10.2478/v10144-009-0036-9

Control of Comfort Parameters in Interior of Railway Coach Using ANN and RFID Tasks

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Abstract - **The main idea of this paper is to use methods of ANN (artificial neural network) and RFID (radio frequency identification) to create an algorithm and coordination mechanism for climate parameters control in the railway passengers' coach to save an electrical energy and keep a high comfort level in the passengers' interior of railway coach. The article presents mathematical problem using intelligent control of HVAC (heating, ventilation and air conditioning) systems for microclimate parameters optimal control. The methods of the problem solving and the structure of problem solving algorithm are given in the article.**

I. INTRODUCTION

Nowadays great attention is paid to increasing level of passengers' comfort in public electric transport. The aim of it is to provide passengers with a transportation service of a high quality. Elaboration of new HVAC systems has to be performed in order to provide it. Effective work of them can be provided by elaborating control systems with usage of artificial intellect methods and progressive algorithms. HVAC process is characterized with several controlled heat energy flows. 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. To ensure high efficiency working regime of HVAC system, respective control model of system has to be created and working algorithm of that has to be elaborated. Also, it is necessary to define the optimal and energy saving HVAC system working regime, taking into account priorities of railway coach passengers. Deep and detailed investigation of the behaviour of such system, its operation and running processes requires its generalized mathematic modeling, taking into account all possible regimes of the operation of heater, compressor and fan motors and setting an algorithm of their control in all possible regimes under any condition. Possible problem solution is intelligent coordination mechanism – intelligent control system with the artificial neural network, which gives possibility to save the electrical energy $E(t) \rightarrow$ min., at the same time providing high level of comfort to passengers $Q(t) \rightarrow$ max.

II. ENVIRONMENTAL PARAMETERS

Indoor environment parameters of vehicle passengers' interior to large extent depend on outdoor environment parameters (Fig.1), frequency and intensity of both environments connecting (when opening doors and windows), as well as on the effectiveness of vehicle HVAC system [1]. Heating and cooling processes in the object are characterized with several controlled energy flows. 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 the object. Several detectors control measurable variables.

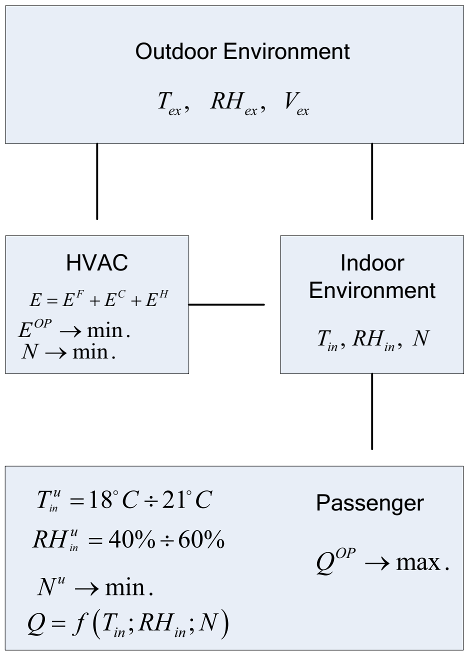

Fig. 1. Environment and HVAC system connection.

Where: Q - passengers comfort level, E - energy consumption, RH - air humidity, N - acoustic noise, V - air velocity, T - temperature, ^{OP} - optimal choice of parameters, $_{in}$ - indoor, $_{ex}$ - outdoor.

Ability of HVAC system to provide optimal level of comfort Q^{OP} directly depends on energy consumption E of HVAC system.

III. HVAC SYSTEM

An electrical equipment of transport systems consists of different elements, including electrical drives. They are electro-mechanical devices for realization of movements and machine operation in technological processes. The modelling and investigation are based on the typical architecture of

HVAC system [11] with a traditional application of AC induction motors [13,14] for driving both compressor and fan of the conditioner. The well-known field-oriented method [4, 9, 10] has been considered for the modelling .

The AC induction motor is fed by a current-controlled PWM (Pulse-width modulation) inverter, which operates as three-phase sinusoidal current source.

The role of the speed controller is to keep the motor speed equal to the speed reference input in steady state and to provide a good dynamics during transients.

There are two control systems (CS) – one is for compressor motor control and the other – for fan motor control (Fig.2).

