RIGA TECHNICAL UNIVERSITY

Ivars BEINARTS

INVESTIGATION OF FUZZY LOGIC CONTROLLERS ALGORITHMS FOR CONTROLLING THERMAL COMFORT IN PASSENGER TRANSPORT COMPARTMENT

Summary of the Doctoral Thesis

Riga 2011

RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of Industrial Electronics and Electrical Engineering

Ivars BEINARTS
Student of the doctoral study programme „Computer Control of Electrical Technology”

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Scientific supervisor:
Dr. sc. ing., professor
A.LEVCHENKOV

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The doctoral thesis proposed for obtaining the Dr.sc.ing. degree will be publicly presented on November 2, 2011 at the Riga Technical University's Faculty of Power and Electrical Engineering, Kronvalda blvd. 1, room 117 .

OFFICIAL REVIEWERS

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CONFIRMATION

Hereby I confirm that I have worked out the present doctoral thesis, which is submitted for review at Riga Technical University in order to obtain the degree of Doctor of Engineering Sciences. This work is not submitted to any other university for obtaining the doctor's degree.

Ivars Beinarts …………………………….(Signature)

Date: ………………………

The Doctoral Thesis is written in Latvian. The thesis comprises of an introduction, 5 chapters, conclusions, references, 2 appendices, 114 pictures and illustrations, 171 pages. The references consist of 177 entries.

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TOPICALITY OF THE THEME

Recently, a rapid computer engineering and electronics development has been taking place, the capacity and velocity of the computer systems and programmable controllers is increasing. This provides a possibility to develop new (connected with an artificial intelligence) methods of control of complicated physical processes, on the basis of which the development of a new (based on a programmable controller) control systems can be facilitated, thus replacing traditional control systems, and improving their operational quality and effectiveness. An application of such artificial-intelligence-based control systems is very wide, however, in the author's opinion, it is important, to exploit scientific and engineering achievements for the improvement of human comfort, as well as for the provision of this comfort for reducing the amount of electric energy consumed.

Everybody has faced the problems of the provision of passenger comfort in public electric transport. The provision of comfort is especially problematic during a summer time, because of a high air temperature and an increased solar emission, as well as during cold winter days, because of a low air temperature. A solution to the problem gets complicated by an external environment's frequent merging with an internal environment of passenger compartments, e.g. when doors are being opened at stops and stations, or when passengers trying to ease the feeling of discomfort open a vehicle's windows. As a result of that, the parameters of the internal environment of passenger compartments change rapidly and thus become uneven in all the inner space. Wherewith, the passengers might get different feelings of comfort evaluation. At present in Latvia, in the exploitable public transport, a possibility of taking into account the passengers' opinions about the level of the provided thermal comfort and of making adjustments to the control parameters of the equipment, which creates the space's environment, accordingly to the situation, is not envisaged. In addition, filling of passenger compartments and passenger allocation in compartments are not taken into account either.

Here the author sees a possibility to produce improvements to the situation and to introduce new control algorithms into the automatic control systems. The new control algorithms with the use of the fuzzy logic controllers and the non-contact identification method would increase the level of passenger comfort and provide a possibility for the passengers to express their opinions on the quality of this comfort.

GOAL OF THE RESEARCH

The research goal is the development and investigation of the recommendations and practically applicable methods for an evaluation of the public transport passengers' thermal comfort and for an automatic application of this evaluation in adjusting the parameters of the passenger compartment's environment.

For achieving the goal the following objectives were defined:

1. To study the parameters and characteristics of the micro-environment of the passenger compartments in public electric transport.
2. To study the influencing factors of passengers' feeling of comfort and the possibilities of their improvement.
3. To study the exploitable heating, ventilation and air conditioning units (HVAC).
4. To develop the algorithm for an evaluation of a passenger comfort level and the method for an application of the evaluation for an optimization of an operation mode of the HVAC system's units.
5. To develop the optimized control algorithms of the HVAC equipment and a structural scheme of the control system.
6. To develop a method and an algorithm of an identification of a passenger compartment's occupancy using wireless technologies.
7. To conduct an experiment in order to test functionality of the main units of the developed control system and their usability for the defined goal.
8. To perform an experiment in order to compare the developed system with the traditional two level control system of HVAC equipment.
9. To provide the conclusions about the possibilities of an improvement of a passenger comfort level and its influence on the electric energy consumption used for the regulation of an environment in comparison to the two level control system.

METHODOLOGY OF THE RESEARCH

In order to attain the goal of the doctoral thesis, the control method of a procedure's fuzzy logic (FL) and the non-contact radiofrequency identification method (RFID) are applied. The Matlab/Simulink computer program is used for modeling a thermal environment of the public transport's passenger compartments. With the help of this program the heating, ventilation and air conditioning equipment sets intended for the regulation of the parameters of the environment, as well as passenger voting were modeled. A fuzzy logic governor is designed using SIEMENS Simatics S7-224XP programmable controller, which is connected to the passenger compartment's computer model. The developed program is written into the controller's memory on the basis of a fuzzy logic control method. An evaluation of passengers' feelings of comfort is carried out virtually, in a Matlab/Simulink computer model, and an adjustment of the setpoint temperature corresponding to the passenger wishes is calculated using a sub-program of a fuzzy logic controller. The comparable traditional HVAC equipment with two level control system is fully simulated in Matlab/Simulink environment.

SCIENTIFIC NOVELTY OF THE RESEARCH

In the doctoral thesis for improving thermal comfort of the public electric transport's passengers the methodology determining passenger's satisfaction with thermal comfort using the fuzzy logic controller, and the method of an automatic adjustment of thermal parameters' setpoint, carried out in passenger compartments and based on an evaluation of passenger satisfaction, are designed.

MAIN RESULTS

The following system units are developed in the doctoral thesis:

- The unit for collecting and analyzing votes on an evaluation of passenger comfort level, with the use of the fuzzy logic controller.
- The HVAC equipment's control system's unit with a fuzzy logic controller for an application in regulating the air temperature and moisture level inside the passenger compartments, taking into account the setpoint parameters, which are adjusted according to the passengers expressed wishes and seasonal changes in an outside environment.
- The determination unit of the passengers' previously expressed comfort wishes and filling in a passenger compartment, using RFID wireless identification method.

By means of experiments the correspondence of the set requirements to the definite goals, and the system's functionality were tested. The programmable controller's program and its' connection to the virtual environment of the passenger compartments of the electric transport and the simulated HVAC equipment are described. In addition, the results and graphical representations, characterizing the most important processes, obtained from the experiments, are provided.

Grounding on the novelty of the system developed in the doctoral thesis, a patent application No: P-11-52, "Automated Identification System of User's Wishes for Room Microclimate

Control", I.Beinarts, A.Levchenkov, L.Ribickis was submitted to the Patent Office of the Republic of Latvia.

PRACTICAL APPLICATION OF THE RESEARCH

The programmable controller program, which was developed in the promotion thesis and the control algorithms, can be applied in the systems of passenger thermal comfort provision in public transport as well as in dwelling and council buildings and other premises, by making partial corrections to the set parameters and control conditions. The programmable controller with the inscribed fuzzy logic control program is applicable for a performance of the control functions of the real HVAC equipment.

APPROBATION

1. EUROCON 2011. International Conference on Computer as a Tool. Lisbon, Portugal, April 27-29, 2011. Report: „Fuzzy Logic Controller Support to Passengers' Comfort for Electric Train Coach Heating System".
2. 50th RTU International Scientific Conference. Riga, Latvia. October 14-16, 2009. Report: "Modeling of Fuzzy Logic Controller Support for Passengers' Interior Heating System of Electric Transport".
3. Baltic Defense Research and Technology 2009, Riga, Latvia, September 10-11, 2009. Report: „Personalized Fuzzy Logic Control of Microclimate in Military Transport Vehicle Cabin".
4. 8th International Conference „Transport Systems Telematics TST 2008". Katowice-Ustron, Poland, November 5-8, 2008. Report: „ Usage of Neuro-Fuzzy Controller for Passengers' Interior Heating System of Railway Electric Transport".
5. 49th RTU International Scientific Conference. Riga, Latvia. October 13-14, 2008. Report: "Modeling of Fuzzy Logic Controller Support for Passengers' Interior Heating System of Electric Transport".
6. 8th Portuguese Conference on Automatic Control „Controlo 2008". Vila Real, Portugal. July 21.-23. 2008. Report: "Usage of Self-Organizing Map for Heating Control in Electric Train Passengers' Interior".
7. 4th International Conference "Mechatronic Systems and Materials 2008". Bialystok, Poland. July 14-17. 2008. Report: "Control of Heating Processes in Electro Transport Mechatronic System Using Feed Forward Neural Network".
8. 16th International Symposium "EURNEX-Žel2008". Žilina, Slovak Republic. June 4-5, 2008. Report: „Usage of Fuzzy Logic Controller for Passengers' Interior Heating System of Railway Electric Transport".
9. 7th International Conference „Transport Systems Telematics TST 2007". Katowice, Poland, October 17-19, 2007. Report: „Passengers' Interior Climate Parameters Optimization Using Intelligent Control with Neural Networks".

10. 11th International Conference „Transport Means 2007”. Kaunas, Lithuania, October 18, 2007. Report: „Climate Parameters Optimization Using Intelligent Control with Multiple Criteria Decision Making”.

