PHD RESEARCH PROPOSAL

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MODELS AND METHODS OF DEVELOPING A SMART ENERGY SYSTEM BASED ON MULTI-AGENT TECHNOLOGIES

6D070300 – Information Systems

Thesis for the degree
Doctors of Philosophy (PhD)

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INTRODUCTION

Relevance of the research topic. Energy conservation and energy efficiency are an important component in energy security. Currently, more than a third of the final energy consumption is accounted for by the housing and communal complex and the service sector. The increase in energy consumption in the non-production sector will continue due to an increase in the population and an increase in the quality of life of people. Considering the structure of energy consumption by non-production facilities and the cost of various types of energy resources, as well as the tightening of standards in the field of thermal protection of buildings, the most common and investment-attractive energy-saving measures are measures aimed at reducing the consumption of thermal energy. Sealing buildings with natural ventilation leads to a decrease in the air exchange of the premises, which worsens the microclimate and reduces the human performance. Prolonged exposure to unfavorable factors of the indoor environment on the human body can negatively affect his health. Therefore, the development of a new method for assessing the effectiveness of energy-saving measures, taking into account both the economic indicators of the energy-saving project and the comfort of the microclimate in residential, public and administrative buildings, is an urgent task.

The beginning of the development of specialized expert systems and artificial neural networks was the appeal of the electric power industry to the field of artificial intelligence.

Object of study. Energy saving and microclimate in non-production buildings.

Subject of study. Heat transfer processes during microclimate formation in non-production buildings.

The purpose of the thesis. Building a system based on multi-agent technology and neural networks to increase a comfortable environment.

Research objectives. To achieve the goal of the research, the following tasks solved:

1. Analysis of methods for assessing effectiveness, microclimate, and methods of mathematical calculation of heat transfer processes in rooms, taking into account temperature, humidity and air quality.
2. A mathematical model of heat exchange in buildings with natural ventilation has been developed to predict microclimate parameters.
3. The architecture of an energy efficiency monitoring system and parameters was proposed with the participation of Grid and Multi-agent.
4. Agents were set that allow you to build a system based on Grid and MAS technologies:
   - State switch agent- used to select Grid
   - Central Coordinator Agent - to communicate with other agents.
   - Load Agent- to control various equipment from the external environment.

- Local Power Management Agent- for managing and monitoring energy consumption

5. Mathematical and software based on multi-agent technologies in the framework of the proposed architecture.
6. Performed experimental studies, debugging the developed testing and verified.

Scientific novelty:

1. A mathematical model of a comfortable microclimate and a SmartGrid model with the participation of multi-agent technologies have been developed
2. Based on the mathematical model, the dependence of the comfort levelon standard energy-saving mechanisms aimed at reducing heat energy consumption due to building insulation has been obtained and a comprehensive comfort criterion has been proposed that takes into account the combined effects of HVAC parameters.
3. Experimentally obtained data on the influence of energy-saving mechanisms on air exchange and microclimate parameters
4. A method for controlling temperature, humidity and air quality has been developed.

Defense Provisions:

1. The energy efficiency system built in the framework of Multi-agent, Neural and Grid technologies to solve the problem of improving the comfortable environment in residential buildings
2. A mathematical model of a comfortable microclimate in buildings with natural ventilation for predicting microclimate parameters, taking into account the composition of the indoor air.
3. Methods for controlling temperature, humidity and air quality was developed.

1. MULTI-AGENT-BASED SMART GRID (MASG) SYSTEM IMPLEMENTATION FOR BUILDING ENERGY MANAGEMENT

Our study is focused on the development of a smart grid EMS by using multi-agent technology. During the study, in developing the system architecture and applying the algorithms, we try to keep the given requirements. To achieve flexibility in the management, a multi-agent system is applied. The comfort in a building or its surrounding areas is usually determined by a combination of temperature, light, humidity, air velocity, and CO_2 concentration [5-7, 14]. Multi-agent technology can be used as a basis for the system of power consumption and comfort management in the building. This technology allows one to divide a complex task into simple subtasks that can be solved with the help of agents. The multi-agent modeling method allows one to model complex systems by focusing on one actor, the so-called agent. Each agent is a virtual pedestrian with prescribed physiological properties, such as gender or body weight, as well as specific routing goals. Following their plans, these agents are actually exposed to various climatic conditions, similar to real pedestrians. The influence of these climatic conditions on individual thermal comfort is constantly monitored by a simple transitional two-node model of the human thermal control system: the individual thermal comfort model (ITCM). A multi-agent intelligent grid system for modeling and analyzing pedestrian traffic and thermal comfort in complex building environments has been developed. The modeling system integrates, in addition to other modules, a model of bio-meteorological thermal comfort.

