Combined system development of heat ventilation air
condition temperature control by fuzzy logic controller

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Abstract. This paper presents the development of combined model, which describes the
temperature control process of an automated heat ventilation air condition system based on
fuzzy logic algorithms and methods. This model solves the problem of hydraulic systems
excessive inertia, what directly affects the quality of regulation. The operation principle of
the system and its advantages, which consist in obtaining high-quality transients for the parameters
of static error and transient process time, are presented. Proposed control principle allows to
increase the system performance improving the quality of temperature parameters regulation.
Model was developed in Matlab Simulink using FuzzyLogicToolbox.

1. Introduction

Ventilation system is essential part of creation optimal and comfortable environment inside the
building for human life activity.

Modern ventilation systems are made a number of requirements for reliability, efficiency and
maintenance of indoor climate conditions. Temperature and humidity are the most important
parameters for a comfortable microclimate. Therefore, accurate maintenance of these parameters
optimal values is the priority function of the ventilation system. In developed system the air
temperature will be maintained by water heating equipment [1], [2].

For more precise optimal control of air parameters, an automated ventilation system is used.
Automation ventilation system is supposed to create a set of methods and tools that allows to realize
the ventilation process control possibility without human interference.

In modern systems of automation heat ventilation air condition automation systems (HVAC), along
with the classic proportional-integral-differentiating (PID) and proportional-integral (PI) controllers,
used fuzzy logic controllers [3], [4].

Fuzzy logic is a logical system, which operates not only with the concepts “true” and “false” in
contrast to Boolean logic, but allows to draw conclusions about the veracity degree of various
statements [5].
Fuzzy logic more accurately and naturally describe human’s thinking and reasoning process than standard logical systems. Fuzzy modeling permit to obtain more adequate results in comparison with the results obtained using standard analytical algorithms and control models [6], [7].

This article describes a fuzzy control system for an automated supply HVAC. This fuzzy control system is implemented on arithmetic and logic controllers. Fuzzy logic conclusions are reached by calculating the characteristic values of the linguistic variable at the output through the characteristic values of the linguistic variables at the input, using logical formulas based on the logical operations “AND” and “OR”.

This type of controllers has a number of advantages over the classic PI and PID:
- fuzzy logic controllers allows to control multiple parameters by a single controller;
- simpler and more convenient control system synthesis in contrast to the classic PI and PID;
- the fuzzy controller structure doesn’t depend on the object parameters;
- ability to achieve higher quality of transition process parameters in comparison with classical regulators.

2. Control system mathematical model

Classical control methods operate with deterministic control object and in a deterministic environment, but fuzzy control methods are optimal to apply in systems with incomplete information or with control object high complexity [8], [9].

The main control parameter of this system is the indoor air temperature. The current room temperature value is received by temperature sensor and transmitted to the controller. Regarding this parameter fuzzy logic controller set the radiator valve servo drive control voltage level \( U_c \). \( U_c \) is proportional to the valve stem position and the diameter of the pipeline \( d \). In case of the pipeline diameter vary the mass flow rate \( G \) of the heat carrier passing through the radiator changes, thereby changing the amount of heat transferred to the air \( Q_{\text{air}} \). Changing \( Q_{\text{air}} \) leads to a change in the air temperature.

The mathematical model of the described system is derived from the thermal balance formula of the air in the room:

\[
Q_{\text{air}} = Q_{\text{wat}} - Q_{\text{los}}
\]  

(1)

where \( Q_{\text{air}} \) - amount of the heat transferred to the air, \( Q_{\text{wat}} \) - heat amount of the heat carrier, \( Q_{\text{wat}} \) - heat loss inside the room [10], [11].

From the equation (1) follows:

\[
c_{\text{air}} \cdot m_{\text{air}} (T_{\text{cur}} - T_{\text{req}}) = c_{\text{wat}} \cdot G \cdot t (T_{\text{sup}} - T_{\text{ret}}) - \frac{\Delta T}{R}
\]  

(2)

where \( c_{\text{air}} \) - air heat capacity; \( m_{\text{air}} \) - air mass; \( T_{\text{cur}} \) - current air temperature; \( T_{\text{req}} \) - required air temperature; \( c_{\text{wat}} \) water heat capacity; \( G \) - heat carrier mass flow rate; \( T_{\text{sup}} \) - heat carrier temperature in the supply pipeline; \( T_{\text{ret}} \) - heat carrier temperature in the return pipeline; \( t \) - time; \( \Delta T \) - temperature difference between indoor and outdoor air; \( R \) - heat transfer resistance through the outer walls.