11. 48th RTU International Scientific Conference. Riga, Latvia. October 11-13, 2007. Report: ”Intelligent Systems for Transport Microclimate Parameters Optimization Using Multi Criteria Decision Making”.

12. 3rd international conference “Mechatronics Systems and Materials-2007”. Kaunas, Lithuania,. September 27. 2007. Report: “Intelligent Mechatronics Systems for Climate Parameters Optimization Using Fuzzy Logic Control”.

13. 12th international conference “Mechanika-2007”. Kaunas, Lithuania,. April 05. 2007. Report: “Modeling of intelligent Mechatronics Systems with Climate Parameters Control”.

PUBLICATIONS OF THE AUTHOR

1. Beinarts I., Levchenkov A. *Fuzzy Logic Controller Support to Passengers' Comfort for Electric Train Coach Heating System*. In proceedings of: EUROCON 2011 International Conference on Computer as a Tool. ISBN 978-1-4244-7485, IEEE Catalog Number:CFP11EUR-CDR. Lisbon 2011. pp.501-504.

2. Beinarts I., Levchenkov A. *Multiple Criteria Decision Support for Heating Systems in Electric Transport*. In Lecture Notes in Economics and Mathematical Systems vol.634. M.Ehrgott, B.Naujoks et.al. ed: „Multiple Criteria Decision Making for Sustainable Energy and Transportation Systems”. ISBN 978-3-642-04044-3, Springer-Verlag Berlin Heidelberg 2010. pp.27-34.

3. Beinarts I., Levchenkov A. *Control of Comfort Parameters in Interior of Railway Coach Using ANN and RFID Tasks.* Enerģētika un Elektrotehnika. - sērija 4, sējums 25. (2009), 171-176. lpp.

4. Beinarts I., Levchenkov A. *Personalized Fuzzy Logic Control of Microclimate in Military Transport Vehicle Cabin*. In proceedings of: International conference Baltic Defence Research and Technology 2009, Riga. – On CD,pp. 3-9.

5. Beinarts I., Levchenkov A. *Using Fuzzy Logic in MCDM Tasks for the Improvement of Passengers' Coach Environment Parameters*. In proceedings of: 20th International Conference on Multiple Criteria Decision Making, 2009. June, China, Chengdu/Jiuzhaigou. – Chengdu, 2009. p.137.

6. Beinarts I., Levchenkov A. *Usage Algorithm of AI Methods in Control of Railway Passengers Coach Environment Parameters*. In proceedings of: 17th International Symposium „EURO-Žel”, 2009. June, Slovakia, Žilina. – Žilina: EDIS, 2009. pp.7-14.

7. Бейнартс И.З., Левченков А.С., Балцкарс П.Я. *Алгоритм интеллектуального управления для системы отопления пассажирского вагона электропоезда*. Шестая международная научно-практическая конференция «Исследование, разработка и применение высоких технологий в промышленности», 2008. Октябрь, Россия, Санкт-Петербург. Издательство Политехнического университета, 2008. p.50.

8. Beinarts I., Levchenkov A., Balckars P. *Control of Heating Processes in Electric Transport Mechatronic System Using Neural Network Controller.* Mašīnzinātne un transports. - sērija 6, sējums 30. (2008), 102-109. lpp.

9. Beinarts I., Levchenkov A., Balckars P. *Usage of Self-Organizing Map for Heating Control in Electric Train Passengers' Interior*. In proceedings of: 8th Portuguese Conference on Automatic Control „CONTROLO" 2008. July, Portugal, Vila Real. – Vila Real: Minfo, Lda., 2008. pp.420-425.

10. Beinarts I., Levchenkov A. *Usage of Neuro-Fuzzy Controller for Passengers' Interior Heating System of Railway Electric Transport*. In proceedings of: 8th International Conference „Transport Systems Telematics" 2008. November, Poland, Katowice-Ustron. – Katowice: Silesian University of Technology, 2008. p.3.

11. Beinarts I., Levchenkov A. *Usage of Neuro-Fuzzy Controller for Passengers' Interior Heating System of Railway Electric Transport*. Jerzy Mikulski, ed.: Advances in Transport Systems Telematics. - Poland, Warszawa: Wydawnictwa Komunikacji i Lacznosci Sp. z o.o., 2008. ISBN 078-83-206-1715-3, p.371.

12. Beinarts I., Levchenkov A. *Usage of Multilayer Perceptron Type Neural Network in Control of Electric Train Passengers' Interior Heating System*. In proceedings of : 24th ISPE International Conference on CAD/CAM, Robotics & Factories of the Future „CARS & FOF". 2008. July, Japan, Koriyama. - Koriyama: Nihon University, 2008. pp.132-137.

13. Beinarts I., Levchenkov A. *Usage of Fuzzy Logic Controller for Passengers' Interior Heating System of Railway Electric Transport*. In proceedings of: 16th International Symposium „EURNEX-Žel" 2008. June, Slovakia, Žilina. - Žilina: EDIS, 2008. pp.238-245.

14. Beinarts I., Levchenkov A. *Multiple Criteria Decision Support for Heating Systems in city Electro Transport*. In proceedings of: 19th International Conference on Multiple Criteria Decision Making 2008. January, New Zealand, Auckland. – Auckland: The university of Auckland, 2008. p.125.

15. Beinarts I. *Modeling The Artificial Neural Network For Heating System Choice For City Electrical Transport.* In proceedings of: 3rd International Workshop „Intelligent Technologies in Logistics and Mechatronics Systems" 2008. May, Lithuania, Kaunas. – Kaunas: Technologija, 2008. pp.109-112.

16. Beinarts I., Levchenkov A. *Modeling of Fuzzy Logic Controller Support for Passengers' Interior Heating System of Electric Transport*. Enerģētika un Elektrotehnika. - sērija 4, sējums 23. (2008), 151-157. lpp.

17. Beinarts I., Levchenkov A. *Modeling of Fuzzy Logic Controller Support for Air Heating System of Railway Coach.* Baskutiene J., Dragašius E., et.al., eds.: Mechatronic Systems and Materials- Scientific Papers. Lithuania, Kaunas: Technologija, 2008, pp.179-184.

18. Beinarts I., Levchenkov A., Balckars P. *Control of Heating Processes in Transport Mechatronic System Using Sigmoidal Neural Network.* Acta Mechanica et Automatica, vol. 2, No. 3, (2008), pp.14-18.

19. Beinarts I., Levchenkov A., Balckars P. *Control of Heating Processes in Electro Transport Mechatronic System Using Feed Forward Neural Network*. In proceedings of: 4th International Conference „Mechatronic Systems and Materials” 2008. July, Poland, Bialystok. – Bialystok: Bialystok Technical University, 2008. pp.73-74

20. Beinarts I., Levchenkov A. *Passengers' Interior Climate Parameters Optimization Using Intelligent Control with Neural Networks*. In proceedings of: 7th International Conference "Transport Systems Telematics” 2007. October, Poland, Katowice-Ustron. – Katowice: Silesian University of Technology, 2007. p.11.

21. Beinarts I., Levchenkov A. *Passengers' Interior Climate Parameters Optimization Using Intelligent Control with Neural Networks*. Jerzy Mikulski, ed.: Advances in Transport Systems Telematics. - Poland, Katowice: Chair of Automatic Control in Transport, Faculty of Transport, Silesian University of Technology, 2007. p.427.

22. *Modeling of Intelligent Mechatronics Systems with Climate Parameters Control*. Beinarts I., Levchenkov A., Kunicina N., Zhiravetska A. In proceedings of: 12th International Conference “Mechanika” 2007. April , Lithuania, Kaunas. – Kaunas: Technologija, 2007. pp.37-42.

23. Beinarts I., Levchenkov A. *Intelligent Systems for Transport Microclimate Parameters Optimization Using Multi Criteria Decision Making*. Enerģētika un Elektrotehnika. - sērija 4., sējums 20. (2007), 143-149.lpp.

24. Beinarts I., Levchenkov A., Kunicina N. *Intelligent Mechatronics Systems for Transport Climate Parameters Optimization using Fuzzy Logic Control*. In proceedings of: 3rd international conference “Mechatronics Systems and Materials” 2007. September, Lithuania, Kaunas. – Kaunas: Kauno Technologijos Universitetas, 2007. pp.165-166.

25. Beinarts I., Levchenkov A. *Climate Parameters Optimization Using Intelligent Control with Multiple Criteria Decision Making*. In proceedings of: 11th International Conference „Transport Means” 2007. October, Lithuania, Kaunas. – Kaunas: Technologija, 2007. pp.23-26.

26. Patent application No: P-11-52, “Automated Identification System of User's Wishes for Room Microclimate Control”, I.Beinarts, A.Levchenkov, L.Ribickis.11.04.2011.

STRUCTURE OF THE DOCTORAL THESIS

Human Thermal Comfort

The main aim of the heating, ventilation and air conditioning system (HVAC), installed in the public transport's passenger compartments, is to provide the conditions for human thermal comfort. Thermal comfort is such a state of human mind, which expresses satisfaction with the conditions of the environment. Thermal comfort depends on a number of interrelated and complicated phenomena, including both subjective and objective criteria, which are influenced by physical, physiological, psychological and other processes. A human's conclusions about thermal comfort and discomfort are drawn from the direct perception of skin temperature and humidity, internal temperature of the body tissues and tension, which is needed for a regulation of the body temperature. On the whole, it can be considered that thermal comfort is provided if the human body temperature is maintained in a small fluctuation range, skin moisture is low and physiological adjustment tension is minimal. Because of individual peculiarities, it is impossible to determine the criteria of thermal environment which would satisfy everybody. The standard determines the criteria for thermal environment, which is accepted by at least 80% of a room's visitors (Fig.1) [5], [42]. A specification of this area is based on the concept of the effective temperature index ET*.