Architecture of the System. Modern control technology ensures more reliability, efficiency and flexibility of the energy system, which introduces the concept of the smart grid. The smart grid concept is a new technology that customers can participate in. This ensures the quality and reliability of the supply. Rising energy demand requires more decentralized generation, owing to changes in market behavior and complex distribution systems. Therefore, it is difficult to manage the network from a central controller. Intelligent control system technology provides a distributed solution for building management technology, with a secure and reliable operation network to deal with various deployment scenarios. Intelligent BEMS is its application. EMS in a commercial building is aimed at improving the environment within the building.

In our study, we consider two types of energy sources: the utility grid and microgrid. The utility grid takes energy from the main grid of a city. The microgridis supplied by renewable energy sources. The second part of the system is the multi-agent system. Since each agent assumes a high level of intelligence for making a local decision, the system requires a new agent model architecture. The multi-agent system takes data from sensors and passengers as input data and makes decisions to implement control on the drives. Management systems are the systems that should be controlled and supply the inhabitants with comfort and energy.

The sensors are distributed throughout the building to monitor its operation. Three types of data, including environmental, user preferences and energy data, can be obtained from the sensor network. Environmental data refers to the environmental parameters of the building, such as indoor and outdoor temperatures, light levels, CO_2 concentration, or even the detection of intrusion or fire alarm signals. Data on occupancy usually include the number of passengers and the presence or absence of passengers. Energy data is mainly focused on the status of the energy supply, such as the state of the utility network, the price of electricity and the availability of renewable resources. These measured data will be used by various local agents to determine their behavior. Figure 1 demonstrates the proposed system architecture.

Sensors are distributed throughout the building to monitor its operation. Three types of data can be obtained from the sensor network, including data about the environment, user preferences and energy. Environmental data refers to the building's environmental parameters, such as indoor and outdoor temperature, light level, CO2 concentration, or even the detection of intrusion or fire alarm signals. Occupancy data usually includes the number of passengers and the presence or absence of passengers. Energy data mainly focuses on the state of energy supply, such as the state of the utility network, electricity prices and the availability of renewable resources. This measured data will be used by various local agents to determine their behavior. Figure 1.1 shows the proposed system architecture.

