Journal of Theoretical and Applied Information Technology
15th June 2020. Vol.98. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

FUZZY-PID BASED SELF-ADJUSTED INDOOR TEMPERATURE CONTROL FOR ENSURING THERMAL COMFORT IN SPORT COMPLEXES

B.S.OMAROV[1] , A.K.ANARBAYEV[1], U.ZH.TURYSKULOV[2], E.D.ORAZBAYEV[1], M.ERDENOV[1], A.Z.IBRAYEV[1], B.B.KENDZHAEVA[1]

[1]A.Yasawi Kazakh-Turkish University, Turkistan, Kazakhstan

[2]South Kazakhstan State Pedagogical University, Shymkent, Kazakhstan

E-mail: bakytzhan.omarov@ayu.edu.kz, bahitzhan01@mail.ru, bakhytzhanomarov@gmail.com,

ABSTRACT

Providing a comfortable indoor temperature in commercial or residential buildings is an extremely important problem. This is directly related to the design of the fast reacted controller for temperature. First, the analysis and building of an interactive nonlinear mathematical model of the required comfort temperature is presented in this paper. Then, the article refers to methods of design of PID controller with self-tuning parameters based on fuzzy logic principles, for heating and cooling processes. Finally, we present the simulation results of a proposed fuzzy-PID controller in Matlab, and analyze experimental results for a 6-month period by applying the proposed system, and conclude the research results.

Keywords: *Fuzzy-PID, Energy Consumption, Microclimate Control System; PID Controller, Sport Complexes*

1. INTRODUCTION

The air environment in buildings, regulated by many parameters of exposure to exogenous and endogenous factors, determines the working and living conditions, health, and comfort of a person. Providing a "healthy" and comfortable air environment is very expensive, because expensive, technically complex, and multi-functional engineering systems are used [1]. In order to remove only 1 kW of excess heat in buildings or premises (to maintain air temperature), could cost in the region of 300–600 USD [2].

For the above mentioned reasons, today indoor environment quality and comfort have become a topic of relevance, and for this reason heating, ventilation, and air conditioning (HVAC) systems have become popular in many buildings. Reducing the power consumption of these systems, while maintaining a suitable comfort level, is of great interest, and has not yet been completely resolved. Traditionally, HVAC systems have not completely ensured the comfort, as they just attempted to maintain the conditions within certain limits. Therefore, comfort optimization depends entirely on the way the system is tailored to the needs of the user.

However, according to some research [3-5], HVAC systems can be regarded as multiple-input multiple-output problems, as they work with interrelated variables to extract sets of output values. Moreover, they are affected by a wide variety of uncertainty parameters as user preferences, occupants' activities, and outdoor environmental parameters that can change their usual operations. Consequently, HVAC control problems can be seen as multi-criteria tasks that are characterized with the help of complex analytical expressions.

Despite conventional PID controllers providing rational solutions, they are not able to completely control the indeterminacy of the dynamics of HVACs that can be readily described by linguistic variables and rules [6]. Fuzzy logic controllers (FLC) act as viable alternatives to traditional controllers, as they do not require mathematical modeling [4], and they are ready to handle different criteria, as they represent the dynamics of the HVAC system in accordance with knowledge. FLCs appear to be a viable solution for conventional controllers, as they are able to handle different criteria that represent the dynamics of the HVAC system. Moreover, they do not require math modeling, and FLC's higher efficiency, and lower power consumption, than PIDs were demonstrated in [7].

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

This paper is organized as follows: in the next section we pass problem statement. Section 3 describes the design process of intelligent PID controllers for indoor temperature, and explains proposed techniques for each controlling parameter; in section 4 we present simulation results, and results from experiments conducted in our laboratory as part of the study. Section 5 discusses the proposed PID performance and analyses the received results by comparing similar researches and analyses the results. Finally, we conclude our work and discuss future work.

2. PROBLEM STATEMENT

The goal of this control strategy is to design strategies by combining conventional and intelligent control technologies for indoor temperature control by computational modeling and experimental investigation, the work is broken down into several parts as shown Figure 1.

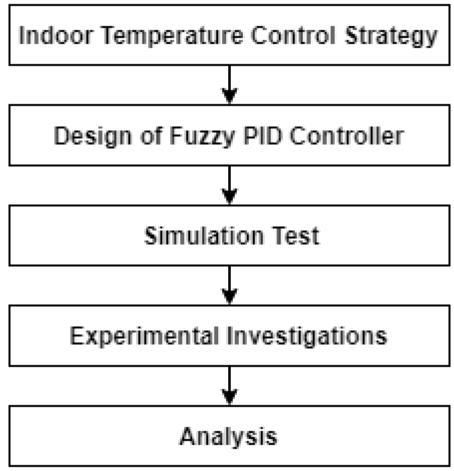


Figure 1: Stages of designing an intelligent PID control system

3. DESIGN

In this paper, in order to control indoor environmental temperature, a fuzzy-logic-based intelligent PID controller is designed. PID control is used because of its practicality. However, its control characteristics are mostly based on the parameters of the PID controller, and incorrect selection will lead to deterioration in the control performance. Thus, to ensure high-level control, and adjust PID control parameters, intelligent control is applied. In this section, we introduce the structure and principle of the proposed fuzzy-PID strategy, and then the controller design and control processes are described in detail.

