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Modelling of Intelligent Mechatronics Systems with Climate Parameters Control

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Abstract

The article presents mathematical problem formulation of intelligent agents in mechatronics problems for climate parameters optimal control. The methods of the problem solving and structure of problem solving algorithm are given in the article. There are main conclusions in the article. This work has been partly supported by European Social Fund within the National Programme "Support for carrying out doctoral study programme's and post-doctoral researches" project "Support for the development of doctoral studies at Riga Technical University" (grant Nr. 2004/0002/VPD1/ESF/PIAA/04/NP/3.2.3.1/0001/0002/0007).

KEY WORDS: *intelligent agents, modelling, intelligent mechatronic systems, intelligent agents, electrical processes, climate control.*

1. Introduction

Public electric transportation vehicles- train, tram or trolleybus are considered as mechatronic system in this article. Interest is concentrated on the climate parameters optimization in passengers' salon.
The main idea of this paper is to use intelligent agent networks and intelligent agent negotiation algorithms to create an algorithm and coordination mechanism for climate parameters control to save electrical energy, and it increases the level of comfort for passengers.

A special interest for investigations and further development is devoted to intelligent HVAC (heating, ventilation and air condition) systems allowing more flexible regulation (control) of the system's compressor and fan operation, and, therefore, improvement of efficiency and energy saving.

It is suggested to use intelligent superagent to interconnect operation of all agents in climate control system. The superagent's functions are to realize negotiation of intelligent agents and make a decision on changing in the system operation according to the environment. This paper provides the mathematical model and algorithm for optimal mechatronic system control of the climate control system. Algorithm is tested in modelling way. Elaborated model of the system can be used for sustaining air temperature in different facilities, buildings and electrical transportation.

2. Problem formulation

Open loop process is presented in Fig. 1. This process is characterized with several controlled energy flows (electrical, mechanical, etc.). Energy flows can be controlled by changing variable characters of low voltage. Thus with the help of electronic devices the flow of energy influences climate parameters in facilities. Several detectors control measurable variables. The purpose is to define the optimal air conditioning system working regime, taking in account priorities of consumers. Nowadays air conditioning systems are widely applied for providing of optimal climate in buildings and electric transport. A special interest for investigations and further development is devoted to intelligent air conditioning systems allowing more flexible regulation (control) of the system's compressor and fan operation, and, therefore, improvement of efficiency and energy saving. Deep and detail investigation of the behaviour of such a system, its operation and running processes requires its generalized mathematic modelling, taking into account all possible regimes of the operation of compressor and fan motors and setting an algorithm of their control in all possible regimes under any condition. The control function is provided with the help of computer which dispatches the control signals according to this algorithm to the power converter which in its turn controls the motors. General mathematical description of one of the modem methods of electric motor control is taken as a base of the modelling of the system. The modem systems provide a simultaneous control of the compressor motor and fan motor and even the input factor as well that gives the possibility to improve the efficiency of the system and follow the energy saving. With the suggested modelling one has a possibility to observe and analyze its electric processes keeping in mind the further improvement of it.

Possible problem solution is intelligent coordination mechanism – intelligent agent system with the superagent, which gives possibility to avoid these charges and can give economy of the electrical energy [1,2].

The following steps are taken for problem solving: to analyze the methods of interactive decisions evaluation, to apply the theory of lists, artificial intelligent [3] (intelligent agent networks), application efficiency for solving of the air conditioning system control taking into account consumers priority.

