Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

Design of Fuzzy-PI Decoupling Controller for the Temperature and Humidity Process in HVAC System

Trinh Luong Mien
University of Transport and Communications
Falcluty of Electrical and Electronic Engineering
Hanoi, Vietnam

Abstract: **Ensuring the comfortable air quality for people, using the heating, ventilation and air conditioning (HVAC) system, in the commercial center buildings or underground infrastructures is extremely important. This is directly related to the design of the controllers for two channels of the air conditioning: temperature and humidity of the indoor air. Firstly, the analysis and building an interactive nonlinear mathematical model of the indoor air is presented in this paper. Then, the article refers to methods of design the traditional PI controller, PI controller combined with decoupled controller and PI controller with self-tuning parameter based on fuzzy logic principle combined with decoupled controller for the heating and humidifying processes of the indoor air. Finally, the proposed controlles for temperature and humidity process is simulatated and tested on Matlab.**

Keywords: Temperature And Humidity; Fuzzy Logic Control; Decoupling Control; PID; Self-Tunning Fuzzy PID; HVAC.

Symbol

Symbol	*Unit*	*Description*
ρ_a	kg/m^3	Air density
C_p	J/kg^{o}C	Heat capacity of air
V_i	m^3	Volume of the room
T_p ,T_q ,T_o	^{o}C	Temp. after heating/cooling coil, temp. after humidifier, and outdoor temperature
τ	s	Time
F_p	m^3/s	Flowrate of hot/cold water
A_w	m^2	Area of the wall
U_w	W/m^2. ^{o}C	Overall heat transfer coefficient
K_b	W/m^{o}C	Thermal conductivity of the brick
d_w	m	Thickness of the wall
h_a	W/m^{o}C	Convection heat transfer coefficient of air
E_p	kJ/kg	Vapour enthalpy
f_a	m^3/s	Flow rate of the supplied air
Fq	m^3/s	Flowrate of steam
H_p , H_q , H_o	%	Humidity after heating/cooling coil, humi. after humidifier, and outdoor humidity
G_{ij} , $i,j=1,2$		Laplace transfer function
α_h , α_t		Channel coupling coefficient
I_t , I_h	mA	Controlled current for temp., hum. valves
T^*, H^*		Setpoint temperature, humidity
θ_{ij}		Delay time

Abbreviation

HVAC	Heating, ventilating, air conditioning
PI, PID	Propotinal, integral, derivative control
NL	Negative large
NS	Negative small
ZE	Zero
PS	Positive small
PL	Positive large
SM	Small,
ME	Medium
LA	Large
QL	Quite large
VL	Very large
ET,DET	Error and derivative error of temperature
EH,DEH	Error and derivative error of humidity
PT,IT	Fuzzy output for tunning-parameters of PI temperature
PH,IH	Fuzzy output for tunning-parameters of PI humidity

I. INTRODUCTION

The strong growth in the civil indutrial construction and transport infrastructure leading to the introduction of more high buildings, commercial centers, many tunnels, undergrounds ... where are required to be equiped with the HVAC system [1]. HVAC systems ensure to supply and maintain the comfortable indoor air for occupants with the desired air temperature, humidity and quality. The comfortable air inside these buidlings depends on the acurate temperature and relative humidity process control in HVAC system [2-4]. The comfortable temperature and humidity range are changing following on seasons and different countries [3]. Moreover, conventional HVAC systems consume approximate half of the total electric energy that is largely depend upon fossil fuel in modern cities [5]. This causes polluted atmophere and increasing in greenhouse gases emissions from HVAC applications. Therefore, the demand for the comfortable indoor air is in conflict with the call for reduction of energy consumption and environmental protection. Besides the problem of energy consumption, sometimes the incorrect operation of the HVAC systems may not help to improve indoor air [6-7]. Hence, it is a necessary to design control temperature and humidity strategies in order to improve the performance of HVAC systems. The control systems for indoor building air can be mainly classified into two categories according to the approaches employed: the conventional controllers and computational intelligence techniques. The proportional integrate derivative (PID) controller is employed the popular in conventional HVAC systems, because of the simpleness, easy installation and use [8-9]. However, PID is not solved completely nonlinear plant, resisting noise weakly, and not satifying demand about the indoor air quality. Intelligent controller, fuzzy logic or neural networks have