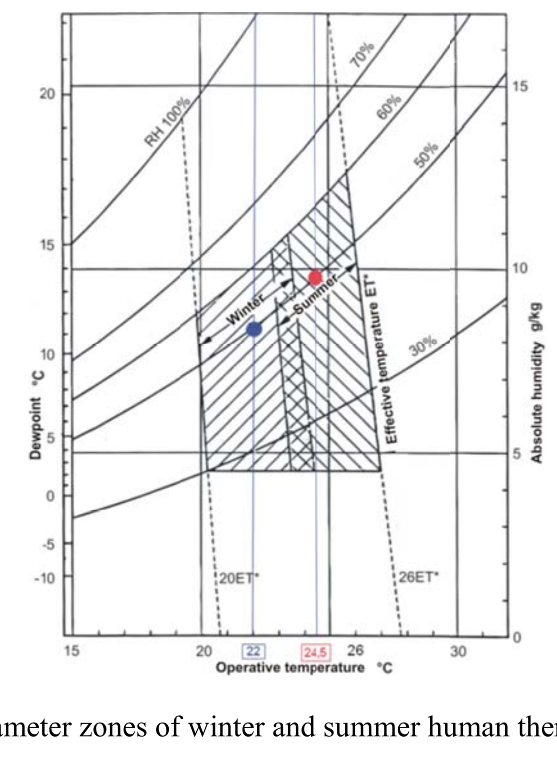

Fig.1. Parameter zones of winter and summer human thermal comfort

The values of an acceptable temperature and moisture, basing on 10% dissatisfaction criterion, are indicated with the shaded areas on the diagram. The diagram depicts different comfort zones for winter and summer, because a sensation of comfort depends on clothing thermal insulation (I_{cl}). Provided that air relative humidity is 50%, and an average speed of an air flow is lower than or equals 0,15m/s, then in winter conditions, an optimal room air temperature for a reasonably dressed person (I_{cl}=0,9), who carries out easy sedentary activities (≤1,2met) is +22°C, but in summer (I_{cl}=0,5) an optimal temperature is 24,5°C. Still, if a 10% dissatisfaction is admitted, then the range of the winter operative temperature is from +20°C to +23,5°C, but the range of the summer one is from +23°C to +26°C.

The greater the shift from the values is, the greater the proportion of the unsatisfied people will be. In the middle of the zone of the seasonal region, when wearing definite clothing appropriate for the season, a typical human's sensation of thermal comfort will be very close to neutral.

Thermal Model of the Object

The smallest unit in a space model is a zone. A zone model consists of two parts: a thermal model and a humidity model [47]. These models are interdependent, because steam saturation pressure depends on the temperature and released latent heat of condensation. In order to calculate the hearing and cooling processes necessary in the zone, it is required to define a number of thermal balance terms:

$$\Phi_l + \Phi_s = \Phi_g + \Phi_p \tag{1}$$

Where Φ_l is a heat loss, Φ_S is accumulated heat, Φ_g is a heat supply, Φ_p is a heat addition from heating or cooling units.

In order to calculate in the air humidity zone, it is necessary to define a number of the mass balance terms:

$$G_l + G_s = G_g + G_p \tag{2}$$

Where: G_l is a humidity loss, G_S is accumulated humidity, G_g is a steam supply, G_p is a humidity addition.

Each modeling zone has three characteristics of it equations (3-5) [47] with heat/cooling capacity, temperatures of two spaces, air humidification / drying and air humidity as unknown variables:

$$f_p \Phi_p = \frac{C_a\left(T_a - T_a^*\right)}{\Delta t - L_{xa}\left(T_x - T_a\right) - \Sigma L_{ab}\left(T_b - T_a\right) - \Phi_{g1}} \tag{3}$$

$$\left(1 - f_p\right)\Phi_p = L_x T_x - \Phi_0 - L_{xa}\left(T_a - T_x\right) - \Sigma L_{yx}\left(T_y - T_x\right) - \Phi_{g2} \tag{4}$$

$$G_p = \frac{\left[a_1\left(C_{va} + C_f^t f_a\right) + a_2 C_v f_m\right] p_{va}}{\Delta t - G_0 - \Sigma L_{vab}\left(p_{vb} - p_{va}\right) - G_g} \tag{5}$$

HVAC System

Heating, ventilation and air conditioning (HVAC) system [2], [31] provides a necessary adjustment of a space's environmental parameters according to the set parameters of a control system. The basic units of the HVAC system are an air heater, an air cooler, an air stream ventilator, as well as an air humidifier and a dryer. With the help of these devices it is possible to make the necessary adjustments of the passenger compartments' environment, ensuring the necessary level of passenger thermal comfort. Preparation of outdoor air according the set quality indicators is done in air handling unit-AHU. It consists of an air heating element and cooling element, humidifier and dryer, which receive heat Q and control signals Y from the HVAC system. When outdoor air is flowing through the AHU, the heat exchange process takes place between air masses and the heater / cooler elements (Fig.2).

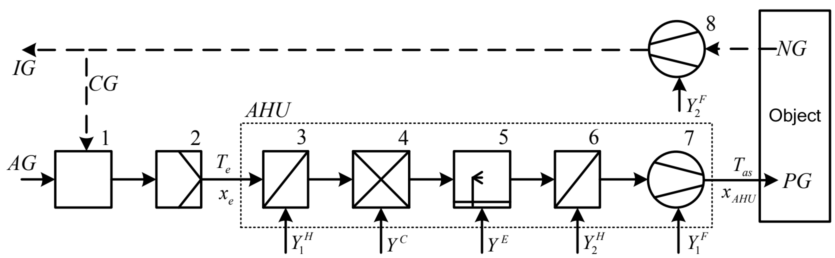

Fig.2. Air system block diagram

Development of the methods of system control

Comfortable and technological air conditioning is based on the principles of heat and air masses exchange theory [4] and is characterized by the ongoing processes of increased complexity, which is justified by a large number of parameters, a large inner relation and alternating numbers and their interaction. Changing one variable of an input process, usually a nonlinear alteration of various parameters takes place. In air conditioning equipment this relation's determination is carried out simultaneously solving thermal, hydraulic and aerodynamic relations [48]. Main alternating values of conditioning processes alter both in time and in space.

A generalized structural scheme of an automatic control system (ACS) is shown in Fig.3.

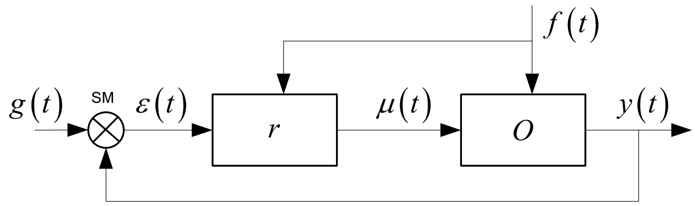

Fig.3. Generalized Structural Scheme of ACS

Where: O is an object, r is a regulator/, SM – a comparator, $f(t)$ is a proponent action, $y(t)$ is an adjustable parameter, $g(t)$ is a set parameter, $\varepsilon(t)$ is an adjustment error, $\mu(t)$ is a managing force.

Fuzzy Logic

A structure of a classic control module of fuzzy logic (FL) [59] consists of a fuzzificator, a decision making unit, a rules base and a defuzzificator (Fig.4).

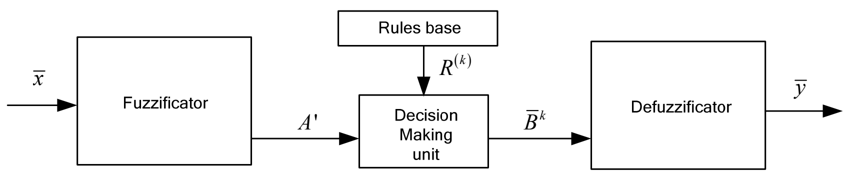

Fig.4. Structural Scheme of a fuzzy logic control module

A Rules base consists of fuzzy rules $R^{(k)}$, $k=1,...,N$, which are written in the following manner:

$$R^{(k)}: IF(x_1 \ is \ A_1^k \ AND \ x_2 \ is \ A_2^k ... AND \ x_n \ is \ A_n^k)$$
$$THEN(y_1 \ is \ B_1^k AND \ y_2 \ is \ B_2^k ... AND \ y_m \ is \ B_m^k) \quad (6)$$

A fuzzificator performs fuzzification of a definite value $\overline{x}=(\overline{x}_1,\overline{x}_2,\overline{x}_3,...,\overline{x}_n,)^T \in X$ of an input signal, as a result of which a fuzzy set $A' \subseteq X = X_1 \times X_2 \times X_3 \times ... \times X_n$ is achieved.

If a fuzzy set $A' \subseteq X = X_1 \times X_2 \times X_3 \times ... \times X_n$ is entered into an input of a decision making unit, then a corresponding fuzzy set will appear in its output.