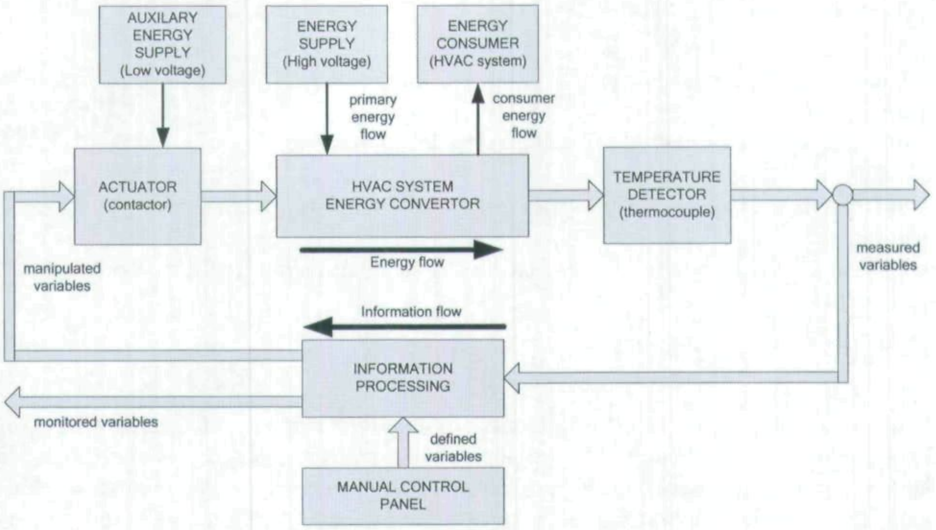

Fig. 1 Open loop process

3. Typical temperature control problem

In this paper, we concentrate on fuzzy logic control as an alternative control strategy to the current proportional integral- derivative (PID) method used widely in HVAC systems. Consider a generic temperature control application shown in Fig. 2:

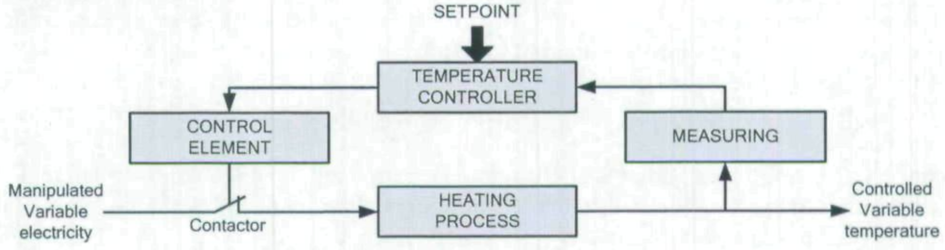

Fig. 2 Typical temperature control problem

The temperature is measured by a suitable sensor such as thermocouples, resistive thermal devices, thermistors, etc. and converted to a signal acceptable to the controller. The controller compares the temperature signal to the desired setpoint temperature and actuates the control element. The control element alters the manipulated variable to change the quantity of heat being added to or taken from the room air. The objective of the controller is to regulate the temperature as close as possible to the setpoint. To test the new fuzzy logic control algorithms, temperature regulation process was used in this research. It uses electricity as a power source to a heater and air conditioner, actuated by a contactor[4].

Currently, the classical PID (proportional, integral and derivative) control is widely used with its gains manually tuned based on the thermal mass and the temperature setpoint.
Fuzzy control is an appealing alternative to conventional control methods when systems follow some general operating characteristics and a detailed process understanding is unknown or traditional system models become overly complex.

4. HVAC system

The modelling and investigation are based on the typical architecture of HVAC (Heating, Ventilaton and Air Conditioning) system with a traditional application of AC induction motors for driving both compressor and fan of the conditioner (Fig.3). There are two control systems (CS) – one is for compressor motor control and the other – for fan motor control. The well-known field-oriented method has been considered for the modelling (Fig.4) as it seems more compatible with the application of intelligent agents for the control suggested here and for the purposes to achieve in this implementation [5,6].

