Energy Efficiency Control of Home Heating

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***Abstract* – One of the possibilities for an efficient use of electrical energy for heating is to apply a certain temperature schedule for heating of the room. In case of optimization using the criteria of minimum electric energy consumption, the time it takes to reach a set temperature increases, and in time-optimal control, the electric energy consumption increases. This article proposes fuzzy control of the heating in a household room in accordance with the energy consumption, response time and accuracy, which is performed within an admissible range specified by the thermal comfort in the home.**

***Keywords* – thermal object control, fuzzy control, energy efficiency.**

1. Introduction

The price of electrical energy continuously increases, yet it is still widely used for heating households [3, 7]. Therefore, one of the requirements observed in control of the thermal objects is cost efficiency of energy consumption. In order to reduce energy consumption, it is necessary to maintain a certain 24-hour temperature schedule of heating the room, in accordance with which the input signal of the system should be changed. Temperature drop in the heated room at certain hours of the day helps for energy saving, but it also requires that the room must be rapidly heated when the set point changes in order to maintain thermal comfort. Minimum energy consumption control results in an increased duration of the transient response, while time-optimum control leads to higher energy consumption. [6]. Therefore, both cost effectiveness and thermal comfort of the heating of household premises need to be considered for the heating system control synthesis.

To prevent an overload of the home electrical network it is necessary to prepare a 24-hour heating energy consumption schedule in advance. A system of this kind, which considers the set limitations for the electric power used for heating is non-linear, and the classic methods of control give way to fuzzy control [1,4,5]. When the ambient temperature and the limitations on the electric power used for heating are such that the set point of temperature cannot be reached within the respective 24-hour schedules of energy and temperature, the deviation from the set point necessary to maintain the thermal comfort must be within admissible limits.

The results of several studies [1, 2, 4, 5] show that the control by means of a fuzzy controller in conditions of uncertainty provides better system quality parameters than control by linear controllers. Therefore, by choosing the appropriate linguistic variables and control rules, it is necessary to implement home temperature control consistent with the requirements for cost-effectiveness and thermal comfort under external conditions that vary within a wide range.

The objective of this article is to offer fuzzy control of the heating of a household room which considers the energy consumption, response time and accuracy within admissible limits, determined by the thermal comfort in the home.

2. Description of the thermal object

The object of control is a heated room, with an output variable the temperature in the room, and control action – the power of the heat source.

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The transfer function of the generalized object is

$$W(p) = \frac{k_1 k_2}{(T_1 p + 1)(T_2 p + 1)} e^{-\tau p}$$

where k_1 and T_1 are the parameters of the heated room,

k_2 and T_2 – parameters of the thermal converter,

τ – delay in the control channel [7].

The control action is limited in value $|u(t)| \leq P_{max}$.

The values of the parameters of the thermal object are

$$k_1 = 0.009 \frac{°C}{W}, k_2 = 1, T_1 = 700.2s, T_2 = \\ = 30s, P_{max} = 2600W, \tau = 200s.$$

3. Fuzzy control synthesis

The block diagram of the control system is shown in Fig. 1. The output signal in the system is temperature y, °C, and the control action is the power of the electric heaters used for heating the home. The synthesized controller has three input variables –error e in the system, expressed in °C, the ambient temperature T_a and the level of electric power, used for heating, P. The error e represents the difference between the temperature in the home and the temperature setting fixed in the 24-hour heating temperature schedule, shown in Fig. 2a. The error is set by 5 linguistic variables in the range from -1 to 10°C: NSD – negative small difference; ZD – zero difference; PSD – positive small difference; PMD – positive medium difference; PBD – positive big difference.