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

recently become practical as a fast, accurate and flexible tool to HVAC control strategy modeling, simulation and design [10-14]. With the designed controller, the performance of a HVAC system can be significantly improved [4,15]. Moreover, there are several disadvantages that limit the performance of current control technologies, such as: the on/off control causes the system switching working state too frequently; and neural networks are hard to put into application; controller is so complex. The results of applying the seft-tuning intelligent PID, fuzzy adaptive PID, adaptive predictive decoupling control, fuzzy control combined with neural network for the HVAC system, in papers [16-21], are to impove performance of the HVAC system. But the nonlinear model and the interaction between temperature and humidity process were not regarded completly. Hence, it is worth developing temperature and humidity process controllers of HVAC system for the purpose of impoving the indoor air quality and energy efficiency.

In this paper, by combining advantages of the self-turing parameters fuzzy PI control and decoupling control mothod, new temperature and humidity controller are developed and their performances as well as their potentials in HVAC control systems are discussed. The proposed control system is finally tested and evaluated by the simulation on Matlab.

II. MATHEMATICAL MODEL OF THE INDOOR AIR TEMPERATURE & HUMIDITY CONTROL SYSTEM

We study a room, equiped with the base HVAC system which has the heater by hot/cold water and the humidifier by steam, such as Fig.1. 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 humidified by the steam humidifier, and then it is 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-humid energy P by changing the hot/cold water flowrate F_p through the HWR/CHR control valve. The steam humidifier also gives the indoor air a thermal-humid energy Q by varying the steam flowrate F_q through the control steam valve. This system uses the temperature & humidity controller to adjusting the position of hot/cold water, steam valves, and then can change flowrate F_p, F_q following equation:

$$P = \alpha_p . F_p; \; Q = \alpha_q . F_q \qquad (1)$$

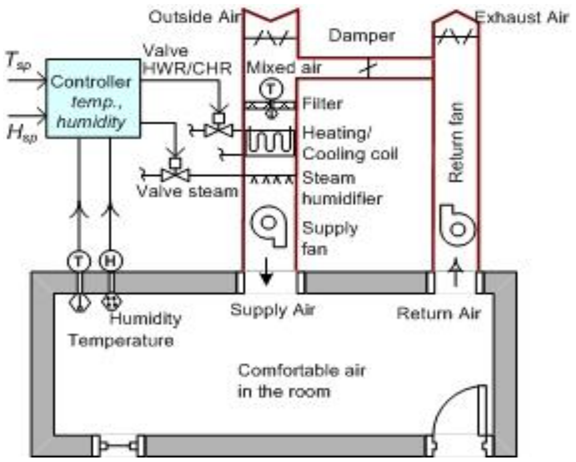

Fig. 1. Schematic diagram of the indoor air temperature & humidity control processes in HVAC system

2.1. Mathematical model of the indoor air temperature

The indoor air temperature is affected by the outside air temperature, initial indoor air temperature, volume of the room, heat loss from the wall, hot/cold water flowrate and steam flowrate as presented in Fig. 1. Thus, the indoor air temperature can be expressed as follow:

$$T(\tau) = T_p(\tau) + T_q(\tau) \qquad (2)$$

The main temperature T_p is supplied by the hot/cold water flowrate through the heating/cooling coil. Hence, it can be expressed as follows based on energy conservation principle:

$$r_a C_p V_i \frac{dT_p}{dt} = a_p F_p(t) - U_w A_w [T_p(t) - T_o(t)] \qquad (3)$$

The overall heat transfer coefficient for the wall U_w when the individual convection heat transfer coefficients for fluid on each side of the wall is equal, can be calculated as [3,6-7]:

$$U_w = \left(\frac{2}{h_a} + \frac{d_w}{K_b}\right)^{-1} \qquad (4)$$

By using Laplace transform, after changing equation (2) can be described as follows:

$$\left[\frac{r_a C_p V_i}{U_w A_w} s + 1\right] T_p(s) = \frac{a_p}{U_w A_w} F_p(s) + T_o(s) \qquad (5)$$