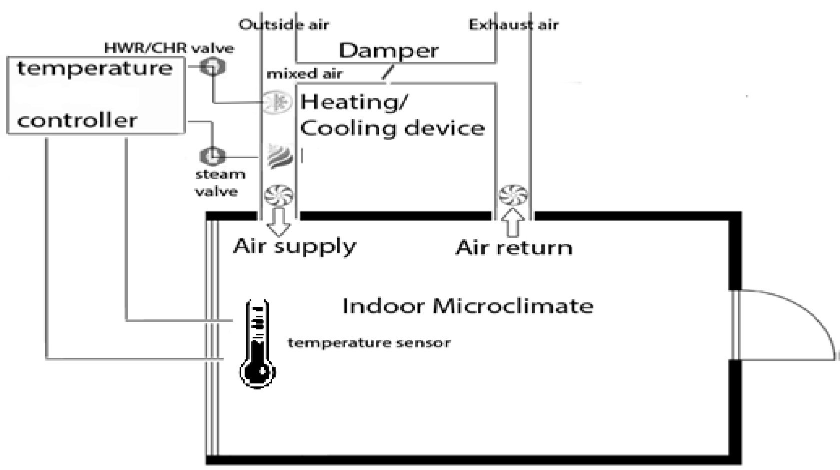


Figure 2: Schematic diagram of indoor air temperature control processes in heating/cooling system

We study a room, equiped with the base HVAC system which has the heater by hot/cold water, such as Figure 2. Depend on the mixed air temperature after the filter, the outside air is heating or cooling by the heating/cooling coil. Then, the outside air can be supplied into the room by the supply fan. The exhaust air is conducted out the room by the return fan. The heating/cooling coil gives the indoor air a thermal energy P by changing the hot/cold water flowrate Fp through the HWR/CHR control valve. This system uses the temperature controller to adjusting the position of hot/cold water, steam valves, and then can change flowrate.

Indoor temperature is affected by the initial indoor microclimate air temperature, outdoor temperature, volume of the premises, heater or conditioner, and heat loss from the wall. The indoor environment parameters are controlled by PID controllers using the system error (e), and the system error changing rate (ec) as input parameters. e(k) is the error between actual output and target output, and it can be expressed as follows:

$$e(k) = r(k) - y(k) \qquad (1)$$

ec(k) is the changing rate of *e(k)* and is given as:

$$e(k) = r(k) - y(k) \qquad (2)$$

The output of the PID controller is the working intensity of a heater, and the system output is the indoor air temperature. Equation (3) represents the PID control algorithm:

$$k_i e(k-1) + k_d\left(e(k) - 2e(k-1) + e(k-2)\right)$$

$$u(k) = u(k-1) + k_p\left(e(k) - e(k-1)\right) + \qquad (3)$$

The efficiency of PID control is mainly dependent on the choice of PID controller parameters kp, ki, and kd. The fuzzy block of the fuzzy-PID control strategy is designed to auto-tune the values of the parameters.

3.1 Fuzzy Block Design

The function of the fuzzy logic controller is to configure the parameters of the PID controller, k_p, k_i, k_d on-line by fuzzy logic control rules based on time-varying **e** and **ec**. Fuzzy self-adjusting of PID parameters is the detection of a fuzzy relationship between the three PID parameters, and e and ec. It measures the output of the system (y) and then computes (e) and (ec) based on y and the input parameter, r. The controller with fuzzy logic then sets up three parameters according to the rules of fuzzy control in online mode, so that the monitored objects achieve better dynamic and stable operation. Therefore, it is necessary to understand the function of each PID parameter. It is then possible to determine the relationship between the fuzzy output, k_p, k_i, and k_d and the fuzzy inputs e and ec. Finally, the fuzzy rules are built. The fuzzy rule base contains three matrices that show how k_p, k_i, and k_d will change (Δk_p, Δk_i and Δk_d) when e and ec vary as shown in Table 1. The fuzzy rule base is constructed by using several if-then statements, and premise and consequences of each statement which are fuzzy propositions.

Table 1: Effects of kp, ki and kd tuning

Parameter	Rise time	Overshoot	Setting time	Steady state error	Stability
Increase kp	Decrease	Small Increase	Increase	Decrease	Deteriorate
Increase ki	Small Decrease	Increase	Increase	Large Decrease	Deteriorate
Increase kd	Small Decrease	Decrease	Decrease	Small Change	Improve

The fuzzy variables are defined for the rule base as **e**, **ec**, Δk_p, Δk_i and Δk_d, and they have following form: «Negative Big» (NB), «Negative Medium» (NM), «Negative Small» (NS), «Zero» (ZO), «Positive Small» (PS), «Positive Medium» (PM), «Positive Big» (PB).

Figures 3 (a-d) present membership functions for e, ec, Δk_p, Δk_i, and Δk_d. A membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. In this case, the combined triangular and Gauss membership functions are used for all variables. The physical domain of e and ec is {-3, -2, -1, 0, 1, 2, 3, }; the physical domain of Δk_p is {-0.3, -0.2, -0.1, 0, 0.1, 0.2, 0.3}; the physical domain of Δk_i is {-0.06, -0.04, -0.02, 0, 0.02, 0.04, 0.06}, and that of Δk_d is {-4, -3, -2, -1, 0, 1, 2, 3, 4}.

We can get the Δk_p, Δk_i, and Δk_d values based on the fuzzy rule base and function membership.