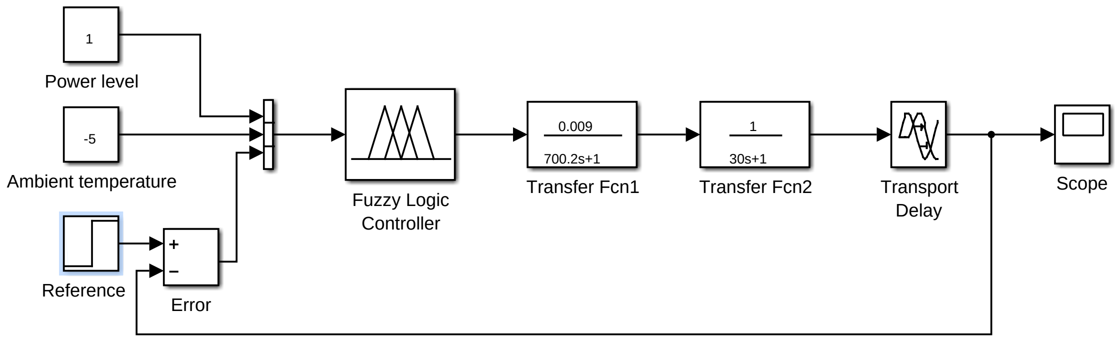
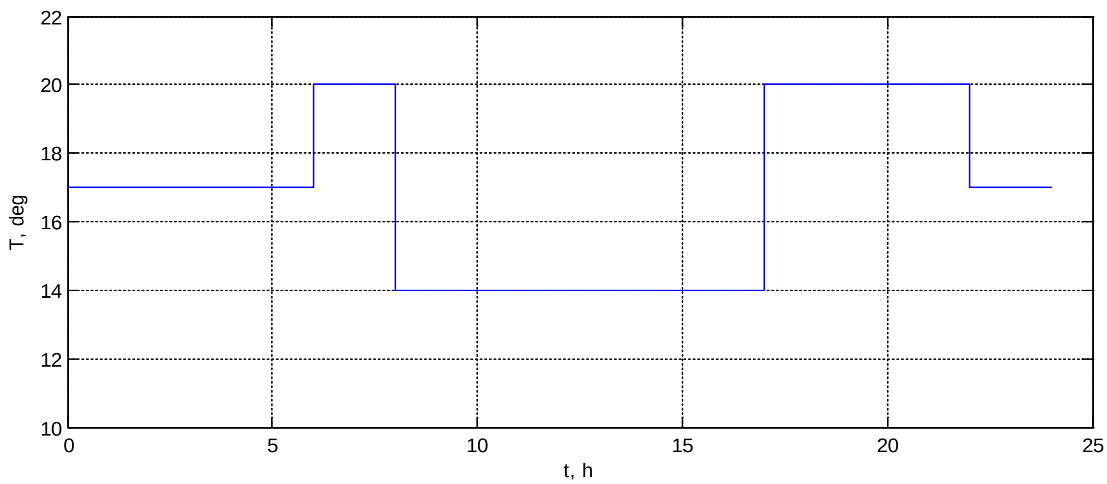


Fig. 1. Block diagram of the control system

The input variable T_a is set by three linguistic variables in the range from -15 to 15°C: Very Low, Low and Normal for the season. The input variable P indicates the maximum permissible electric power which can be used for heating in accordance with the 24-hour schedule given in Fig. 2b. It is set by three linguistic variables: Low, Middle and High level of electric power used for heating. Triangular functions are selected for membership of the linguistic values of the variables e, T_a and P.



a)