Assume $T_o=0$ and consider effect of the time delay of the heat transfer process in the room, such as θ_{tp}, then (5) can be simply transferred as follows:

$$G_{11} = \frac{T_p(s)}{F_p(s)} = \frac{k_{tp} e^{-q_{tp} s}}{t_{tp} s + 1}; \; t_{tp} = \frac{r_a C_p V_i}{U_w A_w}, k_{tp} = \frac{a_p}{U_w A_w} \qquad (6)$$

The indoor air temperature is also affected by the steam humidifier. Calculating the same as the main temperature, the temperature T_q causes by the steam humidifier, is expressed as

$$G_{12} = \frac{T_q(s)}{F_q(s)} = \frac{k_{tq} e^{-q_{tq} s}}{t_{tq} s + 1}; \; t_{tq} = \frac{V_i}{f_a}, k_{tq} = \frac{a_q a_t}{f_a r_a E_p} \qquad (7)$$

2.2. Mathematical model of the indoor air humidity

The indoor air humidity is directly affected by the steam humidifier, initial indoor air humidity, heating/cooling coil as in Fig.1. The indoor air humidity can be expressed as follows:

$$H(\tau) = H_p(\tau) + H_q(\tau) \qquad (8)$$

The main indoor air humidity H_q is produced by adjusting the position of the steam valve. So that it can be described as follows based on the energy conservation principle:

$$r_a V_i E_p \frac{dH_q}{dt} = a_q F_q(t) - r_a f_a E_p (H_q - H_o) \qquad (9)$$

Assume $H_o=0$ and consider the time delay of the humidity spread process in the room, such as θ_{hq}, then (9) can be simply transferred in Laplace - domain, as follows:

$$G_{22} = \frac{H_q(s)}{F_q(s)} = \frac{k_{hq} e^{-q_{hq} s}}{t_{hq} s + 1}; \; t_{hq} = \frac{V_i}{f_a}, k_{hq} = \frac{a_q}{f_a r_a E_p} \qquad (10)$$

The indoor air humidity is also affected by the heating/cooling coil. So that humidity H_p can be presented as:

$$G_{21} = \frac{H_p(s)}{F_p(s)} = \frac{k_{hp} e^{-q_{hp} s}}{t_{hp} s + 1}; \; t_{hp} = \frac{r_a C_p V_i}{U_w A_w}, k_{hp} = \frac{a_p a_h}{U_w A_w} \qquad (11)$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

2.3. Dynamic model of control valve

Most of the control valves are usually designed so that the flowrate through the valve is a nearly linear function of the signal to the valve actuator. Therefore, a first-order transfer function is an adequate model [8,14] for the dynamic characteristic of the electric-pneumatic valve in this project:

$$G_{vt} = \frac{F_p(s)}{I_t(s)} = \frac{k_{vt}e^{-\theta_{vt}s}}{\tau_{vt}s+1};\ G_{vh} = \frac{F_q(s)}{I_h(s)} = \frac{k_{vh}e^{-\theta_{vh}s}}{\tau_{vh}s+1} \qquad (12)$$

2.4. The mathematical model of the control object in the indoor air temperature and humidity control system

When considering interaction between temperature and humidity, the indoor air temperature and humidity processes is a two-input two-output model. The matrix transfer of control object in the indoor air temperature and humidity control system, when adding the model of the control valve, is given as follows:

$$\begin{bmatrix} T \\ H \end{bmatrix} = \begin{bmatrix} G_{vt}G_{11} & G_{vh}G_{12} \\ G_{vt}G_{21} & G_{vh}G_{22} \end{bmatrix} \begin{bmatrix} F_p \\ F_q \end{bmatrix} \qquad (13)$$