Then, k_p, k_i, and k_d can be calculated using the following equations:

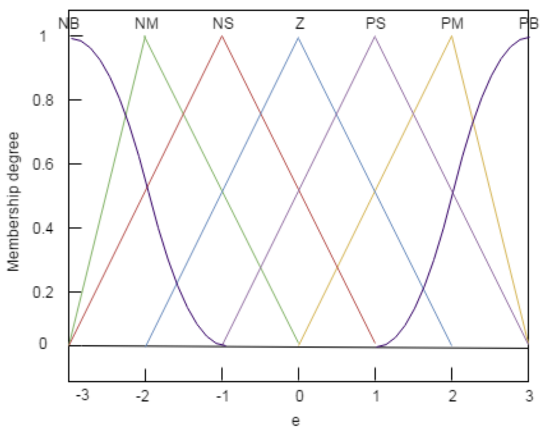
$$k_p(k+1) = f_{kp}(e, ec) = k_p^{'}(k) + \Delta k_p(k) \qquad (4)$$

$$k_i(k+1) = f_{ki}(e, ec) = k_i^{'}(k) + \Delta k_i(k) \qquad (5)$$

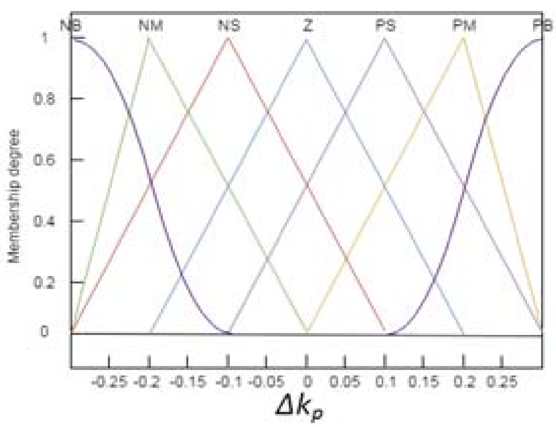
$$k_d(k+1) = f_{kd}(e, ec) = k_d^{'}(k) + \Delta k_d(k) \qquad (6)$$

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

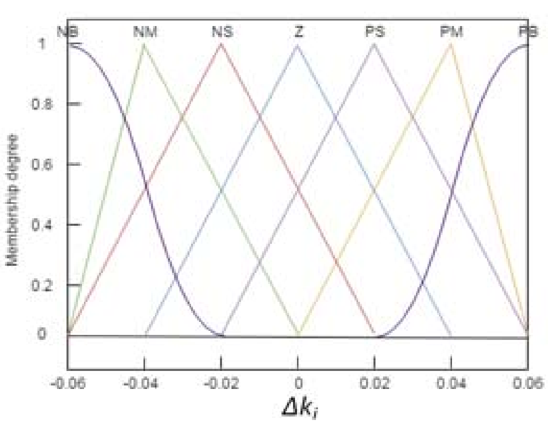
The desired k_p, k_i, and k_d values can be obtained by using the FLC, and transferred to the PID controller in order to operate the heating/air-conditioning equipment correctly, and obtain comfortable indoor temperature.



a) Membership function for system error & change rate



b) Membership function of Δkp



c) Membership function of Δki

Figure 3: Membership functions for e, ec, Δk_p, Δk_i, and Δk_d

The control process of the fuzzy-PID controller shown in Figure 4, and summarized as follows:

- Collect control data at sample step k by using measuring equipment.
- Calculate the system error and changing rate of the system error.
- Fuzzification of e and ec by using the membership function as presented in Figure 3a.
- Get fuzzy values of Δk_p, Δk_i, and Δk_d by using the fuzzy rules.
- Defuzzification of Δk_p, Δk_i, and Δk_d by using membership functions from Figures 3 b-d
- Calculate k_p, k_i, and k_d.

k_p, k_i, and k_d are provided to the PID controller for indoor temperature control.

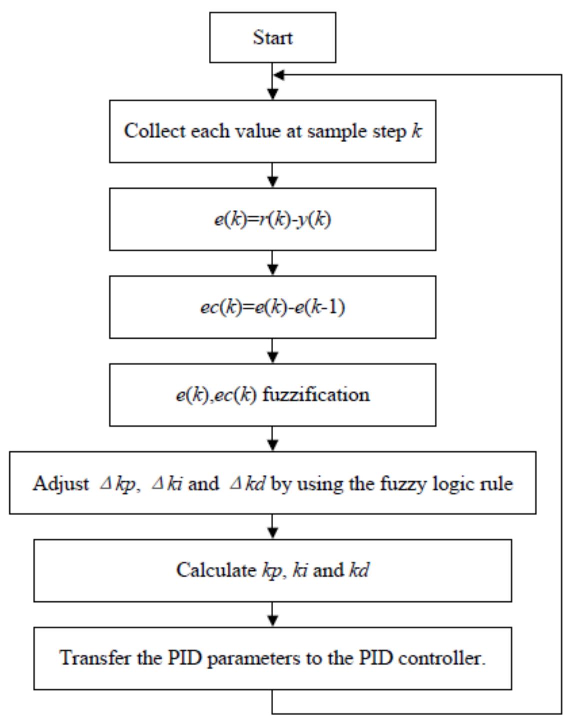


Figure 4: Flow chart of fuzzy-PID controller

3.2 Fuzzy Rules for Heating Equipments

To calculate the required power to maintain internal thermal comfort, a controller with fuzzy inference is designed for this subsystem. The input of this fuzzy controller includes error and error

Journal of Theoretical and Applied Information Technology
15th June 2020. Vol.98. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

correction. The changing error is the difference between the previous and current errors.