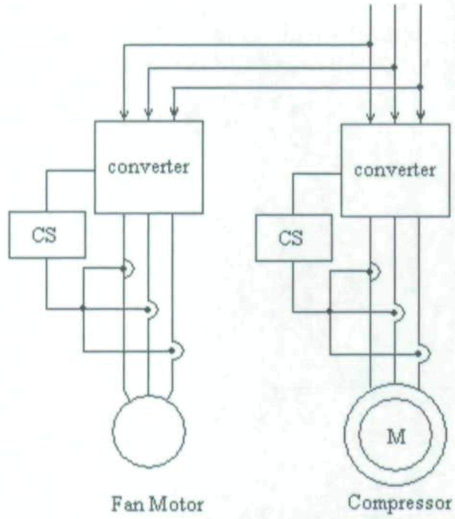

Fig. 3 HVAC system

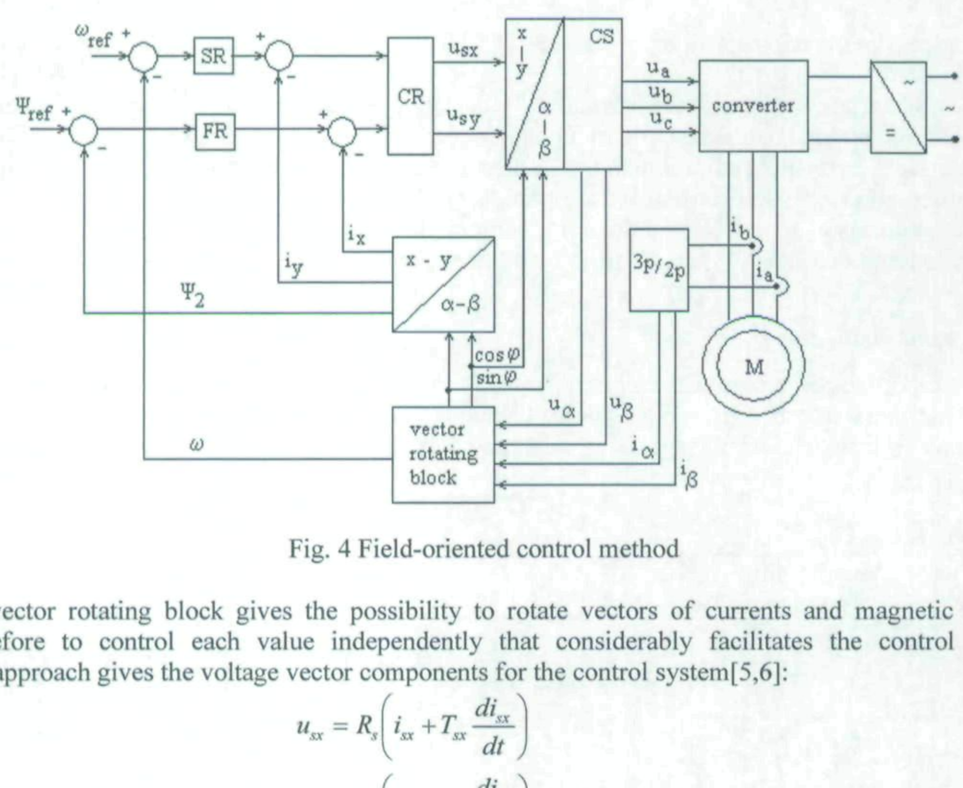

Fig. 4 Field-oriented control method

The vector rotating block gives the possibility to rotate vectors of currents and magnetic flux separately allowing therefore to control each value independently that considerably facilitates the control of the motor. Mathematical approach gives the voltage vector components for the control system[5,6]:

$$\begin{aligned} u_{sx} &= R_s\left(i_{sx} + T_{sx}\frac{di_{sx}}{dt}\right) \\ u_{sy} &= R_s\left(i_{sy} + T_{sy}\frac{di_{sy}}{dt}\right) \end{aligned} \tag{1}$$

electromagnetic torque:

$$M = {}^{3}\!/_{2}\, p_n k_r \Psi_{rx} i_{sy} \tag{2}$$

and flux linkage:

$$\Psi_{rx} = L_{sr} i_{sx} \tag{3}$$

where T_{sx} is motor time constant, p_n is number of motor poles pairs, k_r is rotor magnetic factor.

5. Fuzzy Logic Control System Design

The FLC developed here is a Zadeh-Mamdani type two-input single-output controller.
The structure of it consists of the following elements:

- ✓ fuzzifier, converts incoming crisp signal to fuzzy sets,
- ✓ knowledge base, which store information about respective actions of each function,
- ✓ decision- making unit, which depending knowledge base data gives command about doable actions,
- ✓ defuzzifier, that transform decisions made by IL system into crisp signal and deliver it to plant.

The two inputs are the deviation from setpoint error, *d(k),* and error rate, *Δd(k).* The FLC is implemented in a fuzzy output signal converter to HVAC system recognized digital control signals- CSC (Control Signal Converter) as shown in Fig. 5. Fuzzification and defuzzification involve mapping the fuzzy variables of interest to "crisp" numbers used by the control system. Fuzzification translates a numeric value for the error, $d(k)$, or error rate, $\Delta d(k)$, into a linguistic value such as positive large with a membership grade. Defuzzification takes the fuzzy output of the rules and generates a "crisp" numeric value used as the control input to the plant. HVAC system is used as plant.