In this paper, we assume that the length of the testing room is 4m, width is 2m, heigh is 3m; the thickness of the brick wall is 0.3m; and the desired indoor temperature is 20°C. Therefore $V_i=24m^3$, $A_w=36m^2$, $d_w=0.3m$, $f_a=0.015m^3/s$. From [3-4] we recieve values as follows: $E_p=2538kJ/kg$, $C_p=1005J/kg.^oC$, $K_b=0.6W/m.^oC$, $\rho_a=1.2kg/m^3$, $h_a=10W/m.^oC$. And then we can calculate: $U_w=1.43$, $k_{tp}=0.019$, $\tau_{tp}=562.24$, $k_{tq}=0.009$, $\tau_{tq}=1600$, $k_{hp}=0.006$, $\tau_{hp}=562.24$, $k_{hq}=0.022$, $\tau_{hq}=1600$, We assume: $\alpha_t=0.4$, $\alpha_h=0.3$, $\theta_{tp}=5.6$, $\theta_{tq}=6.4$, $\theta_{hp}=1.7$, $\theta_{hq}=16$, $k_{vt}=22$, $\tau_{vt}=1.5$, $\theta_{vt}=0.6$, $k_{vh}=23.75$, $\tau_{vh}=2.5$, $\theta_{vh}=1.2$

III. A FUZZY - PI DECOUPLING CONTROLLER FOR THE TEMPERATURE AND HUMIDITY PROCESS

The temperature and humidity processes in the room are complicated: when making change the humidity then the temperature is also changing and on contrary while adjusting the temperature then humidity is also affected. So that , it is necessary to adding decoupling controllers in order to remove the relations between these two channels.

In HVAC system, it is common traditional PID controllers. However, the parameters of PID controllers is offten fixed in all operating time. This reduces the quality of control system when the process requires operating in different modes, or when the object parameters change, or impact noise. Meanwhile, the fuzzy logic has advantages in controlling uncertain objects and lets take advantage of experience operating the system.

Therefore, two PI controllers with seft-tunning parameters based on fuzzy logic calculations is proposed for two feedback control loop of the temperature & humidity processes. The structure of the Fuzzy-PI controllers decoupling controller for the temperature and humidity control in HVAC system is proposed as in Fig.2. The R_T, R_H are Fuzzy-PI controllers (FPI); k_{P0}, k_{I0} are initial parameters of PI controller; k_P, k_I are seft-tunning parameters based on fuzzy logic calculations (FC). The R_{TH}, R_{HT} are the decoupling controllers, designed based on the decoupling control principle.

3.1. The PI controllers design

The purpose of this PI controllers design is determined the initial paramaters for Fuzzy-PI controllers (k_{P0}, k_{I0}) for two temperature & humidity feedback control loop. If neglecting interaction between temperature and humidity, the transfer function of the temperature control loop object as:

$$G_T = G_{vt}G_{11} = \frac{0.42e^{-6.2s}}{(562.24s+1)(1.5s+1)} \qquad (14)$$

The transfer function of the humidity control loop object:

$$G_H = G_{vh}G_{22} = \frac{0.52e^{-17.2s}}{(1600s+1)(2.5s+1)} \qquad (15)$$

Applied Skogestad's approximation method, we have:

$$G_T = \frac{0.42e^{-6.95s}}{562.99s+1} = \frac{0.42}{(562.99s+1)(6.95s+1)} \qquad (16)$$

$$G_H = \frac{0.52e^{-18.45s}}{1601.25s+1} = \frac{0.52}{(1601.25s+1)(18.45s+1)} \qquad (17)$$

Arcoding to the optimal module principle [22], the parameters k_{P0}, k_{I0} can be determined as follows:

$$R_T^0(s) = k_{P0}^T + \frac{k_{I0}^T}{s},\ R_H^0(s) = k_{P0}^H + \frac{k_{I0}^H}{s} \qquad (18)$$

$$k_{P0}^T = \frac{562.99}{2x0.42x6.95} = 96.44,\ k_{I0}^T = \frac{1}{2x0.42x6.95} = 0.17$$

$$k_{P0}^H = \frac{1601.25}{2x0.52x18.45} = 83.45,\ k_{I0}^H = \frac{1}{2x0.52x18.45} = 0.05$$