The problem is to determine the temperature corresponding to the level of control to the digital-to-analog converter regulator, the input variables of which are as follows: e (difference between the desired and actual temperature), Δe (the first derivative of temperature change during the computing cycle)

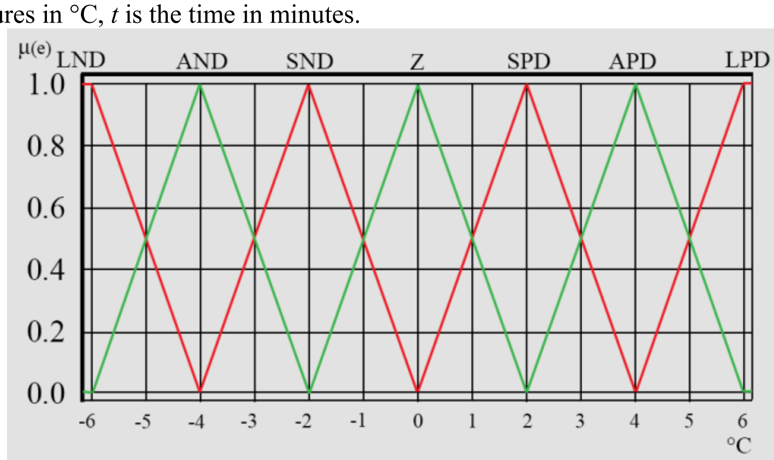
$$\Delta e = T_{desired}(t) - T_{current}(t) \quad (7)$$

Where $T_{desired}(t)$, $T_{current}(t)$ are the desired and current temperatures in °C, *t* is the time in minutes.

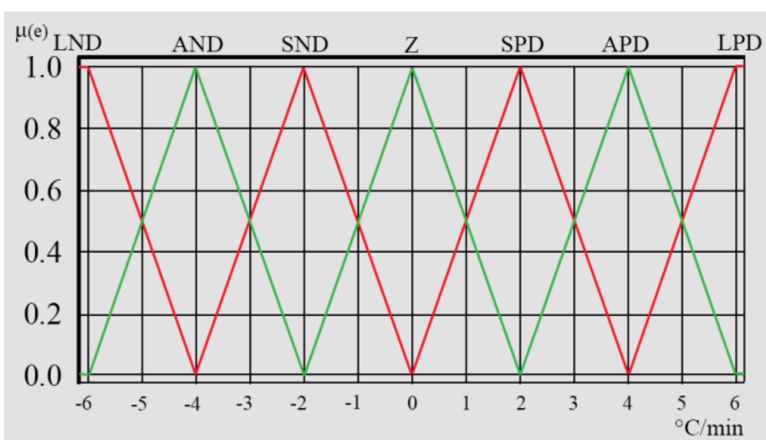
Naturally, the greater the temperature difference, the greater the rate of cooling or heating. The rate of temperature change is given by:

$$\Delta e = \frac{e(t_1) - e(t_2)}{t_1 - t_2} \quad (8)$$

As the indoor temperature approaches the target, the rate of temperature change therein will decrease, as well as, for example, the air conditioning cooling level.



(a)



(b)

Figure 5: Linguistic membership functions by the input parameter

Determine the linguistic fuzzy variables e, Δe membership functions $\mu(e)$ and $\mu(\Delta e)$ are used. We construct two membership functions. In one case, the argument is a temperature difference (e) (Figure 5a); in the second, it is the rate of temperature change (Δe) (Figure 5b). For $\mu(e)$ and $\mu(\Delta e)$, (Figure 5) the identifiers have the form: «Large Positive Deviation» (LPD),

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

«Average Positive Deviation» (APD), «Small Positive Deviation» (SPD), «Zero Deviation» (Z), «Small Negative Deviation» (SND), «Average Negative Deviation» (AND), «Large Negative Deviation» (LND).

The result of the joint effect of the two membership functions of the output parameter value is determined by the corresponding program embedded into the logic device.

The terms that are listed in Table 2 show how the linguistic variables are used, obtained by summing the fuzzification for the response signal using operator intuition. When connected to the output membership function and the corresponding de-fuzzification, we get a clear signal to the control action. In this case, the control signal is determined by the level of heating or cooling from the data [−2, −1, 0, 1, 2, 3, ...].

Table 2: Fuzzy control rules for local temperature controller.

		Temperature difference (e)						
Rate of temperature change		***LND***	***AND***	***SND***	***Z***	***SPD***	***APD***	***LPD***
	LND	C3	C3	C2	C1	NO	NO	H1
		Fast	Fast	Med	Slow	Z	Z	Med
	AND	C3	C2	C2	C1	NO	NO	H1
		Fast	Med	Med	Slow	Z	Z	Med
	SND	C3	C2	C1	C1	NO	NO	H1
		Fast	Med	Slow	Slow	Z	Z	Med
	Z	C2	C1	C1	NO	NO	H1	H1
		Med	Slow	Slow	Z	Z	Med	Med
	SPD	C1	C1	NO	NO	H1	H1	H2
		Slow	Slow	Z	Z	Med	Med	Fast
	APD	C1	C1	NO	NO	H1	H2	H2
		Slow	Slow	Z	Z	Med	Fast	Fast
	LPD	C1	C1	NO	NO	H2	H2	H2
		Slow	Slow	Z	Z	Fast	Fast	Fast

e	+ very cold	conditioner
	- very hot	
Δe	+ heat consumption	ventilator
	- cold consumption (heat output)	

The relationship between the input and output are listed in the table of fuzzy rules (Table 2.). Each entry corresponds to its fuzzy rule. For example, if the current internal temperature is 30 °C and the preset temperature is 24 °C, this means (NB); if it has the large positive deviation (LPD), then the cooling rate would be C3, cooled to SOC level with fan speed as (Fast), i.e., "Very high," and the heating rate would be equal to 0. In logical notation, this is as follows: if e = NB and THEN NW and fan speed Fast and the heating rate would be equal to 0. In logical notation, this is as follows: IF e = NB and $\Delta e = LPD$ C3 and Fan speed is "Fast."