The control system provides an adjustable conversion of electrical energy of the feeding system with parameters U_a, I_a, f_a to energy of other parameters u, i, f which are connected to the motor with the following conversion to mechanical one for production machine- fan, compressor etc. (Ribickis and Rankis, 1996).

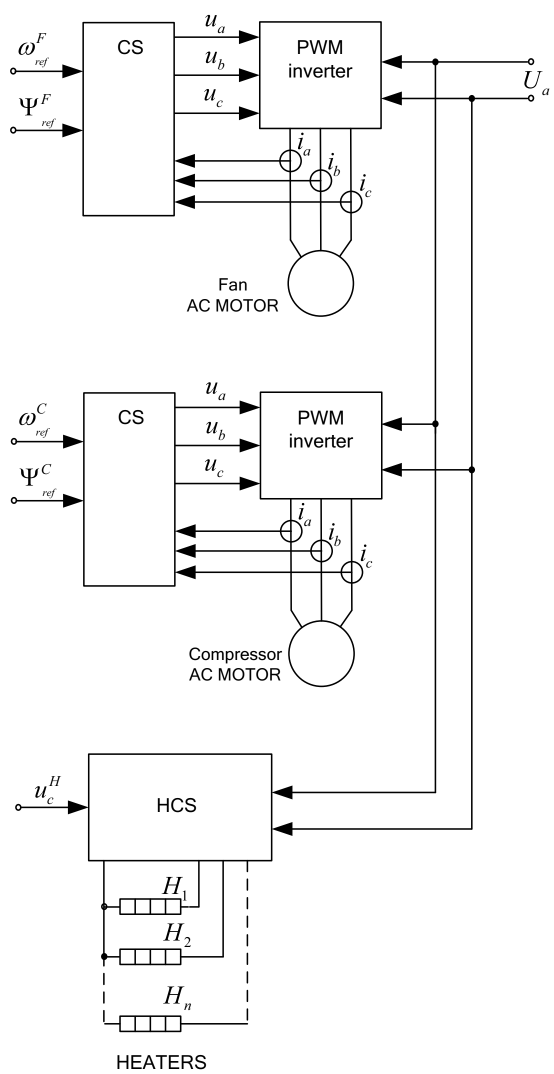

Fig. 2. Power part of HVAC system.

Where: CS- control system, ω_{ref} - speed control signal, Ψ_{ref} - flux linkage control signal, i - current, f - frequency, u_c^H - heater control signal.

Heater control system (HCS) is used for control of electric heaters, control of which is realized according to signal u_c^H .

IV. CONTROL SYSTEM DESIGN

HVAC system control is performed using computer system. Processing of environmental parameters and passengers' wishes regarding climate parameters is realised using program agents. Overall structure scheme of control system is given in Fig.3. Signal Q_P^S (setpoint) characterises climate parameters wishes of passengers. In order to perform climate parameters' control of the object- coach passengers' interior, an interior is divided into n sectors i_n and in each of them there is placed microclimate parameters' adress sensor, which produces respective signal Q_n^m . To one input of fuzzy logic controller (FLC) setpoint and measured signal difference $e_N = Q_P^S - Q^n$ are delivered, but to the other input changing rate $\Delta e_N = e_N - e_{N-1}$ of comfort level at sampling period is delivered.

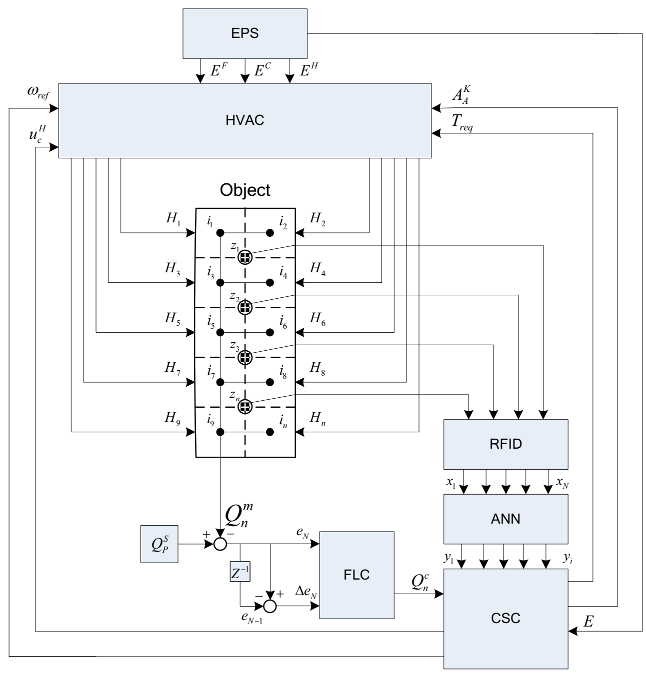

Fig. 3. Heating control system structure.