In the output of the decision making unit, either N fuzzy sets $\overline{B}^k$ with possessive functions $\mu_{\overline{B}^k}(y)$, $k=1,2,3,...,N$, or a single fuzzy set B' with a possessive function $\mu_B(y)$ are formed.

The aim of a defuzzificator is to transform these fuzzy sets (or a set) into a sole output signal with a definite value $y \in Y$, which will be used for the provision of control efficiency in the object.

Takagi and Sugeno [59] applied the algorithm in realization of which the rules, in which a fuzzy form is only partially IF, but THEN contains functional relations, were used:

$$R^{(N)}: IF\left(x_1\ ir\ A_1^N\ AND\ x_2\ ir\ A_2^N \ldots AND\ x_n\ ir\ A_n^N\right) THEN\ y_N = f^{(N)}\left(x_1, x_2, \ldots x_n\right) \quad (7)$$

If a signal $\overline{x} = \left(\overline{x}_1, \overline{x}_2, \overline{x}_3, \ldots, \overline{x}_n\right)$, which can be interpreted as a vector of an object's condition, is transmitted into an input of a fuzzy control module, then it is possible to determine the module's output signal $\overline{y}$. $R^{(N)}$ for each rule can be calculated:

$$\mu_{A_1^N}\left(\overline{x}_1\right), \mu_{A_2^N}\left(\overline{x}_2\right), \ldots, \mu_{A_n^N}\left(\overline{x}_n\right) \quad (8)$$

$$W^N = \begin{cases} \min\left\{\mu_{A_1^N}\left(\overline{x}_1\right), \mu_{A_2^N}\left(\overline{x}_2\right), \ldots, \mu_{A_n^N}\left(\overline{x}_n\right)\right\} \\ vai \\ \mu_{A_1^N}\left(\overline{x}_1\right), \mu_{A_2^N}\left(\overline{x}_2\right), \ldots, \mu_{A_n^N}\left(\overline{x}_n\right) \end{cases} \quad (9)$$

$$\overline{y}_N = f^{(N)}\left(\overline{x}_1, \overline{x}_2, \ldots, \overline{x}_n\right) \quad (10)$$

An output signal of Takagi-Sugeno fuzzy control module is a normalized weighted sum of individual output $\overline{y}_1, \overline{y}_2, \ldots, \overline{y}_N$ signals:

$$\overline{y} = \frac{\sum_{k=1}^{N} W^k \overline{y}_k}{\sum_{k=1}^{N} W^k} \quad (11)$$

A structural scheme of the fuzzy logic regulator is provided in Fig.5. The regulator performs a maintenance of a value of an adjustable parameter in accordance with the setpoint g in the object O. Into one input/entry of the fuzzy logic controller, used in operation, the values y of the adjustable parameter measured in the object O and the difference x_1 of the setpoint g are delivered, but into the second input/entry, the shift (Z^{-1}) value x_2 of the parameter of the prior measurement are transmitted. In this way the controller is provided with information about a shift of a current value of the adjustable parameter from the setpoint and about a speed of a parameter's alteration in time.

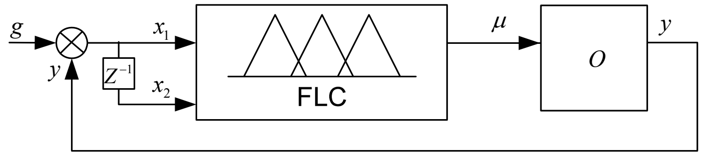

Fig.5. Structural Scheme of a Fuzzy Logic Regulator

The controller (FLC), with the help of the output control signal μ and according to the rules defined in the database, makes alterations of the adjustable parameter in the object.

Non-contact Radio Frequency Identification Method

Non-contact radio frequency identification method (RFID) [53] is intended for recognition of identification markers and for reading and a modification of data written in them. The RFID system consists of the following constituents (Fig.6):

1. A transponder is an electronic marker (IC card), which is located near a recognizable object.
2. A wireless reader- writer which is installed in a control point (TRX).
1. Application of data reception/collection (DK), which is intended for processing the collected data.

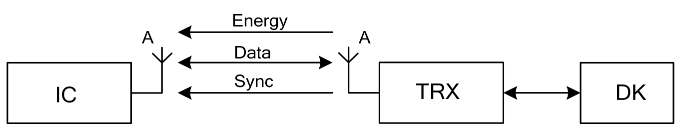

Fig.6. Flow Chart of the RFID System

When an IC card together with a recognizable object comes into TRX operational zone, it receives a TRX transmitted energy charge, under the influence of which an activation of feeding the processor built into the IC card takes place. The feeding causes data exchange between IC and TRX. The data exchange between the devices is synchronized owing to the TRX transmitted synch-impulses. The received data comes from TRX into application DK, where these data is processed and analyzed. RFID method provides a non-contact way possibility to read information about the personal requirements for the environmental parameters and a comfort level, which is written on a passenger's personalized identification card (IC). In addition it allows determining the location of each particular passenger in a vehicle.

In order to apply this method, all the passengers must be provided with RFID identification cards. An IC card also can be used for the passenger's trip payment verification requirements, if this is offered by a transporting company. RFID transmitting-receiving devices (TRX) are placed in a passenger compartment of a vehicle, near passenger seats.

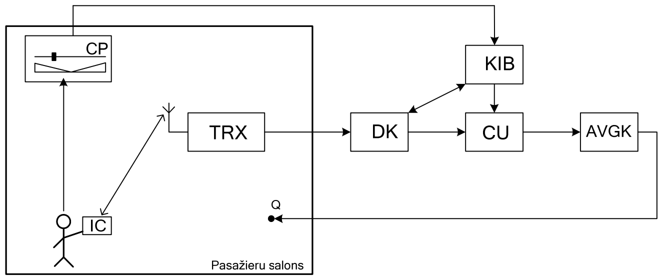

Fig.7. Structural Scheme of an RFID System's Application

The system operates in the following way: an individualized RFID identification card IC (Fig.7), on which a user's saved identification code (ID) comes to the TRX operational zone at the time when the passenger takes their seat. As a result data exchange process gets activated.

An identification code of the card and a value of a desired effective temperature index ET*, which is saved on it, are automatically read with the help of the wireless RFID receiver TRX and passenger data are passed to the data processing controller DK. Read effective temperature index value ET* is sent for processing to a comfort individualization unit KIB, which generates an output signal for the control unit CU, in which a new passenger's comfort choice is processed, which influences the alteration of the values of an adjustment of the set passenger compartment environment parameters of the HVAC equipment.

Evaluation System of Passengers' Sensation of Comfort

In order to set a passenger compartment's environmental parameters, which would satisfy the majority of the passengers, it is necessary to find out the passengers' opinions about the correspondence of the currently provided comfort to their wishes. The author solves this task undertaking periodic passenger surveys. Technically this is realized making use of individual button panels (Fig.8) located near passenger seats.

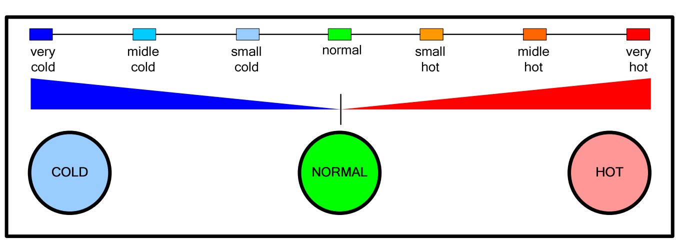

Fig.8. Individual Button Panel of Passenger Comfort Evaluation

The passengers can express their dissatisfaction with the level thermal comfort once or several times, by pressing the buttons 'Cold' or 'Hot'. The passengers also are offered to press the button 'Normal', in cases when they wish to express their satisfaction with the level of the provided comfort. If a passenger does not take any action, this will be considered that the passenger is satisfied with the level of comfort. Collected voting results are summed up according to the categories 'Cold' - V_S^C and 'Hot' - V_S^C :

$$V_S^C = \sum_{i=1}^{F_S} w \cdot V_i^C \tag{12}$$

$$V_S^H = \sum_{i=1}^{F_S} w \cdot V_i^H \tag{13}$$

Passenger comfort vote-rating chart is given in Fig.9.

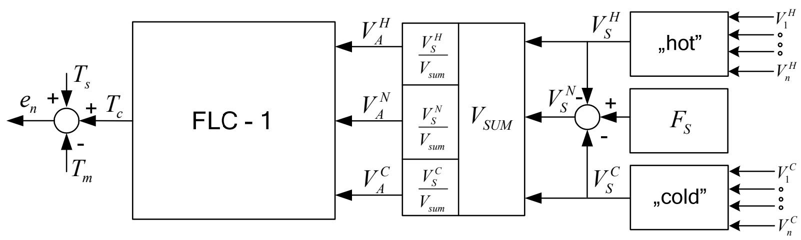

Fig.9. Structural Scheme of Passenger Comfort Evaluation System

In order to define the number of the passengers, who are satisfied with the comfort level, the number of the passengers having 'Cold' and 'Hot' votes is subtracted from the total number of the passengers F_S present in the compartment of a vehicle.

$$V_S^N = F_S - \sum_{i=1}^{F_S} V_i^C - \sum_{i=1}^{F_S} V_i^H \tag{14}$$

The total sum of passenger votes V_{SUM} is equal with the maximal possible evaluation sum multiplied by the corresponding number of votes.