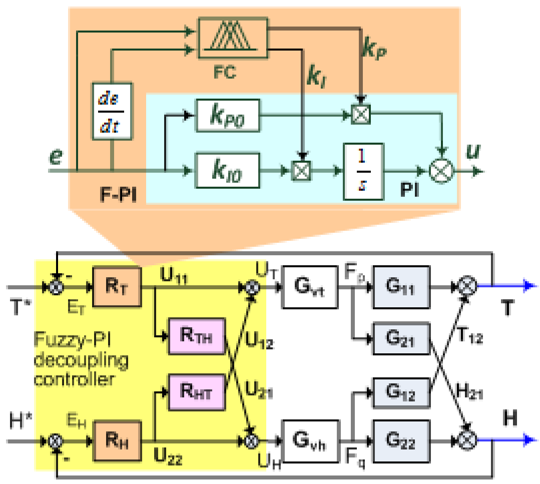

Fig. 2. Structure of Fuzzy-PI decoupling controller for HVAC system

3.2. The decoupling controllers design

Arcoding to the decoupling control principle, the decoupler R_{TH} is designed to cancel H_{21} arising from process interaction between U_T and H, and the decoupler R_{HT} is designed to cancel T_{12} arising from process interaction between U_H and T. In order to cancelling the influence between temperature and humidity chanels, output U_{21} & U_{12} need to satisfy conditions:

$$G_{vt}G_{21}U_{11} + G_{vh}G_{22}U_{21} = 0,\ G_{vh}G_{12}U_{22} + G_{vt}G_{11}U_{12} = 0 \quad (19)$$

Hence we obtain the transfer function of the decouplers:

$$R_{TH}(s) = -\frac{G_{vn}(s)G_{21}(s)}{G_{va}(s)G_{22}(s)},\ R_{HT}(s) = -\frac{G_{va}(s)G_{12}(s)}{G_{vn}(s)G_{11}(s)} \quad (20)$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

Using Skogestad's approximation [22], the decoupling controllers have the following form:

$$R_{TH}(s) = -\frac{0.25(1601.25s+1)(18.45s+1)}{(562.99s+1)(3.05s+1)} \quad (21)$$

$$R_{HT}(s) = -\frac{0.51(562.99s+1)(6.95s+1)}{(1601.25s+1)(8.85s+1)} \quad (22)$$

3.3. The fuzzy logic calculation blocks design

Fuzzy logic calculations blocks (FC) have: two inputs - temperature/humidity error (ET or EH), derivative of temperature error (DET or DEH); two output is PT (or PH), IT (or IH) corresponding to the output value k_{PT}, k_{IT} *(or* k_{PH}, k_{IH}*).*

Using membership functions are shaped triangular for all variables, fuzzied for all input variables by 5 fuzzy sets {NL (Negative Large), NS (Negative Small), ZE (ZEro), PS (Positive Small), PL (Positive Large)}, fuzzied for all output variables by 5 fuzzy sets {SM (SMall), ME (MEdium), LA (LArge), QL (Quite Large), VL (Very Large)}. The physical domain of the input & output variables are determined as: ET∈[-50,50], DET∈[-5,5], PT∈[0,100], IT∈[0,0.5]; PH∈[0,95], IH∈[0,0.5], EH∈[-95,95], DEH∈[-10,10].

Depending on the characteristics of the indoor air temperature (or humidity) control process and the PID control principle in order to improve quality control for system (see Tab.1), we define the 25 base fuzzy rules as Tab.2.

Tab.1. The effect of k_P, k_I tunning

Closed-loop respond	**Rise time**	**Settling time**	**Over-shoot**	**Steady state error**	**Stability**
Increasing k_P	Decrease	Increase	Small increase	Decrease	Degrade
Increasing k_I	Small decrease	Increase	Increase	Large decrease	Degrade

Tab.2. The base fuzzy rule of k_{PT}, k_{IT} (or k_{PH}, k_{IH})