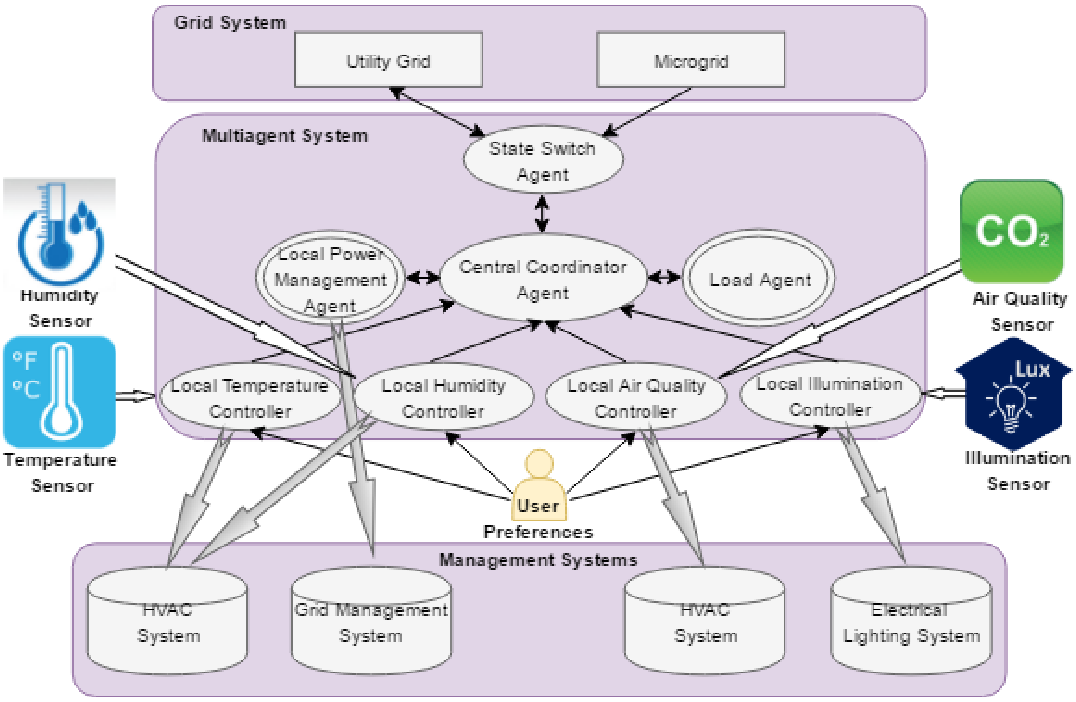


Figure 1.1 - Architecture of the proposed multi-agent control and management system

2. Multi-agent-based Smart Grid (MaSG) System Implementation for Building Energy Management

2.1 State Switch Agent

Agent-switch is located on the first level. The switch agent receives data from the central coordinator on the energy consumed and generated. According to this information, the switch agent receives power from the power grid when there is not enough power from renewable sources and batteries to satisfy the demand of the required load. In addition, the switch agent can deliver excess energy back into the network when the renewable energy is more than the building's needs, which can then be stored in the batteries. The total integrated building and microgrid system has two modes of operation: grid connection mode and isolated mode. The state switch agent communicates with the central coordinator agent to determine the status of the switch for connecting/disconnecting the microgrid to/from the utility grid is considered. Figure 2.1 illustrates the procedure for selecting a particular operating mode in different scenarios. If there is any damage to the power system or if the rate of power consumption is not acceptable to consumers, the microgrid will be disconnected from the main grid.