FLC produces respective output signal Q_n^c . Information about the passengers topographical disposition in the object is obtained using RFID controller with the help of position sensitive antenna $z_1 - z_n$ [12]. Information about the passengers disposition is the object is processed by SOM type artificial neural network (ANN) [1], which is recognizing by the passengers topographical disposition picture and produces the respective control signals at the output. ANN outputs $y_1 - y_i$ are connected to the Control Signal Controller (CSC). The output of FLC controller is connected to CSC, too, and delivers the information about the necessary comfort level changes in the actual sector of the object. CSC performs HVAC power part control with signals: T_{req} - required temperature, ω_{ref} - motor speed and u_c^H - heater control, as well as it forms the address of actual control sector A_A^K . In each sector of the interior there is an independent output of HVAC system. Adress A_A^K selects which of the interior sector has to be influenced by HVAC system. Control signal Q_P^S shows a necessary level of comfort which however is determined by passengers' wishes which are identified by using fuzzy logic controller (FLC) which is described in [3], or some other way. Electro power supply (EPS) provides HVAC system with a controlled flow of electric energy: $E = E^F + E^C + E^H$, size of which is controlled and data on its value E are passed to CSC, which provides an optimal control regime of energy consumption using multicriteria decision making (MCDM) methods [2].

V. PROBLEM DECISION METHODOLOGY

A. Self-Organizing Map

In the paper a self-organizing map (SOM) is used which is a type of artificial neural network that is trained using unsupervised learning to produce a low-dimensional, discretized representation of the input space of the training samples, called a map.

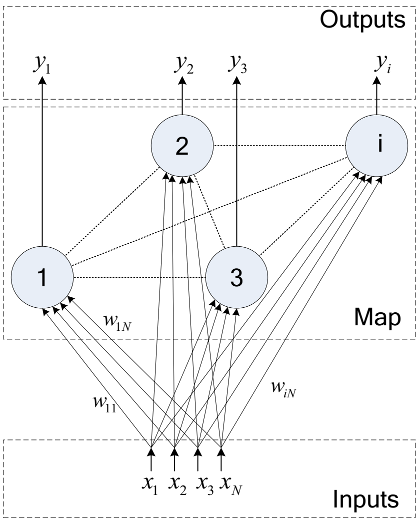

Fig. 4. Self-organizing map type network.

The map seeks to preserve the topological properties of the input space. SOM has ability to adapt the weights without assistance, according to the training data. Here one layer network is used where each neuron receives all components of the input signal X. The structure scheme of neural network is given in Fig.4.

Synaptic weights of neuron i create the vector:

$$W_i = [w_{i1}, w_{i2}, ..., w_{iN}]^T \tag{1}$$

Except the synapses clearly presented in the scheme, while training, there are synapses between neurons, which allow understanding level of neighbourhood of neurons, however, meaning of the concept „neighbourhood" can differ. Such networks require normalization of the input vector very often. For performing normalization, redefining of the components of vectors is offered according to the formula:

$$x_n \leftarrow \frac{x_n}{\sqrt{x_1^2 + x_2^2 + ... + x_N^2}} \tag{2}$$

For measuring distance between the vectors Euclidean distance measurement is used:

$$d(X, W_i) = \|X - W_i\|_2 = \sqrt{\sum_{n=1}^{N} (x_n - w_{in})^2} \tag{3}$$

Before using SOM, it is necessary to train it. The goal of the training is to cause different part of the network to respond similarly to certain input patterns [6].

The training is realized without the presence of an external teacher. The unsupervised weight adapting algorithms are usually based on some form of global competition between the neurons [8].

Minimization of the error of quantification is the aim of training of the self organizing network on the basis of competition:

$$E_q = \frac{1}{p} \cdot \sum_{k=1}^{p} d\left(X^k, W_{w(k)}\right) \tag{4}$$

Where: p - number of training vectors X^k , $W_{w(k)}$ - vector of weights of the winning neuron when presenting vector X^k .