FLC-1 input values V_A^C, V_A^N, V_A^H of evaluation of the passengers' level of comfort are calculated in the following way:

$$V_A^C = \frac{V_S^C}{V_{SUM}} \tag{15}$$

$$V_A^N = \frac{V_S^N}{V_{SUM}} \tag{16}$$

$$V_A^N = \frac{V_S^H}{V_{SUM}} \tag{17}$$

Then, according to FL rules, at the fuzzy logic controller FLC-1 output the parameter adjustment value of T_c is generated, which influence changes of the set temperature target values for T_m.

Control of HVAC systems' devices with the help of FL controller

Control of the HVAC system is established making use of two fuzzy logic controllers FLC-2 and FLC-3 (Fig.10).

The FLC-2 controller performs a control of air heater's, air cooler's and air flow fan's power with corresponding output signals y_H, y_C and y_F, providing an optimal temperature regime in a passenger compartment. FLC-3 is intended for control of air humidity and its level's alterations. FLC-3 with the help of the control signals y_E and y_D conducts an operation of an air humidifier and an air dryer. Air cooling and drying is provided by an air conditioner. During the drying regime the temperature of an outgoing air stays unchangeable, separating a definite quantity of humidity from it.

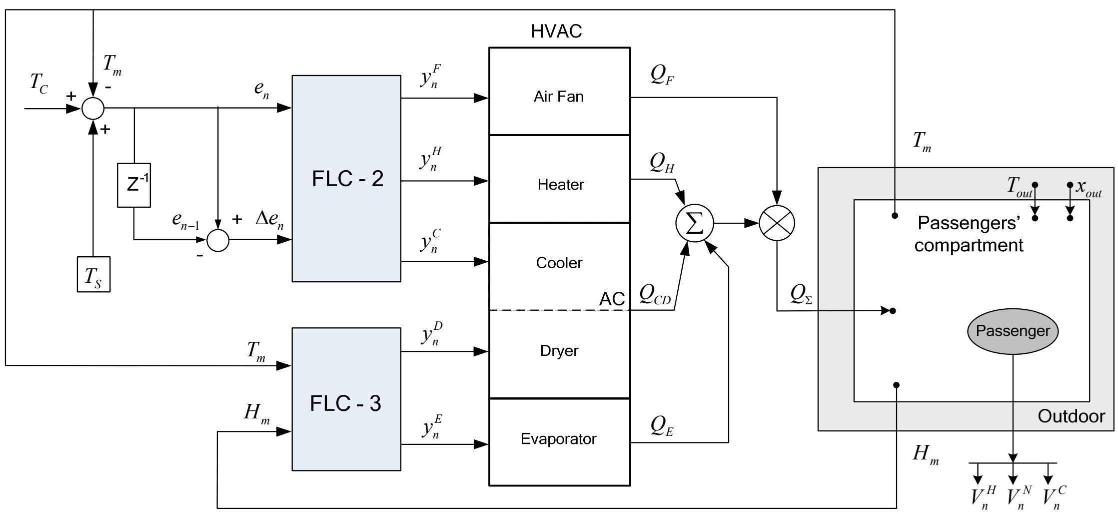

Fig.10. Structural Scheme of a HVAC System Control

The passenger compartment' air temperature T_m is adjusted according to the passengers' set requirements, which are expressed with the temperature adjustment value T_C. The temperature's set value e_n is calculated according to the following expression:

$$e_n = T_S + T_C - T_m \tag{18}$$

The setpoints of the adjustable comfort parameters are selected from the comfort diagram (Fig.1) for average values of seasonal regions and they are: the target temperature T_s in summer is +24°C, but in winter it is +22°C with a 50% relative air humidity.

Air humidity control is ensured by the fuzzy logic controller FLC-3. The task of the controller is to provide a level of humidity which would correspond to the room air temperature. It has two entrances and two exits. At the entrances information about the values of the measures room temperature and humidity is received, but at the exit, according to FL rules, the air humidifier's and the air dryer's control signals are generated. H_m relative humidity value characterizing air humidity of a passenger compartment is maintained at the corresponding level for the measured air temperature T_m, securing the midpoint of the range of the values required for passengers' comfort (RH=50% ±5%).

Modeling of System Control

The following equipment is made use of in modeling (Fig.11) and computer programs:

1. A programmable controller Siemens Simatics S7-224XP;
2. A control board with a display Siemens TD-400C;
3. PC-RS232 connective adapter Siemens RS232/PPI Multi-Master Cable;
4. P4 computer with Windows XP operating system;
5. Matlab 7 software with a Simulink supplement;
6. Siemens Step 7 Micro/Win v4.06 software;
7. S7-200 PC-access V1.03 software;
8. RFID non-contact card reader;
9. RFID non-contact identification cards.

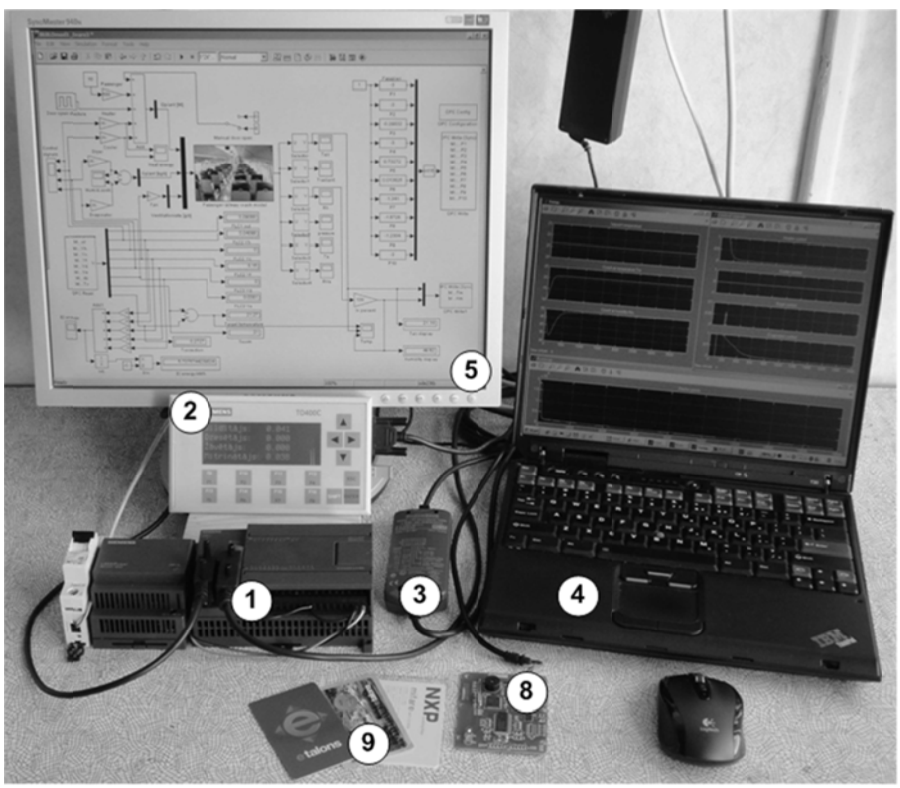

Fig.11. Equipment Used in an Experiment

The goal of the experiment: to check the operation and get acquisition curves for the control system of HVAC devices for public electric transport's passenger compartment, with a serial programmable controller and fuzzy logic algorithm, elaborated by the author.

The experimental system consists of the following elements (Fig.12):

- A controller with a fuzzy logic algorithm program,
- A Simulink model of a public electric vehicle's passenger compartment with 10 passengers.
- OPC server, which links the Simulink model with the controller.