The mass flow rate \( G \) is determined by the equation:

\[
G = \frac{\pi d^2}{4} \cdot \nu \cdot \rho
\]  

(3)

where \( d \) - pipeline diameter; \( \nu \) - water flow velocity; \( \rho \) - water density.

From the equation (3) follows:
\[
d = \sqrt{\frac{4G}{\pi \rho}}
\]

Water flow velocity \( v \) is determined by the Torricelli’s equation:

\[
v = \sqrt{2gH}
\]

where \( g \) - gravity; \( H \) - water column height. As \( H = \frac{P_{\text{wat}}}{\rho \cdot g} \)

From the equation (5) follows:

\[
v = \sqrt{\frac{2 \cdot P_{\text{wat}}}{\rho}}
\]

where \( P_{\text{wat}} \) - water pressure inside the pipeline.

From the equations (4), (6) follows:

\[
d = \sqrt{\frac{4G}{\pi \sqrt{2P_{\text{wat}} \cdot \rho}}}
\]

\( d \) directly proportional to the control voltage \( U_c \):

\[
d = \frac{U_c \cdot d_{\text{max}}}{U_{\text{max}}}
\]

where \( U_{\text{max}} \) - maximum rate of control voltage, \( d_{\text{max}} \) - maximum value of pipeline diameter.

From the equations (8), (7) follows:

\[
U_c = \frac{U_{\text{max}}}{d_{\text{max}}} \cdot \sqrt{\frac{4G}{\pi \sqrt{2P_{\text{wat}} \cdot \rho}}}
\]

Equation (9) – mathematical model of the control object. The block diagram of this model is shown in “Figure 1” [12], [13].
Figure 1. Mathematical model block diagram.

The control action is directed to the servo drive of the supply pipeline valve. The system of equations for the servo dynamics:

$$\begin{align*}
U &= RL + L \frac{dI}{dt} + k_\omega \omega \\
M &= k_M I = \dot{\omega} J_d
\end{align*}$$

where $U$ – voltage, $L$ – inductivity, $\omega$ - angular velocity, $\dot{\omega}$ - angular acceleration, $I$ – current, $k_\omega$ - speed constant, $k_M$ - torque constant.

In Laplace’s form:

$$\begin{align*}
U &= RL + LpI + k_\omega \omega \\
M &= k_M I = p\omega J_d
\end{align*}$$

A servo model can be assembled in Simulink based on this equations. The servo transfer function can be obtained, as follows:

$$T_e = \frac{L_d}{R_d}$$
where $J$ - moment of inertia, $T_e$ - electromechanical constant of time, $L_d$ - drive inductance, $R_d$ - drive resistance, $W_1$ - drive transfer function, $W_d$ - drive transfer function closed by velocity feedback.

In our case, it is necessary to install and maintain the position of the heater valve. We consider position control mode, which is realized by angular control of drive output shaft with feedback, performed by angle sensor (Figure 2).

The heater valve required position is provided by control voltage, transmitted in PWM mode [14]. For heater valve control, we use servo drive made by “MAXON” company. Model: DC-max 16 S Ø16 mm, CLL precious metal brushes, sintered bearings. Model block diagram of this servo drive presented at “Figure 2”:

**Figure 2.** Model block diagram of servo drive.

### 3. Controller based on fuzzy logic

All numeric data in membership function obtained empirically. The input linguistic variables in the developed controller are set as follows: room air temperature ($envir_temp$), heat carrier temperature in the supply pipeline ($water_temp$). For linguistic variable $envir_temp$ the following membership functions are set: very_low is typical Z-membership function [15], described by the following expression:

$$
very\_low(envir\_temp) = \begin{cases} 
1, & 0 \leq envir\_temp \leq 7 \\
\frac{13 - envir\_temp}{6}, & 0 \leq envir\_temp \leq 7 \\
0, & 13 \leq envir\_temp \leq 30 
\end{cases}
$$

and presented at “Figure 3”;

$low$ is typical triangular membership function, described by the following expression:
and presented at “Figure3”; 

normal is typical \(P\)-membership function, described by the following expression:

\[
normal\left(\text{envir } \text{temp}\right) = \frac{1}{1 + \left|\frac{\text{envir } \text{temp} - 22.5}{21}\right|^4}
\]  

(17)

and presented at “Figure3”;

high is typical \(S\) membership function, described by the following expression:

\[
high\left(\text{envir } \text{temp}\right) = \begin{cases} 
0, & \text{envir } \text{temp} \leq 23 \\
\frac{\text{envir } \text{temp} - 23}{7}, & 23 < \text{envir } \text{temp} < 30 \\
1, & \text{envir } \text{temp} \geq 30
\end{cases}
\]  

(18)

Figure 3. Membership function (terms) \textit{envir}\_\textit{temp}.