Kohonen algorithm [7] is used for training self organizing networks on the basis of competition. Neighbourhood of neurons has topological character. Correction of neurons' weights during the training is completed according to the Kohonen algorithm described by the equation:

$$W_i^{k+1} = W_i^k + \eta_i^k \cdot G^k\left(i, X^k\right) \cdot \left(X^k - W_i^k\right) \tag{5}$$

Neighbourhood function $G^k\left(i, X^k\right)$ is usually defined according to Gaussian formula:

$$G^k\left(i, X^k\right) = \exp\left(-\frac{d^2\left(i, X^k\right)}{2 \cdot \left(\sigma^k\right)^2}\right) \tag{6}$$

where: $d\left(i, X^k\right)$— distance from the neuron i to the winning neuron with index w^k during the training cycle k . And $d\left(w^k, X^k\right) = 0$, $d\left(i, X^k\right) = 1$.

For all closest neighbours w^k , $d\left(i, X^k\right) = 2$ for all "outer" closest neighbours to the closest neighbours of winning neuron with index w^k and so on.

Training coefficient η_i^k, the value of which decreases with the decreasing of the distance from neuron i to the winner, and the parameter of the width of the Gaussian function σ^k are decreasing during the training process (when k is increasing).

Summary of Kohonen algorithm:

Step 1. At the input of network training vector X^k is given.

Step 2. For each neuron the distance between vectors X^k and W_i is defined $d\left(X^k, W_i\right)$.

Step 3. The winning neuron is found; the distance $d\left(X^k, W_i\right)$ appeared the smallest one for it.

Step 4. Around the winning neurons space S_w^k is formed by neurons-neighbours at the known „distance" from the winner.

Step 5. Weights of the winning neuron and weights of its neighbours are précised according to the rule of Kohonen.

As a result of training of Kohonen layer according to such algorithm the topologically neighbouring neurons become typical members of the clusters training data, neighbouring in multidimensional space.

B. Radio Frequency Identification

Non-contact radio frequency identification method (RFID) is used for identification of passengers and their location in the object [15]. The method gives possibility to read information about personal requirements for microclimate parameters and comfort level from personalized passenger's identification card (IC), as well as to identify location co-ordinates of each concrete passenger in the interior of vehicle. In order to use this method, all passengers must be provided by RFID identification cards. IC card can be used as a passenger's pay card for transportation services.

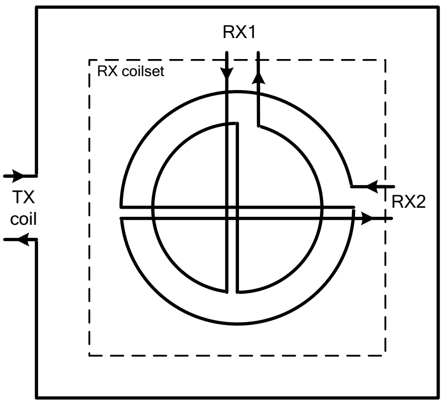

Fig. 5. Disposition of RFID system antenna coils.

In the passengers' interior of vehicle one or several (according to the room space and configuration) RFID transmitting-receiving devices- RFID readers (RD) are located. System operation principle is the following: RD, using connection initiation antenna TX, placed in a sector of the interior, transmits request signal with IC card identification code. IC card, which is with the passenger, when receiving signal with the respective identification code, generates and transmits reply signal with the information encoded in that (Fig.9). This reply signal is received with the help of antennas RX1 and RX2, placed in the interior. Antennas are located with mutual location angle 90(Fig.5) and receiving surfaces are located with concentrated declivity to the point of intersection.

Such a disposition of antennas gives a possibility to identify location of IC card in x-y co-ordinates system in relation to the point of intersection of antennas [12].

RFID control system structure sheme is given in Fig.6.

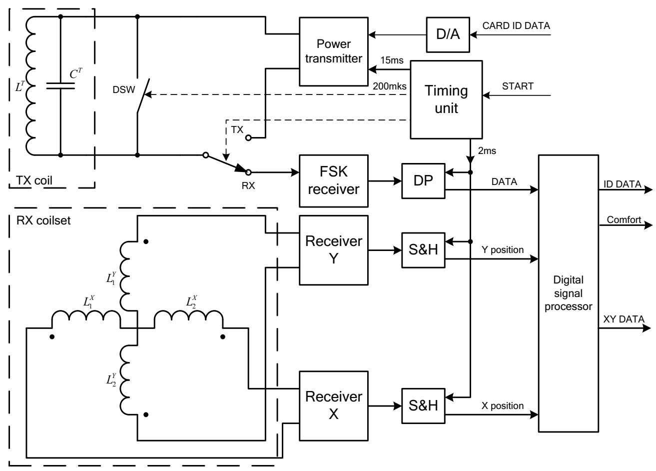

Fig. 6. RFID system structure scheme.