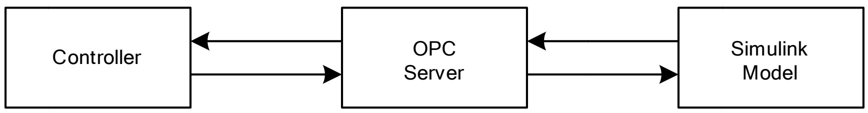

Fig.12. Link Scheme of the Elements of the Experimental System

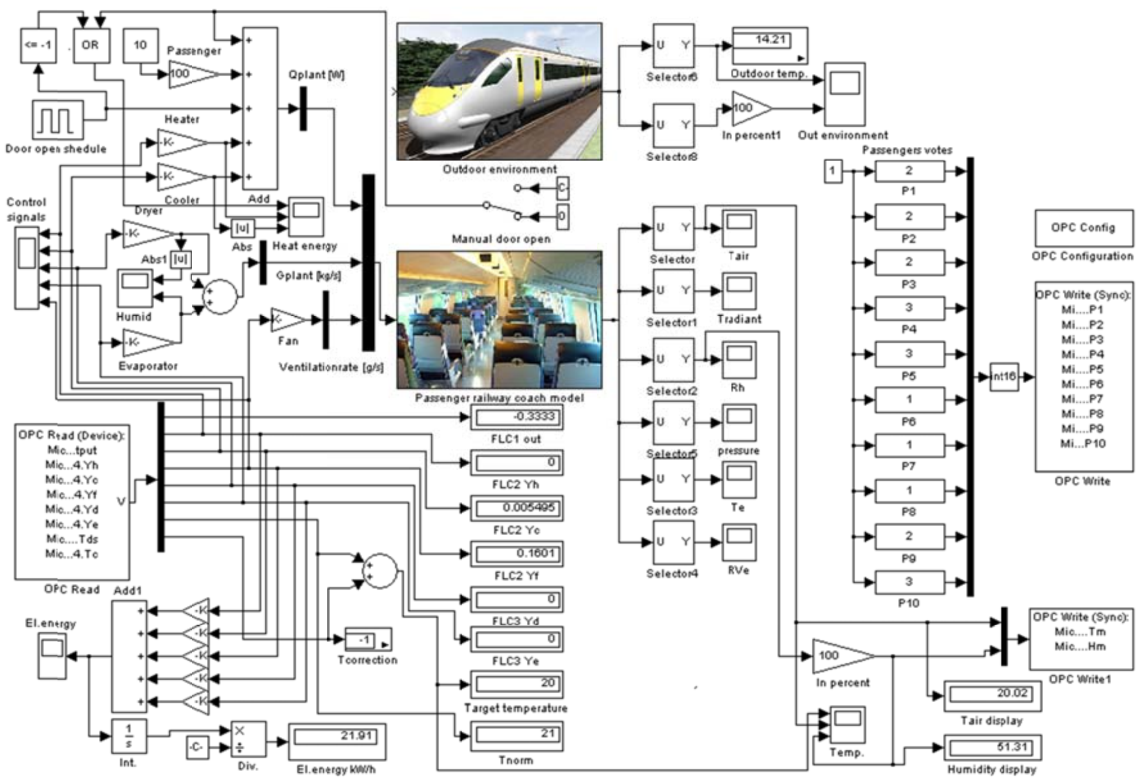

Fig.13. Experimental Matlab/Simulink model

The model of experiment (Fig.13) consists of the following parts:

- A model of an environment of passenger compartment,
- 24 hours model of an outside environment parameters,
- Controlled devices of a HVAC system: a heater, a cooler, a dryer, a humidifier and a fan,

- Passenger compartment temperature and humidity sensors,
- Passengers' sensation of the level of thermal comfort voting entry elements,
- Elements for an automatic and manual opening of the door of a passenger compartment,
- Electricity consumption meter.

The Matlab/Simulink model (Fig.13) is linked with the programmable controller, in which a fuzzy logic program is entered. The controller receives information (entered by the passengers) from the vote's entry elements and from compartment temperature and humidity sensors. In one programmable controller three fuzzy logic sub-programs are realized; they are FLC-1 which is intended for processing of the evaluation of comfort of passengers and for determining temperature alteration value , FLC-2 which is intended for controlling the heater, cooler and fan, and FLC-3 which for controlling a dryer and humidifier. The results of the operation of the controller's program are transmitted from the controller to the model, where a control of the devices and their influence on a compartment's environment is realized, as well as feedback is realized making use of an OPC server program and a computer-programmable controller connective adapter. A compartment of an electric train, with 10 passengers in it, is modeled. Each passenger has a possibility with the help of a regulator to evaluate a current state according to their sensation.

In order to perform comparison of the developed HVAC system model with the widely applied electric passenger control system with a two-step commutation, modeling of such a control system was performed, using power packs of passenger compartment and HVAC equipment identical to the previous model. Air temperature for the set target values for heating and cooling modes are different in the model (+21°C for heating and cooling from +23°C), with the control zone of ± 1°C of set value.

The Results of System Modeling

Simulating the operation of the developed HVAC equipment with changing set target temperature value in accordance the wishes of passengers, several changes in the target temperature were modeled: 21°C, 18°C, 18,5°C, 20°C, 24°C and 22°C (Fig.14).

As the result of system modeling a number of alterations of the environmental parameters of the interior of passenger carriages and the characteristic graphs of the HVAC devices' output parameters were obtained (Fig.15-21). When passengers take votes, the value of the set temperature alters. As the result of these alterations, the temperature of the passenger compartment also alters (Fig.16). Changes of relative humidity are seen in Figure 16.