PT (or PH) IT (or IH)		ET (or EH)				
		NL	*NZ*	*ZE*	*PS*	*PL*
DET (or DEH)	*NL*	SM	SM	SM	SM	SM
	NS	SM	ME	SM	SM	SM
	ZE	SM	SM	LA	LA	QL
	PS	SM	SM	LA	QL	VL
	PL	SM	SM	QL	VL	VL

Using the Max-Min composition rule and the cetroid defuzzification method, we can obtain the clear output value of FCs: k_{PT}, k_{IT} for temperature loop and k_{PH}, k_{IH} for humidity loop. Then, the self-tuning parameters of PI controllers can be calculated by equations:

$$k_P^{*T} = k_{P0}^T k_P^T,\ k_I^{*T} = k_{I0}^T k_I^T \quad (23)$$

$$k_P^{*H} = k_{P0}^H k_P^H,\ k_I^{*H} = k_{I0}^H k_I^H \quad (24)$$

IV. SIMULATION AND RESULT

The simulation is carried out to analyse the performance of three controllers for the humidity and temperature control loops in HVAC system: (1)- PI controller (PI), (2)- PI decoupling controller (PIdcp); (3)- fuzzy-PID decoupling controller (FPIDdcp). The PI controller was designed in 3.1, The PI decoupling controller is composed of the decoupler in 3.2 and the PI controller in 3.1. The fuzzy-PID decoupling controller consists of the decoupler in 3.2 and the PI controller with seft-tunning parameters (the fuzzy logic calculation block was designed in 3.3, the PI initial parameters in 3.1). The simulations have been taken on the platform of Matlab as described in Fig.3. The simulating results are used to indicate the controllers' performance including several indexes: overshoot, steady time, steady error, coupling effect.

The simulation was tested with initial indoor air situations: 15^0C, 10% and assume required humidity & temperature

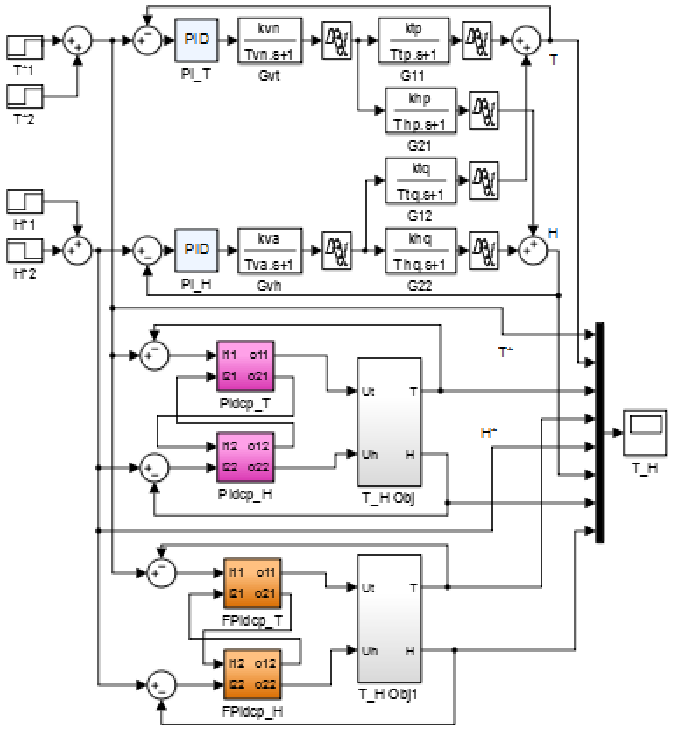

Fig. 3. *Simulating the temperature & humidity control processes in Matlab*

The simulation was tested with initial indoor air situations: 15^0C, 10%; Assume required indoor air temperature increased from 35ºC up 55ºC at 200 seconds, and humidity varied from 90% down to 70% at 400 seconds (Fig.4). The response curves of the indoor air temperature & humidity control processes with 3 controllers is presented in Fig.4.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