When receiving request signal "Start" and actual ID of IC card from the system controller, RD generates 15ms long output signal (Fig.7) trough antenna TX. During receiving process of the signal, the passive IC card receiver accumulates energy, which is used for feeding of IC cards' electronic elements. Simultaneously the received signal with ID code of IC card is amplified and decoded.

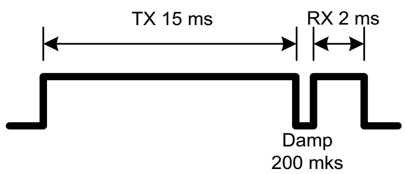

Fig. 7. RFID system transmitting/ receiving time slots.

Then RD transmitter is switched off and 200 mks. long signal damping action is done in TX antenna circuit using DSW. At the end of the cycle (2ms), IC card reply signal is received by antennas RX1 and RX2 and then it is amplified and analyzed.

The cycle (Fig.8) is repeated until all the IC cards, registered in the system, are called to. After amplifying and detecting, the signal phases and voltage values are fixed by S&H analog-digital convertor.

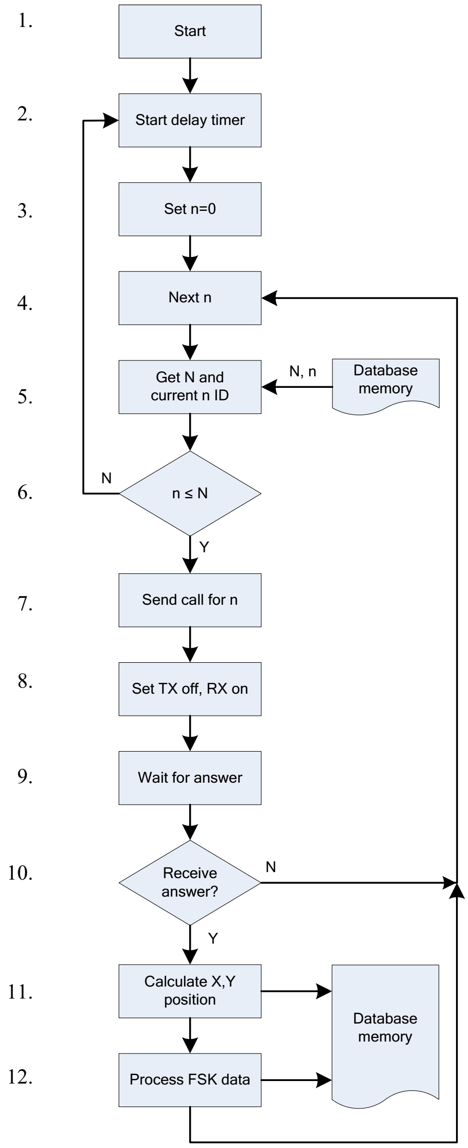

Fig. 8. RFID reader operation algorithm.

At the output the received signal localization codes for x and y axes are generated. Digital signal processor calculates location x-y position of IC card from location codes. Simultaneously with identifying the position, decoding of FSK (Frequency-shift keying) information from the received signal by antenna TX is done. It is done by FSK receiver and data processor (DP). The unique code of IC card user is identified from the decoded signal, which is forwarded to the system server for reading of the personal comfort level criteria of the user from the database.

RD operation is provided according to the following algorithm (Fig.8):

Step 1. System initializing.

Step 2. Start delay timer.

Step 3. Reset the counter of row number of ID records database.

Step 4. Get the next number of the record in the database.

Step 5. Call for the total number of recordings N and the card ID number currently having number n from the database.

Step 6. Comparison of the current number n with the maximal number of recordings N.

Step 7. Transmitting of TX request with the current ID number of the card.

Step 8. Switch off TX, switch on RX.

Step 9. Receiving of reply signal.

Step 10. Analyzing the existence of reply.

Step 11. Calculation of IC card location co-ordinates.