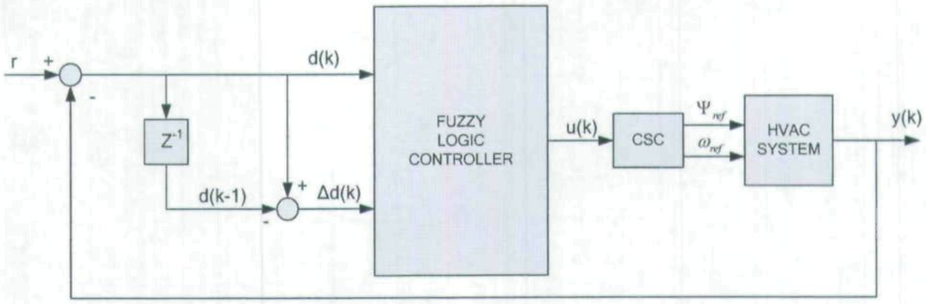

Fig. 5 Closed-Loop FLC System

6. Problem decision algorithm

Step 1. Determine consumers P^m heat perceiving slopes, write them down as alternative set $A(P^m)$;

Step 2. Evaluate correlation of consumers' wishes (decrease temperature for n degrees at decision making point and watch consumers reaction. This consumer's behaviour will be labelled as $A^k(t) - A$, alternative, k – consumers set, t – continuous time).

Step 3. If consumer is performing activity U – set control regime $A^k{}_w(t)$ (determining it during planning stage with the help of correlation).

Step 4. Use PseidoRastrigins' adaptation procedure f^{PR} (adaptation of temperature with learning according wishes of consumers), in order to provide optimal control of air conditioner.

Step 5. Provide system parameters control with intellectual agents. Supra program agent provides system control with the minimal consumption of electrical energy accordingly priorities of consumer. Supra agent control procedure is minimization in compressor, motor electrical energy consumption x cooler electrical energy consumption x control system electrical energy consumption, considering consumer k with control regime w under control procedure $A^k{}_w(t)$ during time t: $E= E(E)x\ E(V)x\ E(C),\ A^k{}_w(t) \rightarrow min.$

7. Problem decision methodology

Evaluation of temperature in passengers salon is taken as linguistic variable named x=„temperature in room". Value of linguistic variable can consist of words or combination of words from some existing, natural or artificial language. Defining variable with words without usage of numbers is more characteristic for human nature.

Table 1

Semantic rules M

Quantificator	Membership function ($u \in U$)
Not T	$1-\mu_t(u)$
Large T	$(\mu_t(u))^2$
Middle T	$\sqrt{\mu_t(u)}$
Where: T- cold, hot.	

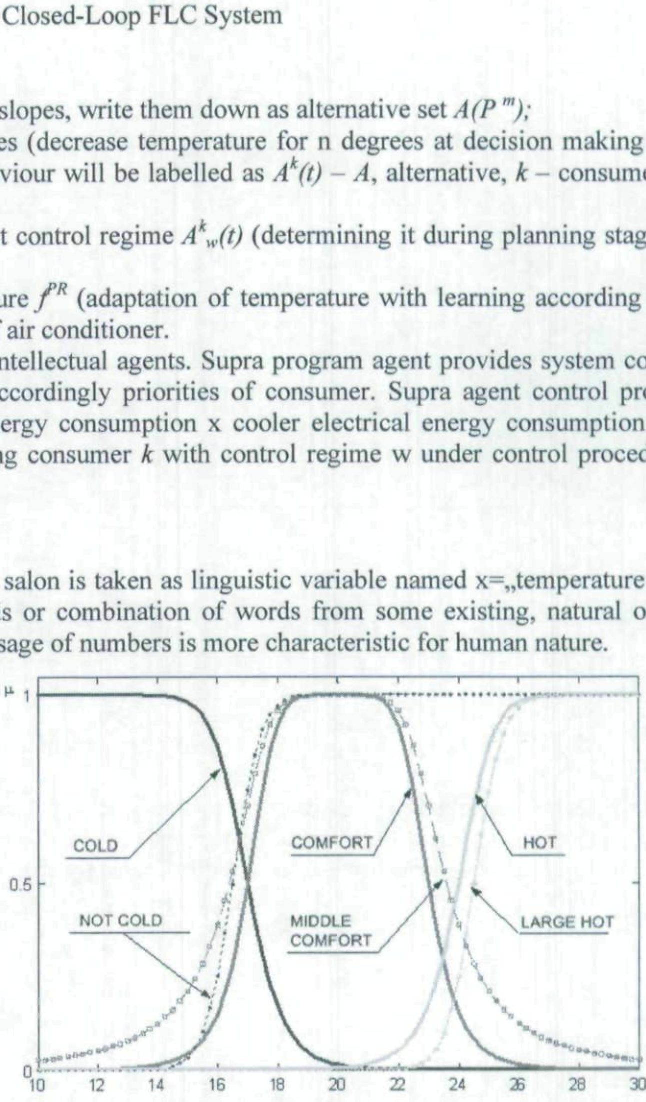

Fig. 6 Linguistic variable „temperature in room"