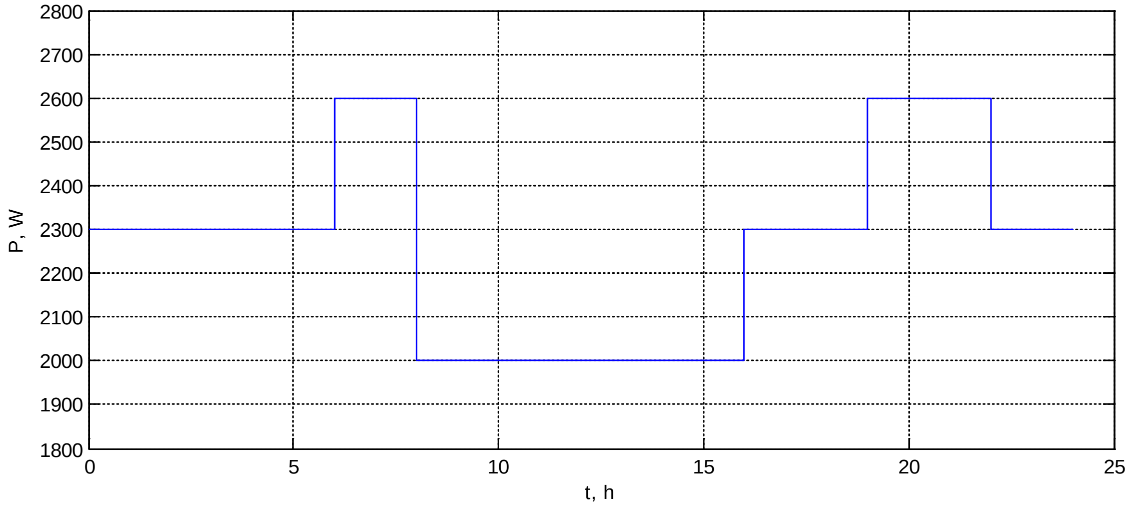


Fig. 2: a) 24-hour heating temperature schedule; b) maximum permissible power schedule

The Sugeno algorithm is applied to convert the controller input variables into an output variable. The controller output variable u is determined by the discrete levels 0, 2000, 2300, 2600W. These levels of electric power are set by the variables Mf1, Mf2, Mf3 and Mf4, accordingly. The control rules, 45 in total, part of which appear in Table 1, are constructed to meet the requirement for thermal comfort in the home. For instance, for a very low ambient temperature a higher level of electric power used for heating is envisaged than at normal ambient temperature for the season. The control action in the system u is obtained after defuzzification of the fuzzy output value into a numerical form.

Table 1. Logic control rules

If T_a is Very low			
e \ E	Low	Middle	High
NSD	Mf2	Mf3	Mf3
ZD	Mf2	Mf3	Mf3
PSD	Mf3	Mf3	Mf4
PMD	Mf3	Mf3	Mf4
PBD	Mf3	Mf4	Mf4
If T_a is Low			
e \ E	Low	Middle	High
NSD	Mf1	Mf2	Mf3
ZD	Mf2	Mf2	Mf3
PSD	Mf2	Mf3	Mf3
PMD	Mf2	Mf3	Mf4
PBD	Mf3	Mf3	Mf4
If T_a is Normal			
e \ E	Low	Middle	High
NSD	Mf1	Mf1	Mf2
ZD	Mf1	Mf2	Mf2
PSD	Mf1	Mf2	Mf2
PMD	Mf1	Mf2	Mf3
PBD	Mf2	Mf3	Mf3

4. Results and discussions

In order to assess the proposed control system, a study has been carried out by simulating that system in the MATLAB programming environment.

Fig. 3 presents the transient response in the system without limitation of the electric power used for heating, at different values of the ambient temperature T_a. Curve 1 at $T_a = -15$℃, curve 2 - $T_a = -5$℃ and curve 3 is the transient response, obtained from control without considering T_a. The duration of the transient response is respectively: curve 1 – 21 minutes, curve 2 – 20 minutes and curve 3 – 35 minutes. Therefore, the duration of the transient response with the use of the proposed controller, curves 1 and 2, is 15 minutes less than that of the transient response which does not consider the ambient temperature.

Fig. 4 presents the results at $T_a = -\ 15$℃ and different levels of the electric power used for heating. Curve 1 corresponds to $P = 1$, curve 2 corresponds to $P = 0.8$ and curve 3 corresponds to $P = 0.75$. The duration of the transient response increases by 12 minutes when the level of the used electric power is reduced by 25%. The decrease in the level of electric power used for heating increases the response time of the system, but also reduces the electric energy consumption by 9%.

5. Conclusion

A fuzzy control system for heating of household rooms is proposed, which allows different levels of heating power, aiming at energy saving. It also offers different process duration for reaching the set temperature, thus providing the desired thermal comfort.