Step 12. Decoding of FSK data sent by IC card and recording in the database.

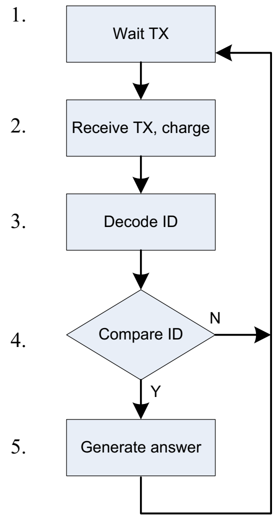

Fig. 9. IC card operation algorithm.

IC card operation is provided according to the following algorithm (Fig.9):

Step 1. Receiving regime, waiting for TX signal.

Step 2. Receive TX, charge power circuit.

Step 3. Decode ID information from FSK signal.

Step 4. Compare received ID with ID code of the card.

Step 5. Generate and transmit reply signal.

VI. PROBLEM DECISION ALGORITHM

System operation is provided according to the following algorithm:

Step 1. Initialization. In the object O HVAC system provides minimal climate parameters Q_O^S set by an operator.

Step 2. Passengers' climate parameter perception slopes are determined and setpoint Q_P^S is defined.

Step 3. RFID controller, according to the information received from antennas placed in the interior, produces topographical map of passengers disposition.

Step 4. SOM ANN, when processing the information gotten from the topographic map produced by RFID controller, activates respective neurons otputs.

Step 5. Neuron output signals and information about the necessary climate parameters changes from FLC are passed to CSC, and are processed using MCDM methods, taking into account electroenergy consumption E .

Step 6. CSC forms control signals of HVAC system T_{req} , ω_{ref}^{C} , u_{c}^{H} and destination unit adress A_{A}^{K} .

Step 7. HVAC system, according to CSC control signals, provides changes of the climate parameters in the pointed sector A_{A}^{K} of the object $i_1 - i_n$, taking into account optimal consumption of electro energy: $E(t) \to$ min. with comfort level $Q(t) \to$ max.

VII. RESULTS OF THE SYSTEM OPERATION

Several variants of passengers' interior occupation were modelled. The most characterizing occupation variants recognized by SOM and corresponding HVAC power allocations are given in Tab.1.

TABLE I
ENERGY CONSUMPTION DEPENDS ON INTERIOR OCCUPATION

	pat. 1.		**pat. 2.**		**pat. 3.**		**pat. 4.**	
	Occ	**Pow**	**Occ.**	**Pow**	**Occ.**	**Pow**	**Occ.**	**Pow**
i_1	1	F	1	F	0	H	0	L
i_2	1	F	1	F	0	H	0	L
i_3	1	F	0	H	1	F	0	L
i_4	1	F	0	H	1	F	0	L
i_5	1	F	0	L	0	H	0	L
i_6	1	F	0	L	0	H	0	L
i_7	1	F	0	L	0	L	0	L
i_8	1	F	0	L	0	L	0	L
E	100%		50%		41,5%		25%	

When there are passengers in a sector of the interior of the vehicle, it is marked with 1, but when not – with 0.

HVAC system action is possible at three power regimes- L-low, H-half and F-full. In the bottom row of the table the approximate energy consumption of HVAC system in percentage from full power for each case is given. Modeling results show that in the case, when all sectors in the passengers' interior are occupied, then HVAC system is working with the full power (pat.1) and the parameters of the microclimate are sustained equally in the whole interior. The highest energy economy is possible in the case when the interior is empty (pat.4) and HVAC system is working in minimal microclimate parameters sustaining regime, so consuming only 25% of the energy. In pat.2 and pat.3, cases with partly occupied passengers interiors were modeled, with energy consumption of 50% and 45%.

VIII. CONCLUSIONS

The provided results prove that the use of the artificial neural network of self-organizing map type with the application of the RFID system and proposed algorithms can be useful for solving HVAC technology control problems in the public electric transport. Usage of the created models and algorithms in the climate parameters control system in the passengers' interior of the railway coach will raise the possibility to increase efficiency of the electro energy usage, so exploitation costs of the transport will reduce as well as passengers' comfort level will be increased. Usage of the control system with the progressive algorithms and the intellectual HVAC system is very topical in the modern heating energy tasks. The elaborated system model can be used for sustaining microclimate in the different facilities, public electric transport vehicles and buildings.

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