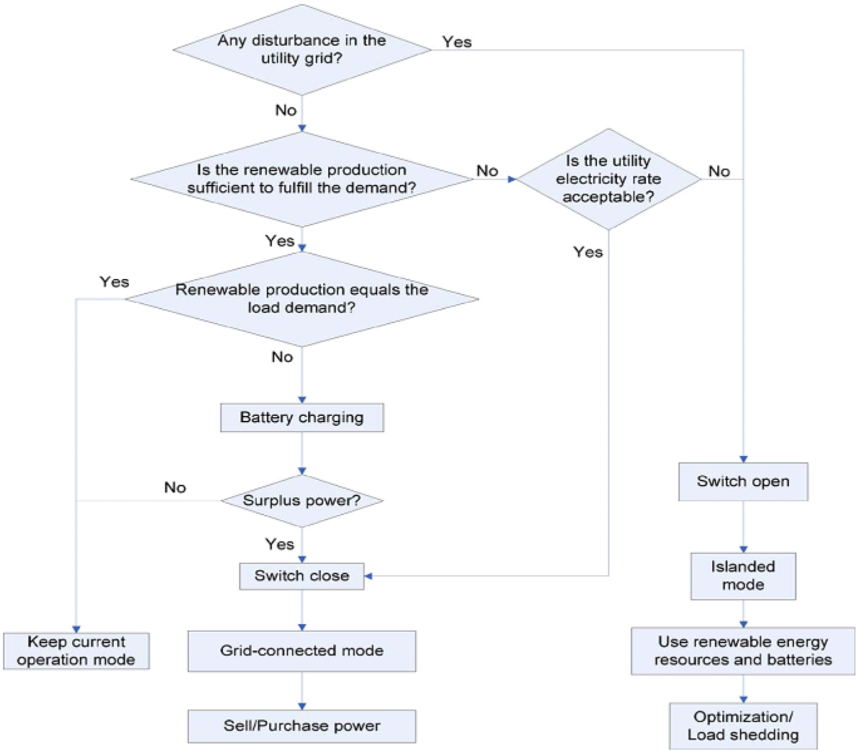


Figure 2.1 – Procedure for the choice of operation modes

The switch in these scenarios will be opened and appropriate optimization or mitigation schemes will be adopted to maximize the overall comfort level using available renewable energy sources; otherwise, the microgrid is connected to the power system. Nevertheless, the building will always consume the available renewable energy in the first place. If there is excess energy from renewable resources, the batteries will be charged. If there is still energy, the excess energy will be sold back to the energy system. Additionally, if there is not enough renewable energy from the “microgrid” and the rate of electricity consumption is acceptable, the power supply will be procured to meet the overall load of the building.

2.2 Central Coordinator Agent

The central coordinating agent, which is located at the second level, is one of the key elements in the management system. It interacts with all agents based on external data (information about weather conditions) and user preferences for thermal, visual comfort and air quality, as well as on data on electrical loads of the building. It also receives information from agents of wind turbines and solar photovoltaics from a battery charge agent. In addition, it determines the amount of energy and the energy needed to cover it and manages it accordingly.

For the central coordinator-agent, the primary task is to coordinate the power allocation and maximize customer comfort while, at the same time, bridging the energy sources and all the lower-level agents.

2.2.1 Negotiation among Agents

Agents negotiate between each other to share the available energy. Negotiation is startedby load agents. The load agents request the other agents for a proposal of power supplies. Power source agents receive a power request from the download agents and send theoffer of the offer. Agents begin to negotiate among themselves and make decisions basedon their own rules. Typical solutions are what power sources must be consumed and howmuch power should be provided by the accepted power supplies. The agent logic is shown in Figure 2.2.