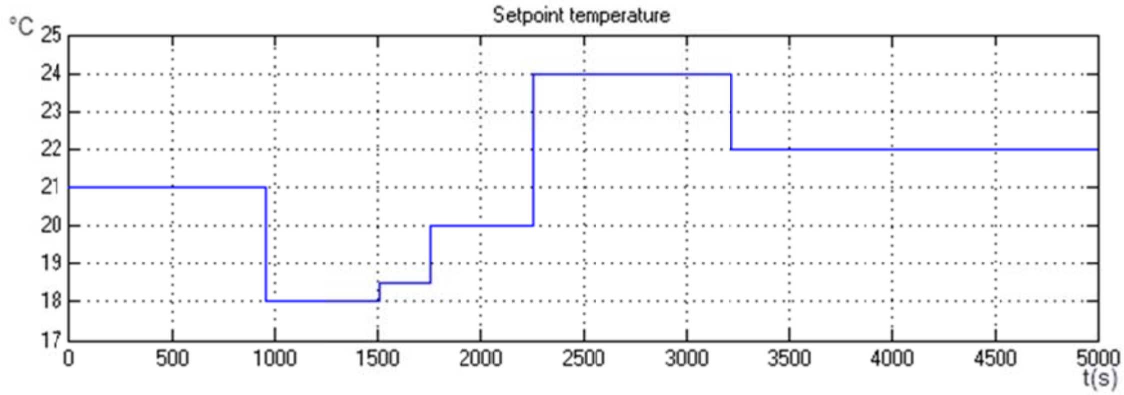

Fig.14. Target Temperature Adjustment According to Passenger Wishes

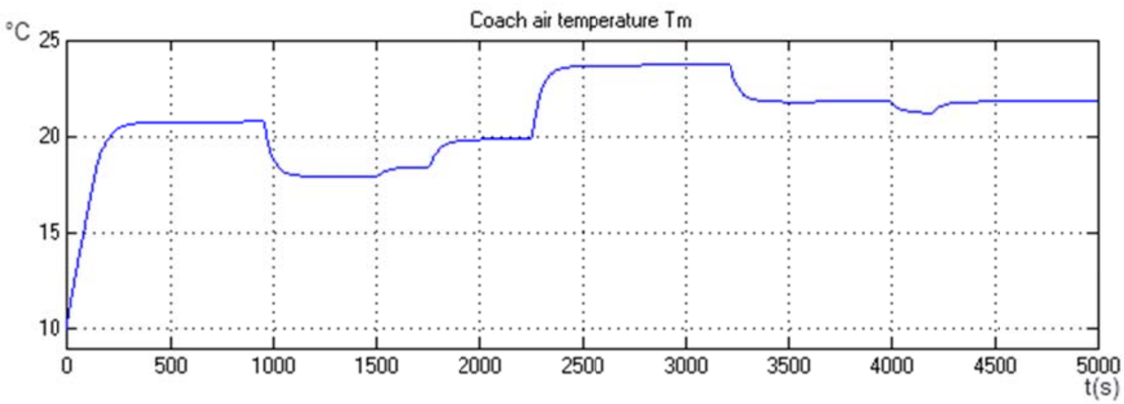

Fig.15. Air Temperature of a Passenger Compartment

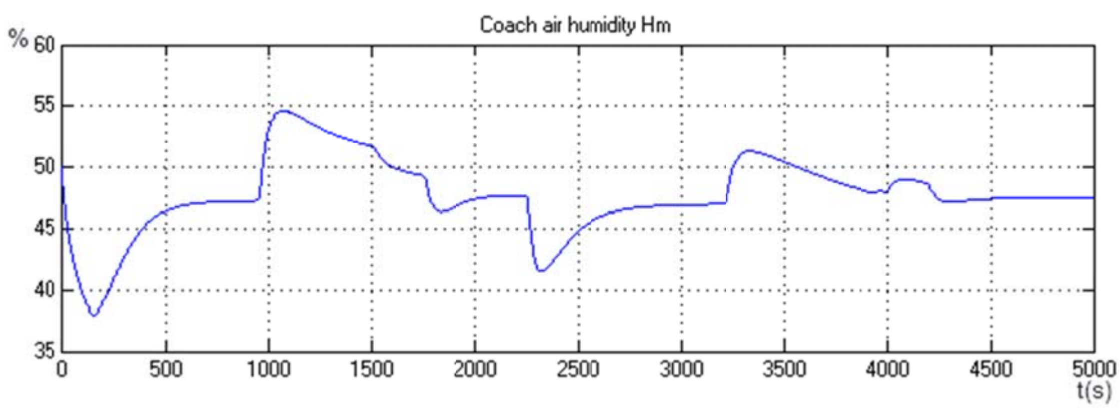

Fig.16. Air Relative Humidity of a Passenger Compartment

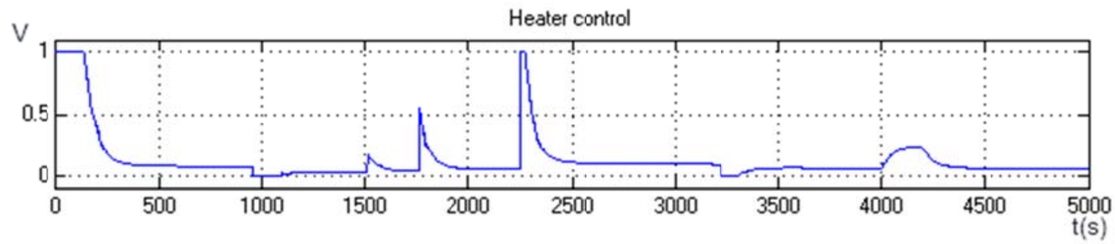

Fig.17. The Control Curve of the Air Heater of the HVAC Equipment

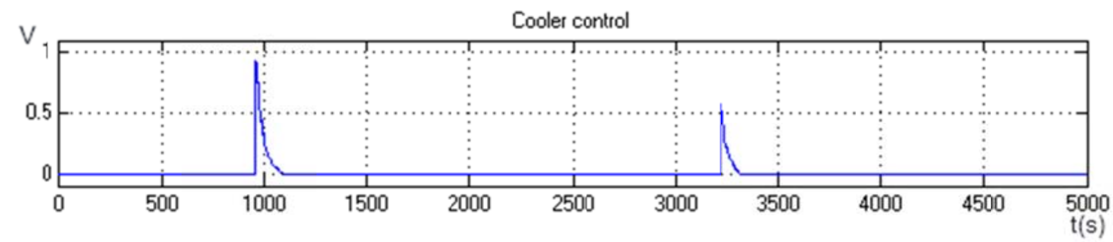

Fig.18. The Control Curve of the Cooler of the HVAC Equipment

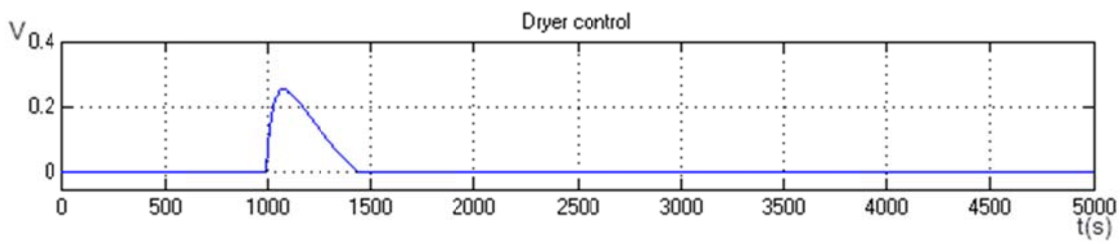

Fig.19. The Control Curve of the Dryer of the HVAC Equipment

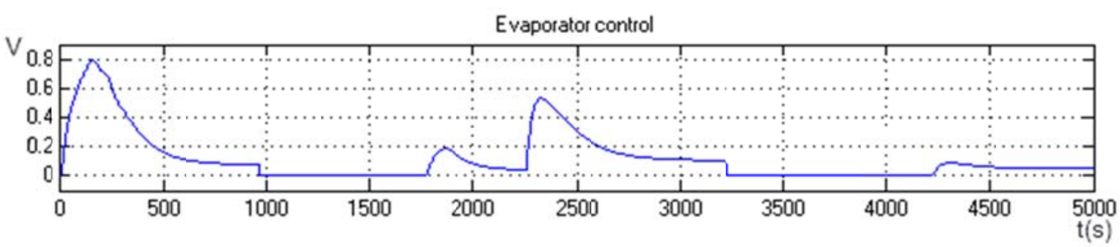

Fig.20. The Control Curve of the Evaporator of the HVAC Equipment

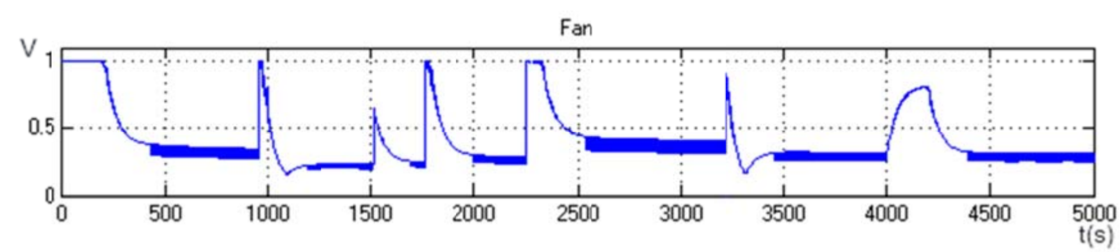

Fig.21. The Control Curve of the Air Fan of the HVAC Equipment

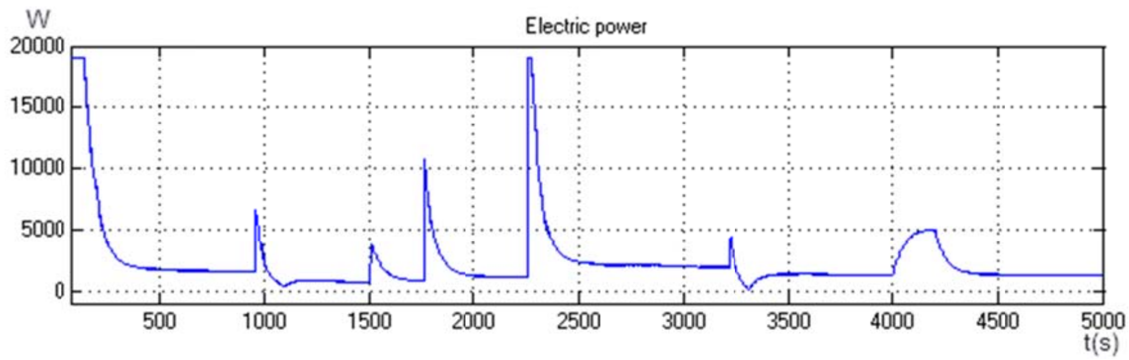

Fig.22. The Consumed Power Curve for the HVAC epuipment

Fig.22 illustrates that the power consumed by the HVAC equipment, and which maximum is reached at the moment of the system's launching until the setpoint environmental parameters are reached. After that the system reduces the power of the HVAC equipment unit and energy is used only for maintaining the environmental parameters of the passenger compartment at the necessary level.

CONCLUSIONS

In the process of the development of the promotion thesis:

1. the following system units were developed:
    - The unit for passenger comfort level evaluation votes reception and their processing with the help of the fuzzy logic controller.
    - Exploitation of the HVAC equipment's control system with the fuzzy logic controller for regulating the levels of an air temperature and humidity of a passenger compartment, by taking into account the setpoints of environmental parameters, which are adjusted according to the wishes expressed by passengers and seasonal changes of an outdoor environment.
    - Determination of a passenger's location in a passenger compartment and determination of previously expresses comfort wishes with the help of RFID non-contact identification technology.
2. The variables required for computer modeling were find out and calculated.
3. The following experiments were conducted:

- The fuzzy logic controller's support for passenger comfort evaluation and the HVAC equipment control realization using a serial programmable controller.
- Computer simulation of two level control system of HVAC equipment.
- Passengers' identification and their previously expressed comfort wishes clarification using non-contact identification method.

By means of experiments the correspondence of the chosen methods to the definite goals, and the system's functionality were tested. The programmable controller's program and the methodology of the controller's connection to the virtual environment of the passenger compartments of the public electric transport and the HVAC equipment are described. By means of experiments the developed FL control system and the traditional two-level control system were compared and the most important characterizing curves were captured.

On the basis of the work carried out it can be concluded that:

1. The control of complicated and unpredictable processes can be conducted in the most accurate manner by applying the fuzzy logic control method, which in contrast to other traditionally applied methods provides an even regulation of the set parameter, thus providing the closes adjustable parameters' values for the setpoint.
2. It is possible to make an alteration of the HVAC system's output parameters according to the comfort evaluations made by passengers, but taking into account 10% dissatisfaction possibility inclination, by using a fuzzy logic control system.
3. An application of the radio frequency identification method provides a possibility to develop HVAC control system which would take a definite passenger comfort wishes into account, and which can perform a setup of the adjustable environmental parameters according to a passenger's location in a passenger compartment.
4. By means of experiments, it was proved, that selection of optimal control regimes, using control of FL controller, allows a rational use of electric energy consumed for operation of the HVAC equipment and the reduction its consumption by 7-9%, because of owing possibility to adjust the power of the HVAC equipment units evenly, according to the necessity. Even greater electric energy savings can be achieved by reducing the HVAC equipment unit power and in the result lowering or raising air temperature (depending on the seasonal outdoor environmental conditions) of the

passenger compartment by 5°C in cases, when no passengers in compartment or in that sector.

The control systems of fuzzy logic controller and algorithms, which were developed in the promotion thesis, can be applied in the systems of thermal comfort provision in public electric transport as well as in dwelling and council buildings and other premises, by carrying out partial changes to adjustable parameters and control rules.