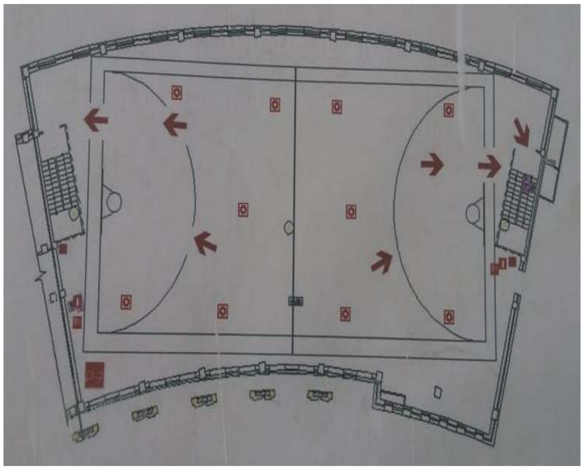
The output of the fuzzy controller is the required power, which maintains the room temperature at a specified value. A negative value indicates that the heating system is running and a positive value indicates that the cooling system is working.

4. DESCRIPTION OF THE FACILITY

We provided experiments in the Sport Hall of A.Yasawi International Kazakh-Turkish University (Turkistan, Kazakhstan) during the sportsmen did different type of sport games. Figure 6 illustrates the sample of plan and view of the sport hall where the experiments were conducted, when students were playing a game.

Journal of Theoretical and Applied Information Technology
15th June 2020. Vol.98. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195



a) Plan of the sport hall where the experiments have been conducted

b) View of the sport hall where the experiments have been conducted

Figure 6: Description of the facility

5. RESULTS

In order to achieve the goal of a comfortable and healthy indoor environment, Fuzzy-PID based self-adjusted indoor temperature controller was proposed. In the simulation results subsection we introduce the simulation performance of the proposed controller, that was conducted using the Python language and a Matlab platform.

5.1 Simulation Results

In this subsection, we describe simulation performance of the proposed controller

5.1.1 Simulation of fuzzy-PID Controller for Temperature Control

Let us assume that the initial room temperature is inconvenient and requires regulation. After determining and setting the desired temperature, the controller starts working to set the desired room temperature. To simulate this process, a signal is used as a reference input to verify the characteristics of the proposed data controller. Suppose the temperature difference between the internal and external medium is 5 °C.

Thus, the signal step, r(k)=5, is entered at time t=0, and the simulation result of the proposed output of the temperature control system is shown in Figure 6a. In the figure, from the time constant τ=0.033 s, and the settling time ts=0.092 s, we can easily determine that the control reacts quickly to the input signal, with a high increase rate. And, as for the response of the fast monitoring speed, there is no overload. The steady state error is 0 at the time the control process settles. This means that the proposed control has excellent performance with a fast response, avoids overloading, and demonstrates control accuracy and stability.

Figure 7a shows the temperature changes in the system output, based on the outputs of the controllers and systems. As soon as the control process begins, to ensure rapid movement of the output of the system, the result of the PID controller, approximately equal to the present value, is used while preventing misses. Since the system is in steady state, the steady-state error is 0 and the PID output is set to 0.

Figure 7b shows the PID response signal. The figure shows that the controller's command is defined, computed with the output, and sent to the device to change the air temperature inside the room.

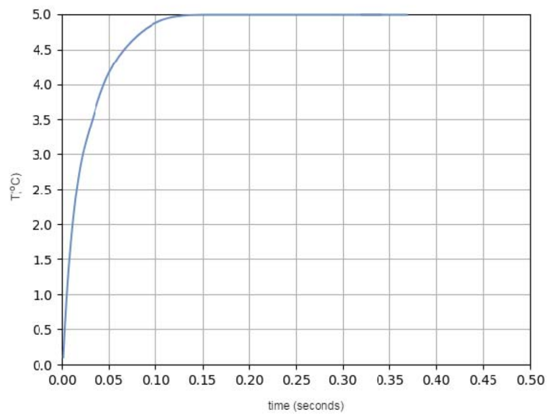
Figure 7c illustrates automatic configuration process of the k_p, k_i, and k_d parameters. Consequently, at t=0, k_p=0.32, k_i=0, and k_d=2.2 the PID parameters are adjusted to ensure the system output setting, and the values change according to the fuzzy logic control rules. In the end, the value of the PID parameters changed to k_p=0.31, k_i=0, and k_d=1.2, and the output of the system was stable.

From the above results, we can definitely say that the fuzzy-PID control can change the

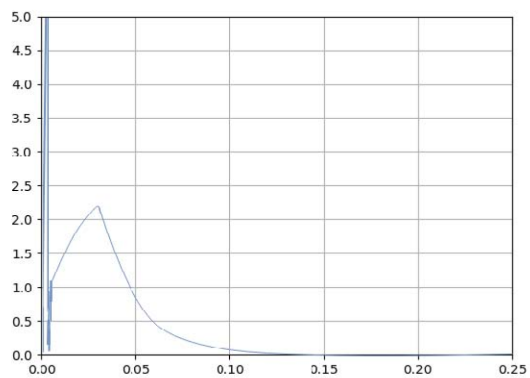
15th June 2020. Vol.98. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