Linguistic variable has an important role in conclusions of fuzzy logic and in taking decisions based on approximate judgments.

Other parameters can be defined:

- Universe: U=[5, 35]
- Statements set: T={„cold", „comfortable", „hot"} with the following membership functions ($u \in U$):

$$\mu_{\text{„cold"}}(u) = \frac{1}{1+\left(\frac{u-10}{7}\right)^{12}} \qquad \mu_{\text{„comfortable"}}(u) = \frac{1}{1+\left(\frac{u-20}{3}\right)^{6}} \qquad \mu_{\text{„hot"}}(u) = \frac{1}{1+\left(\frac{u-30}{6}\right)^{10}}$$

- Syntactic rules G, creating new statements using quantificators „not", „very", „more or less".
- Semantic rules M (see Table 1):

Membership functions graphs of linguistic variable "temperature in room" for statements „cold", „not very cold", „comfortable, „more or less comfortable", „hot" and „very hot" are given in Fig. 6 [7].

For Problem decision algorithm Step 1 realization fuzzy logic elements are used in this way: determine consumers P^m heating perception slopes, write them down as alternative set *A*(P^m);
Step 1. Survey K consumers, make their hot- cold sensitiveness slopes, e.g., Fig. 6.;
Step 2. Adjusting of numerical value to fuzzy evaluations;
Step 3. Checking feeling of comfort (during time t – temperature is not changed manually) Steps 4,5
Step 4. If consumer had been changed temperature manually, system learning is performed using value adaptation methods.
Step 5. If consumer had not regulated switch manually, then to step3
Step 6 End of algorithm
Value adaptation can be provided using Pseudo Rastrigin's adaptation algorithm [8] Fig.7.

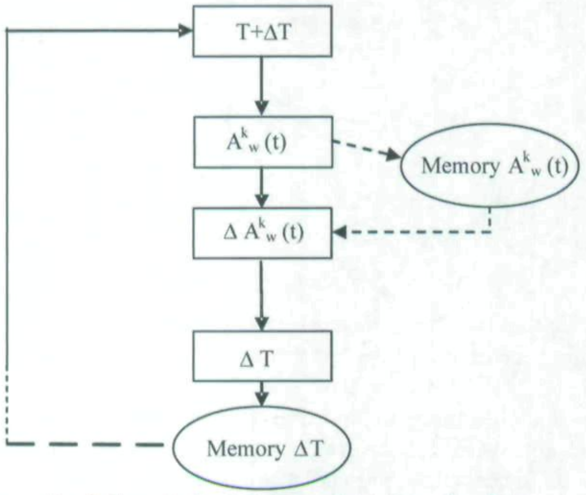

Fig. 7 Pseudo Rastrigin's adaptation algorithm.

Usage of program agents in solving tasks provides with the following advantages:

- scale (being able to deal with large numbers of components and devices);
- flexibility (to be able to achieve the goal through cooperation of many small programs which contain local information and intelligence):
- adaptability (to allows agents to adapt to dynamic changes of the when loads are entering or disappearing at unknown or unsuspecting times);
- wide applicability (to be able to apply the concept of different applications and scenarios).

8. Fuzzy logic controller work results.

The Fuzzy Logic controller (FLC) membership functions are defined over the range of input and output variable values and linguistically describes the variable's universe of discourse (Fig. 8). The triangular input membership functions for the linguistic labels zero (0), small (S), medium (M), and large (L), had their membership tuning center values at 0; 0,2; 0,35 and 0,6 respectively. The universe of discourse for both d and *Δd* is normalized from -1 to 1. The left and right half of the triangle membership functions for each linguistic label was chosen to provide membership overlap with adjacent membership functions. The straight line output membership functions for the labels zero (0), small (S), medium (M), and large (L) are defined with end points corresponding to 10, 30, 70, and 100% of the maximum output, respectively. Both the input and output variables membership functions are symmetric with respect to the origin.