REFERENCES

1. Akmens P., Krēsliņš A. *Ēku apkure un ventilācija.* Riga: Zvaigzne ABC, 1995. - lpp.165.
2. ASHRAE *Handbook - HVAC Applications, SI Edition*. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 2007.
3. ASHRAE *Handbook 1997. Fundamentals*. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1997.
4. ASHRAE *Heating, Ventilating, and Air-Conditioning Fundamentals SI*. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 2001.
5. ANSI/ASHRAE Standard 55-2004 *Thermal environmental conditions for human occupancy*., 2004.
6. Bekker A. *Luftungsanlagen*. Wurzburg: Vogel Industrie Medien GmbH&Co KG, 2000.
7. Berglund L.G. Comfort criteria: Humidity and standards. *In: Proceedings of Pan Pacific Symposium on Building and Urban Environmental Conditioning in Asia*, vol. 2, 1995. pp.369-82
8. Borodiņecs A., Krēsliņš A. *RTU rekomendācijas būvnormatīva LBN002-01 pielietošanai ēku projektēšanā un būvniecībā*. Riga: RTU Izdevniecība, 2007. - lpp.131.
9. Busch J.F. A tale of two populations: Thermal comfort in air-conditioned and naturally ventilated offices in Thailand. *Energy and Buildings*, 1992, 18, , pp.235-49
10. Dirba J., Ketners K., Levins N., Pugačevs V. *Transporta elektriskās mašīnas*. Rīga: Jumava, 2002. p.342
11. Dzelzītis E. *Siltuma, gāzes un ūdens inženiersistēmu automatizācijas pamati*. Riga: Gandrs, 2005.- lpp.414.
12. Kreider.F, et.al. *Handbook of Heating, Ventilation, and Air Conditioning*. Boca Raton: CRC Press LLC, 2001. p.668
13. Fanger P.O. *Thermal comfort*. Malabar, FL: Robert E. Krieger Publishing Company, 1982.
14. Greivulis J., Firago B. *Principles of Electrical Drives in Questions and Answers*. Rīga: RTU, 1993. p.214
15. Greivulis J., Raņķis I. *Iekārtu vadības elektroniskie elementi un mezgli*. Rīga: Avots, 2000. p.288
16. Haines R., Wilson C. *HVAC Systems Design Handbook 2nd izd.* New York: McGraw Hill, 1994.
17. Hordeski M. *HVAC control in the new millenium*. The Fairmount press inc., 2001.
18. Jones M.T. *AI Application programming*. Charles River Media inc., 2003. p.312
19. Kreider J. *"Introduction to the Buildings Sector"Handbook of Heating, Ventilation, and Air Conditioning*. CRC Press LLC, 2001.
20. Leonhard Werner. *Control of Electrical Drives 3rd izd.* Berlin: Springer, 2001. p.460
21. Levine W. *The Control Handbook*. CRC press, 1996.
22. Luger G. *Artificial Intelligence. Structures and Strategies for Complex Problem Solving*. Williams, 2003.
23. Merkurjevs J. *Imitācijas modelēšanas tehnoloģijas. Lekciju konspekts*., 2003.
24. Raņkis I., Bražis V. *Regulēšanas teorijas pamati*. Rīga: Rīgas Tehniskā universitāte, 2001. p.94

25. Raņķis I., Žiravecka A. *Industriālās elektronikas pamati*. Rīga: Rīgas Tehniskā universitāte, 2007. p.212

26. Ribickis L. *Elektriskā piedziņa*. Rīga: RTU izdevniecība, 2006. p.190

27. Ribickis L., Ļevčenkovs A., Gorobecs M. *Sistēmu teorijas pamati industriālās elektronikas modelēšanā*. Rīga: RTU, 2008. p.100

28. Ribickis L., Raņķis I. *Electrical drives static characteristics and methods of speed control*. Rīga: Rīgas Tehniskā universitāte, 1995. p.107

29. Ribickis L., Raņķis I., Ļevčenkovs A., Gorobecs M. *Programēšanas valodas industriālā elektronikā. Metodisks līdzeklis*. Rīga: RTU, 2007. p.70

30. Russel S., Norvig P. *Artificial Intelligence. A Modern Approach 2nd izd.* Prentice Hall, 2006. p.1408

31. Sauer H., Howell R.H. *Principles of Heating Ventilating and Air Conditioning*. Atlanta: ASHRAE, 1994.

32. SIEMENS *SIMATIC S7 Fuzzy Control*. Siemens AG, 1996.

33. Standarts *LVS EN 13053:2007, Ēku ventilācija. Gaisa pārvades un apstrādes iekārtas. Gaisa pārvades un apstrādes iekārtu, to komponentu un sekciju nominālie raksturlielumi un veiktspēja.*

34. Standarts *LVS EN 13129-1:2003, Dzelzceļa aprīkojums - Gaisa kondicionēšana maģistrālo līniju ritošajos sastāvos - 1.daļa: Ērtību kritēriji.*

35. Standarts *LVS EN 13129-2:2004, Dzelzceļa aprīkojums - Gaisa kondicionēšana maģistrālo līniju ritošajos sastāvos - 2.daļa: Tipa testi.*

36. Standarts *LVS EN 13141-1:2004, Ēku ventilācija - Dzīvojamo telpu ventilācijas iekārtu un to komponentu veiktspējas testēšana - 1.daļa: Ārējās un iekšējās gaisa pārplūdes ierīces.*

37. Standarts *LVS EN 13142:2004, Ēku ventilācija - Dzīvojamo telpu ventilācijas iekārtas un komponenti - Obligātie un neobligātie veiktspējas raksturlielumi.*

38. Standarts *LVS EN 14750-1:2006, Dzelzceļa aprīkojums. Gaisa kondicionēšana pilsētas un piepilsētas ritošajos sastāvos. 1.daļa: Komforta raksturlielumi.*

39. Standarts *LVS EN 14813-1+A1:2011, Dzelzceļa aprīkojums. Gaisa kondicionēšana mašīnistu kabīnēs. 1. daļa: Komforta parametri.*

40. Standarts *LVS EN 15140:2006, Sabiedriskais pasažieru transports. Pamatprasības un ieteikumi sistēmām, kas kvantitatīvi novērtē sniegto pakalpojumu kvalitāti.*

41. Standarts *LVS EN ISO 14505-3:2006, Vides siltuma ergonomika. Vides siltuma novērtēšana transportlīdzekļos. 3.daļa: Siltuma komforta novērtēšana ar cilvēka palīdzību.*

42. Standarts *LVS EN ISO 7730:2006, Siltuma vides ergonomika. Termālā komforta analītiska noteikšana un interpretācija, izmantojot paredzamā vidējā balsojuma (PMV) un paredzamā neapmierināto personu procenta (PPD) indeksu kalkulāciju un lokālā termālā komforta kritērij.*

43. Trčka M., Hensen Jan. Overview of HVAC system simulation. *Automation in Construction*, 2010, 2, vol. 19, pp.93-99

44. Valeinis J. *Elektriskās piedziņas vadība*. Rīga: Rīgas Tehniskā universitāte, 1982. p.95

45. Valeinis J. *Ievads elektriskās piedziņas vadības sistēmās*. Rīga: RTU, 2007. p.163

46. Wagner Walter. *Lufttechnische Anlagen (Kamprath- Reihe)*. Wurzburg: Vogel Buchwerlag, 1997.

47. Wit Martin. *Heat Air Moisture Model for Building and Systems Evaluation*. Eindhoven:

Eindhoven University Press, 2006. p.112

48. Бондарь Е., Гордиенко А., Михайлов В., Нимич Г. *Автоматизация систем вентиляции и кондиционирования воздуха*. Киев: Аванпост-Прим, 2005. p.560

49. Герман-Галкин С.Г. *Matlab&Simulink. Проектирование мехатронных систем на ПК*. КОРОНА-Век, 2008.

50. Герман-Галкин С.Г. *Компьютерное моделирование полупроводниковых систем Matlab 6.0.* Санкт-Петербург: Корона, 2001. p.320

51. Герман-Галкин С.Г., Кардонов Г.А. *Электрические машины. Лабораторные работы на ПК*. СПб: КОРОНА принт, 2003. p.256

52. Девятков В.В. *Системы искуственного интеллекта*. Москва : Издательство МГТУ им. Н.Э.Баумана, 2001.

53. Дшхунян В.Л., Шаньгин В.Ф. *Электронная идентификация*. Москва: НТ-Пресс, 2004.-695с.

54. Дьяконов В.П., Круглов В.В. *Matlab 6.5 SP1/7/7 SP1/7 SP2 Simulink 5/6 Инструменты искусственного интелекта и биоинформатики*. Москва: Солон-Пресс, 2006. p.453

55. Калабеков Б.А., Мамзелев И.А. *Основы автоматики и вычислительной техники*. Москва: Связь, 1980.296с.

56. Клюев А.С., Лебедев А.Т., и.др. *Наладка средств автоматизации и автоматических систем регулирования*. Москва: Энергоатомиздат, 1989.-386с.

57. Копилова И., Клокова Б.К. *Справочник по электрическим машинам.том 1*. Энергоатомиздат, 1988. p.455

58. Леоненков А.В. *Нечеткое моделирование в среде MatLAB и fuzzyTECH*. СПб: БХВ-Петербург, 2003. p.736

59. Рутковская Д., Пилиньский М., Рутковский Л. *Нейронные сети, генетические алгоритмы и нечеткие системы*. Москва: Горячая линия-Телеком, 2006.

60. Сандлер А.С. *Регулирование скорости вращения асинхронных двигателей*. Москва: Энергия, 1966. p.319

61. Солодовникова В.В. *Теория автоматического регулирования. Книга 3*. Москва: Машиностроение, 1969. p.606

62. Фираго Б.И., Павлячик Л.Б. *Регулируемые электроприводы переменного тока*. Минск: ЗАО Техноперспектива, 2006. p.363

63. Черноруцкий И. *Методы принятия решений*. СПб.: БХВ-Петербург, 2005. p.416