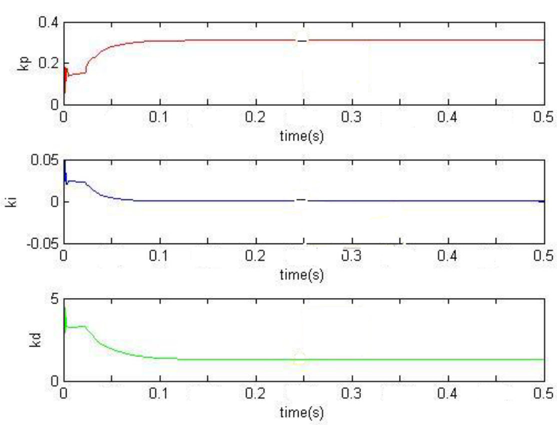
parameters of the PID controller to optimize control performance.



a) System output response



b) PID output response to step input



c) Automatic configuration of PID parameters

Figure 7: Description of the facility

5.2. Experiment Results

The research experiments of the newly developed fuzzy-PID regulator for IEQ improvement is described in this section. In the next sections, experimental installations and the process of experiment control will be described in detail. The data obtained during the study will be depicted on graphs, or processed with signal-processing methods. Finally, the evaluation of the controllers will be evaluated on the basis of an experimental study.

5.2.1 Temperature Control

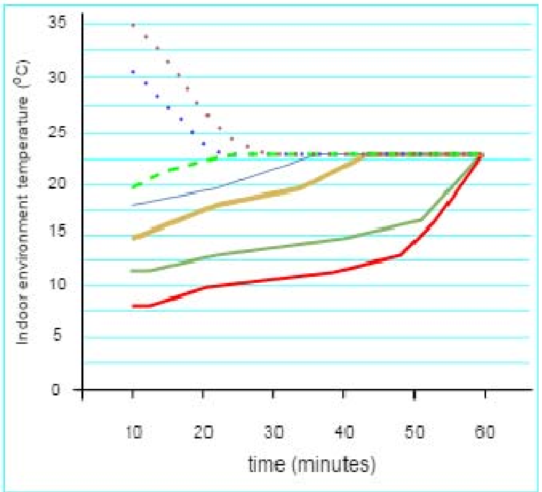
The experiments were carried out on the previously described test facility using the program introduced in Section 4.2, over the period December 2016 to May 2017. When the outdoor temperature is low, the camera should be warmed up. Thus, in the temperature tests:

- the camera for the environment is used to simulate the conditioning zone;
- a thermocouple is used to measure the room temperature;
- a heater is used to supply air heated to a certain temperature;
- the operating power of the heater is controlled by a fuzzy PI controller; and,
- the working hours (when the office is occupied) is selected as 9:00 to 18:00.

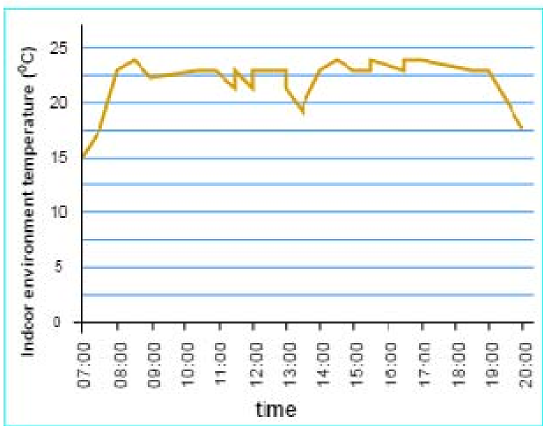
For modeling controllers in any conditions, with problems they may encounter in real buildings, the following adjustments were made:

- the initial room temperature varies depending on the outdoor temperature;
- door and windows open and close in different ways, as different people open and close them.

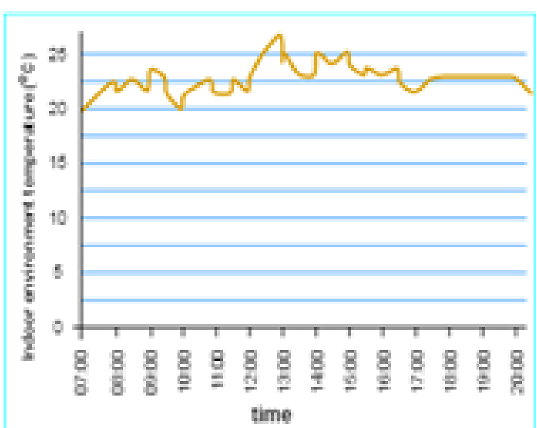
ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195



a) Indoor temperature measurement

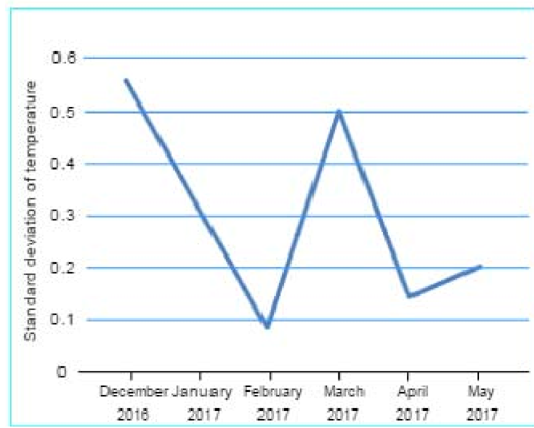


b) Indoor temperature monitored in Dec-2016



c) Indoor temperature monitored in May-2017

d) Average monthly temperature inside and outside the room



e) Monthly standard deviation of indoor temperature

Figure 8: PID parameters regulating process

Figure 8a shows the result of the experiment with the proposed fuzzy-PID controller. To bring the monitored zone to a given point from different values of the initial temperature, it takes between 30–60 min. It becomes shorter if the initial temperature is higher, close to target temperature, and the air conditioning zone is well sealed (windows are not open). If the initial temperature is lower and the door and windows are often opened, the controller takes longer to reach the set temperature. Eventually, the controller did not take more than sixty minutes to achieve a room temperature of up to 21°C, which corresponds to 80% bandwidth satisfaction in accordance with ASHRAE 55-2010 [8] under all conditions. Everywhere the statement that the PID controller is fuzzy starts to working and operate the heater at

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

8:00, in our experiments it is one hour before the starting working time.