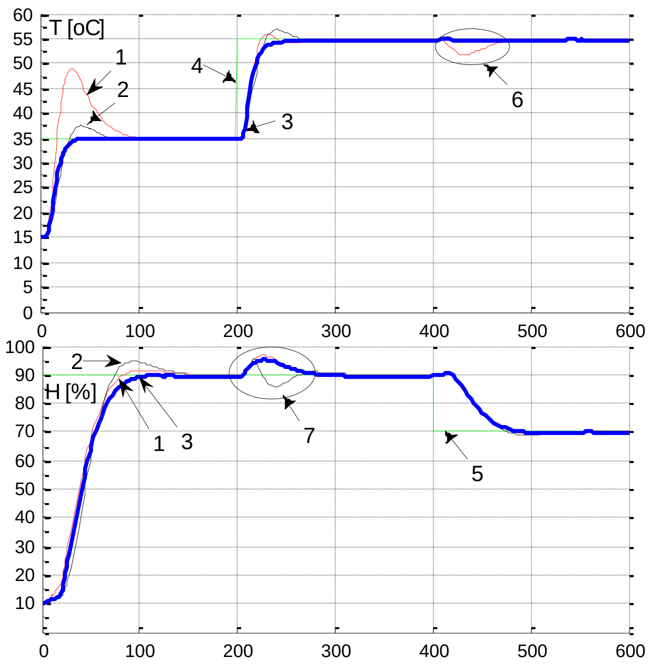

Fig. 4. Response curves of temperature & humidity control with 3 cotrollers: 4-T*, 4-H*, 1-PI, 2-Pidcp, 3-FPIdcp, 6-varying H* affect the temperature response, 7-varying T* effect the humidity response.

The performance of the proposed controllers (PI, PIdcp, FPIdcp) is presented in Tab.3.

Tab.3. The proposed controllers' performance

Control process	Control-ler	Over-shoot (%)	Steady time (s)	Steady error	Coupling effect (%)
Temp-erature	PI	55.9	84.5	0.02	8.3
	PIdcp	15.3	59.5	0.01	2.5
	FPIdcp	~ 0	31.4	0	0.05
Humi-dity	PI	2.1	80.2	0.08	8.2
	PIdcp	5.6	104.3	0.21	5.2
	FPIdcp	~ 0	80.1	0	3.5

The simulating results of the proposed temperature and humidity controllers show that the FPIdcp has the best control quality: no overshoot, eliminating steady error, the smallest steady time and eliminating neraly the effect of the coupling channels disturbaces when it was compared to other controllers: PI, PIdcp.

Therefore, with the proposed FPIdcp controller, the indoor air quality can be well control since: PI controller is suitable for various control object including indoor climate factors control; the fuzzy logic calculation block for optimal PI parameters tuning to ensure adaptability to different situations; better PI control parameters selection can ensure the desired system output; the decoupling controllers eliminate the interaction between temperature & humidity processes.

V. CONCLUSION

The indoor air temperature and humidity control process was studied and presented in this paper. Based on the nonlinear model of the indoor air temperature and himidity, considering the influence of the coupling channels, three controllers (PI controller, PI decoupling controller, fuzzy-PI decoupling controller) were designed, simulated on Matlab.

The simulation results have proved the proposed fuzzy-PI decoupling controller has excellent performance on efficient auto tuning of the PI parameters only when needed: fast response speed; small overshoot; small steady error; and stability and adaptability response to uncertain factors. In other words the fuzzy-PI decoupling controller suitbles for controlling simultaneously the indoor air temperatue and humidity processes in HVAC system. The fuzzy-PI decoupling controller can improve the indoor air quality, increase the process efficiency and bring economic benefits to the user.

REFERENCE

[1] Yu BF, Hu ZB, Liu M. (2009); *Review of research on air conditioning systems and indoor air quality control for human health*; International Journal Refrigeration 32.

[2] Graudenz GS, Oliveira CH, Tribess A. (2005); *Association of air-conditioning with respiratory symptoms in office workers in tropical climate*; Indoor Air 2005;15:62-6.

[3] DeDear RJ, Brager GS (2002); *Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55*; Energy and Buildings, 34(6): 549–61.

[4] S. Soyguder, H. Alli; *An expert system for the humidity and temperature control in HVAC systems using ANFIS and optimization with Fuzzy Modeling Approach*; Energy and Buildings 41 (2009) 814–822.