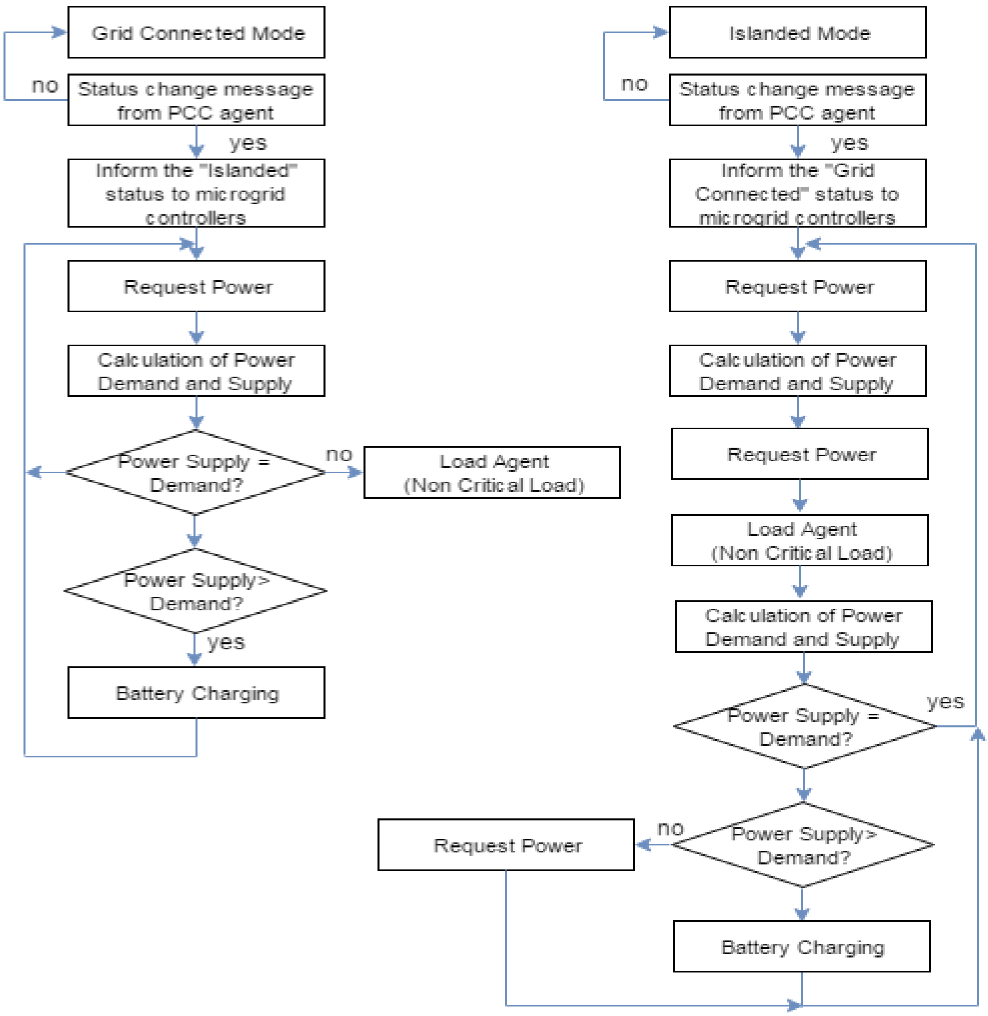


Figure 2.2 – Negotiation among agents

2.3 Local Climate Controllers

For the monitoring of thermal comfort, visual comfort and air quality, four local agent controllers are used. These controller agents compare the current values of the comfort parameters with the given ones and determine the amount of energy needed to control the actuators of the building's engineering systems.

2.3.1 Local Temperature Controller

To calculate the required power to maintain internal thermal comfort, a controller with fuzzy inference is designed for this subsystem. The input of this fuzzy controller includes error and error correction. The changing error is the difference between the previous and current errors.

2.3.1 Local Humidity Controller

To identify the required power for internal humidity comfort, we apply fuzzy PD design. The fuzzy control for humidity has a set of fuzzy variables including Very Dry, Dry, Normal, Humid and Very Humid. Power requirement is changed depending of each mode.

2.3.2 Local Air Quality Controller

Local Air Quality Agent controls CO_2 concentration level in the building. A common misapprehension is that the contaminated air is on the outside, when the truth is that concentrations in the air of various irritating, carcinogenic and mutagenic compounds may be higher than their corresponding concentrations outside the premises even in industrial areas. Most indoor pollutants are, CO and other gases from cigarette smoke, fugacious organic mixture from cleansers, disinfecting, paints, glues, pollutants from copying machines, etc.

The best way to reduce the concentration of these contaminants is to introduce as much fresh air into the indoor environment as possible, nevertheless, this usually requires a certain price, because fresh air usually needs to be heated or cooled depending on the outdoor climate. As an indicator of indoor air quality. This is provided taking into account that the concentrations of other pollutants will follow similar trends, which in some cases may be inaccurate.

2.4 Local Power Management Agent

The role of a Power Management Agent is to adapt the power consumption to the available power resources, taking into account the user comfort criteria. It limitsthe use of supplementary resources, which require additional investment, to avoid the expensive need of storage. A Local power management agent controls energy level in the Grid Management system.

2.5 Load Agent

The load agent controls all equipment that do not have a direct connection to the three main comfort factors. It also controls all electrical loads that can be turned off during a power shortage. Consumers are given the opportunity to select preferred load disconnections and prioritize each load through this agent. Some load profiles are created and a graphical user interface is designed to configure the appropriate parameters. Using a graphical platform, customers can not only determine the characteristics of the load, but also control the amount and order of load shedding.

3 Indoor Climate Control

The micro-climate in the room is a fundamental factor for a healthy life and is determined by a number of physical quantities, such as temperature and humidity, the concentration level of harmful substances in it, and the rate of air flow (wind). These factors determine whether the subject experiences "thermal comfort"; is it hot or cold. Thermal comfort state is a condition where the body does not require thermoregulatory mechanisms, i.e., a human will not experience any tremors or sweating, and blood flow is maintained at a constant rate in the peripheral organs. This condition corresponds to the thermo neutral zone

In order to maintain a given level of microclimate and indoor air quality, it is necessary to develop a control system with economical power consumption for a given set of operating conditions. Figure 3.1 illustrates design and optimization of fuzzy controller procedure.

The air flow control system in a large building should be designed for different modes of operations because external weather conditions and the number of people inside the building periodically change from day to night, and from season to season.