Figure 8b shows the results of temperature changes for a single day on the premises, January 17, 2017. The initial room temperature is about 15 °C, and rises rapidly to the set value when heated. During working hours from 9:00 to 18:00, the room temperature is usually maintained between 20 °C and 21 °C. From this it follows that the temperature curve inside the room is relatively stable and there are no abrupt changes during working hours. This means that the controller with a fuzzy-PID controller controls the room temperature well.

Figure 8c demonstrates the indoor air temperature that observed in May 2017, when average outdoor temperature was 25 ºC in daytime, and 11.5 ºC at night. The day when the experiment conducted is May 18, 2017, that time the highest outdoor temperature was 29 ºC. In this temperature the controller keeps the desired temperature due to working power of conditioning system. When the working day starts initial temperature was about 20 ºC, from 8.00 the PID controller starts to regulating. There is the highest temperature can be observed between 12.00 and 14.00 because of opening the window that time. Despite, does not exceed 26 ºC, although it needs more working power of conditioneer and requires more power consumption.

Figure 8d illustrates the result for the 6-month experiment for indoor and outdoor temperatures. The green line is the monthly average outdoor temperature, the blue line the average temperature using the proposed system, the red line the average temperature when the proposed system kept steady state. Suppose that the average room temperature in a stationary state lies between 20.6–21.1°C. The lowest monthly temperature in the room was measured in December 2016. During that month the controller was tested under conditions of opening or closing the window for relatively long periods. Average indoor temperature depends on outside temperature. As the constant error of the process is not significant, from the results of the experiment we can see that the proposed temperature controller of the fuzzy-PID controller has good control properties.

In Figure 8e, another characteristic is calculated, the standard deviation of the measured temperature, for examining the proposed temperature controller by the amount of data collected. The highest standard deviation of room temperature was obtained in December 2016, because during this month the controller was tested under conditions when the window was opened for relatively long period. This results in higher standard deviations, as the standard deviation indicates how much variation or dispersion exists from the mean. As a result, monthly standard deviations were obtained. Their values were small, that means that the monitored data on indoor temperature, collected in the experiments, are usually very close to the average and spread over a small range of values. From the experiments, a fuzzy-PID temperature controller has good control properties and stability characteristics, and it also adapts well to indoor temperature control, while a comfortable internal temperature can be provided in the conditioned air zone, which is also controlled by the proposed controller.

6. DISCUSSION AND ANALYSIS

In Europe, on average, buildings consume 41% of the total primary energy, most of which is spent on heating, ventilation, air conditioning [9]. To ensure the process of performance and energy monitoring, more buildings are using the building management system. These systems also simplify the development and implementation of these systems, which increases the energy efficiency and the quality of the indoor environment of the building.

6.2 Temperature Control

Control on the basis of the Controller with fuzzy-PID controller has its own peculiarities when controlling the room temperature:

- The best option for selecting PID parameters provides the desired output of the system
- PID controller provides stability and reliability when controlling the system
- PID controller can easily adapt to different situations to ensure optimum tuning for various control objects

Simulation tests are conducted to study the controller's performance for optimizing the quality control of the indoor environment. The results show that the proposed temperature data in the intelligent temperature controller has excellent performance in controlling the room temperature:

• The simulation results show that the values of kd, kp and ki were obtained based on an error at the output of the system (e), as well as changes in the system output error (ec) using fuzzy information rules. The output of the PID control will maintain the control process in a steady state.

• Regularity and Stability of the data at the output indicate control accuracy where there is no overflow error and steady state.

When fuzzy logic rules are used in the process of PID control, the accuracy of fuzzy control is increased, as well as its performance. Experiments to control the temperature in the room were conducted during the period from December to May 2017. At an uncontrolled temperature during the experiment period, it was left standing similar to the outside temperature, which was at that time cold or too hot due to overheating, in which the internal environment would be uncomfortable and unhealthy for inhabitants. The results of the study show that the room temperature control is improved with the proposed controller.

• If the temperature heating is necessary, it starts one hour before (based on the preliminary measurement) to the set time value based on fuzzy-PID control. At this time, room temperature is adjusted to the set value.

• When the process goes into a stable state, the room temperature settles down and remains stable. Figure 7d shows the monthly average temperature, which shows a small sustained error guaranteeing control accuracy.

• When a sudden change occurs, the fuzzy logic control rule quickly learns the situation when other control parameters are set for better performance. Such violations include: an open window or door for a long period; accumulation of more people in the help where gives an increase in the source of heat and so on.

Figures 7a-d show the standard deviation, which proves that the temperature in the room is regulated, spreads over a short range. The results of the experiment show that the control has excellent stability and adaptability. Consequently, the room temperature can be well controlled in all situations.