[5] S.W. Wang (2010); *Intelligent Buildings and Building Automation*; Spon Press (Taylor & Francis), London and New York, 2010.

[6] Taleghani, M., Tenpierik, M., Kurvers, S. (2013); *A review into thermal comfort in buildings*, Renewable and Sustainable Energy Reviews, 26, 201-215.

[7] Wolkoff, P. (2013); *Indoor air pollutants in office environments: Assessment of comfort, health, and performance*, International Journal of Hygiene and Environmental Health 216, 2013, 371-394.

[8] W.S. Levine, Ed. (1996); *PID Control: The Control Handbook*; Piscataway, NJ: CRC IEEE Press, 1996, pp. 198–209.

[9] K.H. Ang, G. Chong, and Y. Li (2005); *PID control system analysis, design, and technology*; IEEE Trans. Contr. Syst. Tech., vol. 13, no. 4, pp. 559–576.

[10] S.W. Wang, X.Q. Jin (2000); *Model-based optimal control of VAV air-conditioning system using genetic algorithm*; Build. Environ. 35 (6), 471–487.

[11] F.W. Yu, K.T. Chan (2006); *Advanced control of heat rejection airflow for improving the coefficient of performance of air-cooled chillers*; Appl. Therm. Eng. 26 (1), 97–110.

[12] X. Jin, Z. Du, X. Xiao (2007); *Energy evaluation of optimal control strategies for central VWV chiller systems*; Appl. Therm. Eng. 27 (5-6), 934–94.

[13] T.Y. Chen (2002); *Application of adaptive predictive control to a floor heating system with a large thermal lag*; Energy Build. 34.

[14] S.W. Wang (1998); *Dynamic simulation of building VAV air-conditioning system and evaluation of EMCS on-line strategies*; Building and Environment 1998, 36 (6).

[15] Yang, S., Wu, S., Yan, Y.Y., (2013). *Control strategies for indoor environment quality and energy efficiency - a review*; International Journal of Low - Carbon Technologies.

[16] Song, Y., Wu, S., Yan, Y. (2013); *Development of Self-Tuning Intelligent PID Controller Based on 115 for Indoor Air Quality Control*; International Journal of Emerging Technology and Advanced Engineering, 3:11:283-290.

[17] Huang, S., & Nelson, R. M. (1994); *Rule development and adjustment strategies of a fuzzy logic controller for an HVAC system: Part one – analysis*; ASHRAE Transaction, 100 (1), 841–850.

[18] Soyguder, S., Karakose, M., Alli, H. (2009) *Design and simulation of self-tuning PID-type fuzzy adaptive control for an expert HVAC system*; Expert Systems with Applications, 36.

[19] Soyguder, S., Alli, H. (2009); *An expert system for the humidity and temperature control in HVAC systems using ANFIS and optimization with Fuzzy Modeling Approach*; Energy and Buildings 41, 814–822.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

[20] S. Soyguder, M. Karakose, H. Alli (2008), *Design and simulation of self-tuning PID-type fuzzy adaptive control for an expert HVAC system*; Expert System with Applications 42.

[21] Song, Y., Huang, X. and Feng, Y. (2013); *A Kind of Temperature and Humidity Adaptive Predictive Decoupling Method in Wireless Greenhouse Environmental Test Simulation System*; Adv. J. Food Sci. Technol., 5(10): 1395-1403.

[22] Sigurd Skogestad (2001); *Probably the best simple PID tuning rules in the world;* Journal of Process Control.

Trinh Luong Mien obtained his Ph D degree in automation and control of technological processes and manufactures at Moscow State University of Railway Engineering (MIIT) in Russia Federation in 2012.

Trinh Luong Mien is a lecturer at Faculty of Electrical and Electronic Engineering - University Transport & Communications in Vietnam since 2004. His main research is the development of intelligent control algorithms for the technological and manufacturing processes in industry and transportation based on fuzzy logic, neuron network, adaptive & optimal theory; study control algorithms & guarantee safe movement of the electrical train in ATP/ATO/ATS/ATC system of the urban railway; design of supervisory control and multi-channel data collection systems.