For linguistic variable \textit{water}\_\textit{temp} the following membership functions are set:

\textit{water}\_\textit{temp}\_\textit{low} is membership function, described by the following expression:

\[
\text{water}\_\textit{temp}\_\textit{low}\left(\text{water}\_\textit{temp}\right) = \begin{cases} 
1, & \text{water}\_\textit{temp} \leq 40 \\
\frac{87 - \text{water}\_\textit{temp}}{47}, & 40 < \text{water}\_\textit{temp} < 87 \\
0, & \text{water}\_\textit{temp} \geq 87
\end{cases}
\]  

(19)

\textit{water}\_\textit{mid}\_\textit{temp} is trapezoidal membership function, described by the following expression:
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The output linguistic value *output1* describes the extent to which the valve stem is opened and has the following functions: *I_smin, I_min, I_mid, I_max* “Figure 5”.

The fuzzy control action is realized on the basis of the following rules:
1. if (*envir_temp* is *very_low*) and (*water_temp* is *water_temp_low*) then (*output1* is *I_max*);
2. if (*envir_temp* is *very_low*) and (*water_temp* is *water_mid_temp*) then (*output1* is *I_max*);
3. if (*envir_temp* is *very_low*) and (*water_temp* is *water_temp_high*) then (*output1* is *I_max*);
4. if (*envir_temp* is *low*) and (*water_temp* is *water_temp_low*) then (*output1* is *I_max*);
5. if (envir_temp is low) and (water_temp is water_mid_temp) then (output1 is I_max);
6. if (envir_temp is low) and (water_temp is water_temp_high) then (output1 is I_mid);
7. if (envir_temp is normal) and (water_temp is water_temp_low) then (output1 is I_mid);
8. if (envir_temp is normal) and (water_temp is water_mid_temp) then (output1 is I_min);
9. if (envir_temp is normal) and (water_temp is water_temp_high) then (output1 is I_smin);
10. if (envir_temp is high) and (water_temp is water_temp_low) then (output1 is I_smin);
11. if (envir_temp is high) and (water_temp is water_mid_temp) then (output1 is I_smin);

4. Combined control system

For system presented at “Figure 6” has been developed the combined control system: a fuzzy controller controls the system by the input temperature parameters: input_water_temp, environment_temp. The PID controller controls the position of the valve stem by vary angle of servo drive.

![Figure 6. Model block diagram of control system with the fuzzy logic controller.](image)

When using these regulators, was obtained a transition process, presented on “Figure 7”:

![Figure 7. The transition process under nominal temperature values.](image)
The quality of the transition process is defined by overshoot rate and the established static error. The value of these parameters is presented in “Table 1” [16].

**Table 1. The quality value of the transition process.**

| Time of re-regulation, sec. | Established static error |
|----------------------------|--------------------------|
| 0,7                        | 0,005                    |

This transition process is built at nominal values of the supply water temperature of 95°C. If the input parameters deviate from the nominal values, the regulators of this system provide an equivalent transition process with similar quality parameters “Figure 8”

The quality parameters of this transition process are presented in “Table 2”.

**Table 2. The quality value of the transition process.**

| Time of re-regulation, sec. | Established static error |
|----------------------------|--------------------------|
| 0,8                        | 0,003                    |

As can be seen from the data presented, even if the input parameters deviate from the nominal values, the combined control system with a fuzzy controller keep high quality parameters of the transition process.

5. Conclusion
As part of the work described in the paper was developed a combined model to describe the process of temperature control in the supply and exhaust ventilation system. The fuzzy controller settings have been determined to regulate the position of the valve according to the parameters of the room temperature and water in the supply pipeline of the heater. It was shown that a control model ensures high quality of the transition process with various deviations of the input parameters.
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