6.2 Discussion and Analysis

In this section, we compare performance of controlllers of similar researces and their energy efficiency rate. Different temperature setting and outdoor temperature rate give different results. The results show that the Fuzzy-PID controller is always have lower energy consumption compared to on/of, fuzzy PI, and model based control. Energy saving achieved is between 27 to 39%. Some related research on energy-saving measures that have been made using inverter technology include adjustable fan speed, refrigerant flow control, indoor temperature control, and water flow control, control of dampers, evaporator and expansion valve [10-12]. As an example, by using refrigerant flow control and variable air volume (VAV) system which adopted inverter technology resulted in energy savings of 22.2% and 11.7%, respectively [13], and 20% [14-16]. In addition, the programmable thermostat control method gave 12% energy saving [17] while the two position control method gave 22.8% saving [18]. There were comparisons with building indoor environment comfort systems through model predictive control. For example Woldekidan, 2015 [9], uses model based control and model predictive control for thermal and visual comfort control that got 17% energy efficiency rate.

7. CONCLUSION

Ensure a comfortable climate in a building, considering energy-efficient operation, attracts a great deal of attention worldwide. In this paper, we proposed a fuzzy-PID controller to ensure a comfortable indoor environment. To obtain high accuracy in controlling the comfort parameters, mathematical models of the parameters are investigated, after which decoupling strategies for comfort parameters are considered. By applying the developed mathematical model, the proposed fuzzy based self-adjusted PID controller was designed.

Experimental results demonstrated the effectiveness of the proposed fuzzy-PID controller. Comfort values of the indoor environment parameters were according to international standards for indoor environment comfort as specified by ASHRAE and ISO. In future, in order to get higher accuracy, we will improve the system by using a presence detector, and training the system in GPU.

REFRENCES:

[1] Peter O. Akadiri, Ezekiel A. Chinyio and Paul O. Olomolaiye. Design of A Sustainable Building: A Conceptual Framework for

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Implementing Sustainability in the Building Sector. Buildings 2012, 2, 126-152;

[2] Stefano Corgnati et. al. Statistical analysis and prediction methods Separate Document Volume V. Total energy use in buildings analysis and evaluation methods Final Report Annex 53 November 14, 2013

[3] Földváry,V.,Bukovianska D. Analysis of Energy Performance and Indoor Climate Conditions of the Slovak Housing Stock Before and After its Renovation. Energy Procedia. Vol 78, November 2015, pp 2184-2189..

[4] Altayeva, A., Omarov, B., & Im Cho, Y. (2018, January). Towards smart city platform intelligence: PI decoupling math model for temperature and humidity control. In 2018 IEEE International Conference on Big Data and Smart Computing (BigComp) (pp. 693-696). IEEE.

[5] Omarov, B., Altayeva, A., Turganbayeva, A., Abdulkarimova, G., Gusmanova, F., Sarbasova, A., ... & Omarov, N. (2018, November). Agent Based Modeling of Smart Grids in Smart Cities. In International Conference on Electronic Governance and Open Society: Challenges in Eurasia (pp. 3-13). Springer, Cham.

[6] Yu, T., Lin, C.: An intelligent wireless sensing and control system to improve indoor air quality: monitoring, prediction, and preaction. International Journal of Distributed Sensor Networks (2015)..

[7] Taleghani, M., Tenpierik, M., and Kurvers, S., A review into thermal comfort in buildings, Renewable and Sustainable Energy Reviews, 2013. 26: pp 201-215.

[8] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE standard 34 designation and safety classification of refrigerants; 2013.

[9] Woldekidan, Korbaga Fantu, "Indoor environmental quality (IEQ) and building energy optimization through model predictive control (MPC)" (2015). Dissertations - ALL. Paper 415

[10] Nasution, H. 2006. Energy Saving of an Air Conditioning System using PID and Fuzzy Logic Controllers. Universiti Teknologi Malaysia, Malaysia

[11] Zhou, Y. P., Wu, J. Y., Wang, R. Z. and Shiochi, S. 2007. Energy Simulation in the Variable Refrigerant Flow Air Conditioning System under Cooling Conditions. Energy and Buildings. 39: 212-222.

[12] Murakami, M., et. al. 2007. Fields Experiments on Energy Consumption and Thermal Comfort in the Office Environment Controlled by Occupants Requirements. Building and Environment. 42: 4022-4027.

[13] Ahmed, S. S., Majid, M. S., Novia, H. and Rahman, H. A. 2007. Fuzzy Logic Based Energy Saving Technique for a Central Air Conditioning System. Energy. 32: 1222-1234

[14] Abidin, N. Z. 1995. Retrofitting of Compressor Motor in Air Conditioning System for Energy Saving. Universiti Teknologi Malaysia, Malaysia

[15] Altayeva, A., Omarov, B., Suleimenov, Z., & Im Cho, Y. (2017, June). Application of multi-agent control systems in energy-efficient intelligent building. In 2017 Joint 17th World Congress of International Fuzzy Systems Association and 9th International Conference on Soft Computing and Intelligent Systems (IFSA-SCIS) (pp. 1-5). IEEE.

[16] Omarov, B. (2017, October). Applying of audioanalytics for determining contingencies. In 2017 17th International Conference on Control, Automation and Systems (ICCAS) (pp. 744-748). IEEE.

[17] Ramankulov, S., Usembaeva, I., Berdi, D., Omarov, B., Baimukhanbetov, B., & Shektibayev, N. (2016). Formation of the Creativity of Students in the Context of the Education Informatization. International Journal of Environmental and Science Education, 11(16), 9598-9613.

[18] Omarov, B. S., Mukhamedzhanov, B. K., Berkimbaev, K. M., Abusseitov, B. Z., Seidakhmetov, E. E., & Kendzhaeva, B. B. (2013). Forming Of Professional Competences Of Future Teacher-Trainers. Global Journal on Technology, 4(2).