv.2018.06.041.

[23] M. Beccali, V. Strazzeri, M. L. Germanà, V. Melluso, and A. Galatioto, "Vernacular and bioclimatic architecture and indoor thermal comfort implications in hot-humid climates: An overview," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 1726–1736, Feb. 2018, doi: 10.1016/j.rser.2017.06.062.

[24] A. Ryzhov, H. Ouerdane, E. Gryazina, A. Bischi, and K. Turitsyn, "Model predictive control of indoor microclimate: Existing building stock comfort improvement," *Energy Conversion and Management*, vol. 179, pp. 219–228, Jan. 2019, doi: 10.1016/j.enconman.2018.10.046.

[25] E. Sanchis, S. Calvet, A. del Prado, and F. Estellés, "A meta-analysis of environmental factor effects on ammonia emissions from dairy cattle houses," *Biosystems Engineering*, vol. 178, pp. 176–183, Feb. 2019, doi: 10.1016/j.biosystemseng.2018.11.017.

[26] A. AbuBaker and Y. Ghadi, "A novel CAD system to automatically detect cancerous lung nodules using wavelet transform and SVM," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 5, pp. 4745–4751, Oct. 2020, doi: 10.11591/ijece.v10i5.pp4745-4751.

[27] A. AbuBaker, Y. Ghadi, A. A. Abu Baker, and Y. Ghadi, "Mobile robot controller using novel hybrid system," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 1, p. 1027, Feb. 2020, doi: 10.11591/ijece.v10i1.pp1027-1034.

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