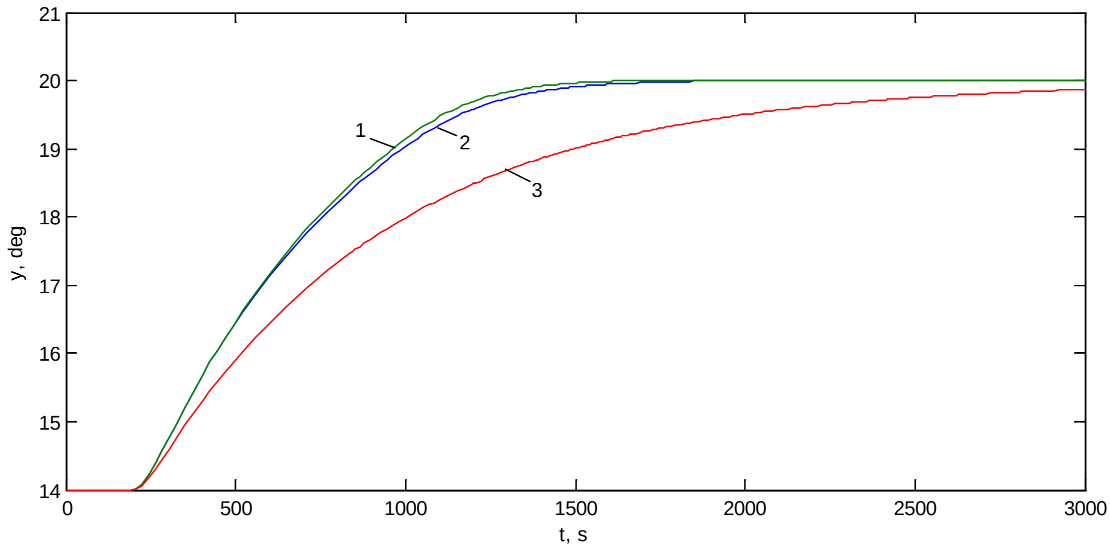


Fig. 3. Transient response in the system without limitation of the electric power, at different values of T_a

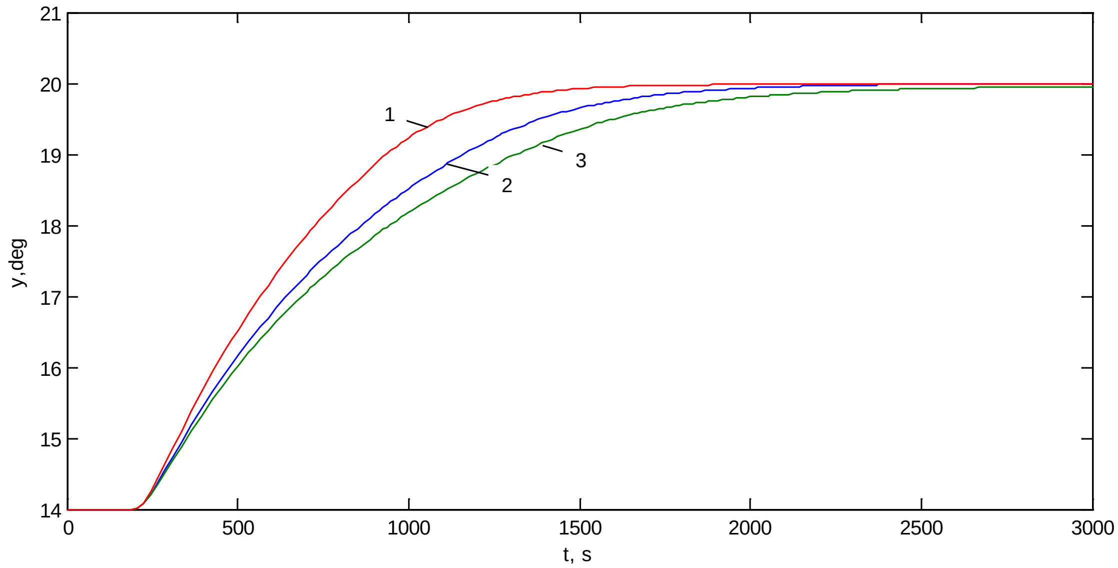


Fig. 4. Transient processes in the system at $T_a = -15$°C, *at different values of the used electric power*

The time taken to reach a set temperature in the household room with the ambient temperature considered is about 15 minutes less compared to the time taken to reach the same temperature without considering the ambient temperature. If the amount of electric power used is reduced by 25%, the duration of the transient processes increases by 12 minutes. Hence, the reduced electric power also reduces the response rate of the system but it also leads to a decrease in the electric energy consumption by 9%.

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