Selection of the number of membership functions and their initial values is based on process knowledge and intuition. The main idea is to define partitions over the plant operating regions that will adequately represent the process variables. The rules and membership functions of the FLC were developed using an intuitive understanding of what a PI controller does for a fixed delay on a first order system. They generalized what a PI controller does for each combination of d and *Δd* in 12 rules as shown in Table 2. Rules use structure: IF (*d* value is) AND (*Δd* value is) THEN (*u* value is). In the table shown symbol N means "negative"(cool) and P- "positive"(heat).
The output from each rule can be treated as a fuzzy singleton. FLC control action is the combination of the output of each rule using the weighted average defuzzification method and can be viewed as the center of gravity of the fuzzy set of output singletons.

Depending on usage of the system it can be necessary to evaluate every possible input signal combination, and then unnecessary rule is deleted from table thus simplifying action of logic and possible speeding up fuzzy logic system.

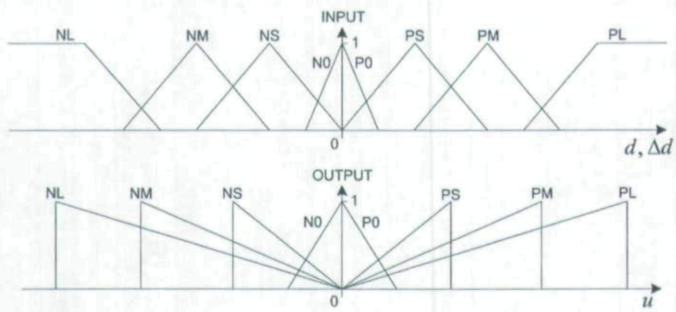

Fig. 8 Fuzzy Membership Functions

Table 2

FLC Control Rules

<table>
<tr><td colspan="2"></td><td colspan="8">Δd</td></tr>
<tr><td colspan="2"></td><td>NL</td><td>NM</td><td>NS</td><td>N0</td><td>P0</td><td>PS</td><td>PM</td><td>PL</td></tr>
<tr><td rowspan="8">d</td><td>NL</td><td colspan="8">NL</td></tr>
<tr><td>NM</td><td colspan="5">NM</td><td colspan="3">PS</td></tr>
<tr><td>NS</td><td colspan="3">No action</td><td>NM</td><td>PS</td><td colspan="3">No action</td></tr>
<tr><td>N0</td><td colspan="8">N0</td></tr>
<tr><td>P0</td><td colspan="8">P0</td></tr>
<tr><td>PS</td><td colspan="3">No action</td><td>NS</td><td>PM</td><td colspan="3">No action</td></tr>
<tr><td>PM</td><td colspan="3">NS</td><td colspan="5">PM</td></tr>
<tr><td>PL</td><td colspan="8">PL</td></tr>
</table>

Conclusions

The provided results prove that the use of Fuzzy Logic with application of the proposed algorithm can be very useful for solving HVAC (heating ventilation and air condition) technology control problems in public electric transport.

Usage of created models and algorithms in air temperature control systems in salon of public electric transport will raise possibility to increase efficiency of electro energy usage, so exploitation costs of transport will reduce as well as passengers' comfort level will be increased. Elaborated systems can be used for microclimate sustaining in different facilities, buildings and public electric transport.

Usage of systems of progressive algorithms and intellectual mechatronic system is very topical in modern heating energy tasks. More appropriate for this purpose are systems working using control core developed on the basis of artificial intelligence which can control current condition of all system, environment parameters independently on operator, and taking into account predictable changes of these conditions to take decision on necessary system actions.

When use artificial intellect, opportunity rises to do system self tuning and to export and change findings with some similar, distant control systems or control center.

Implementing of this kind control method in HVAC systems allows avoiding extra costs related to clarifying of problem, solving and consequences of problems as well as gives possibility to use electric energy with high efficiency that decreases costs for sustaining microclimate of the object, keeping high comfort level in the object.

The elaborated system model can be used for sustaining microclimate in different facilities, buildings and public electric transportation. Authors' further plans are to continue the research of using intelligent agent systems in computer control of HVAC processes for Techtronic systems.

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