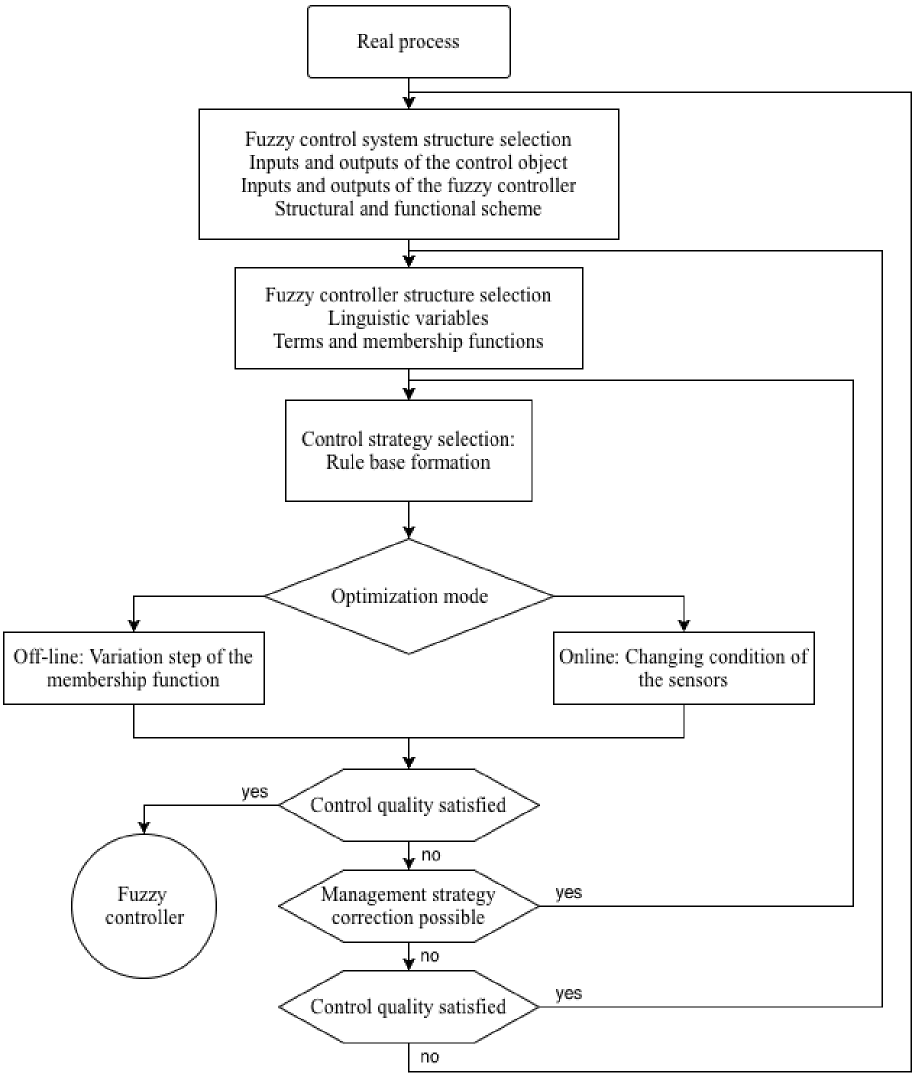


Figure 3.1 – Fuzzy controller design

The problem is to determine the temperature corresponding to a level of control for the digital-to-analog converter regulator, the input variables of which are as follows: e (difference between the desired and actual temperature, ° C), Δe (the first derivative of temperature change during the computing cycle, ° C/min)

$$\Delta e = T_{given}(t) - T_{current}(t) \tag{10}$$

Here, $T_{given}(t)$, $T_{current}(t)$ are the given and current temperature, respectively.

Naturally, the increase in the cooling or heating level should correspond to the temperature difference at a given time. The rate of temperature change is given as follows:

$$\Delta e = \frac{e(t_2) - e(t_1)}{t_2 - t_1} \tag{11}$$

As indoor temperature approaches the target temperature, the rate of temperature change therein will decrease, as well as, for example, the air condition cooling level.

4 Design of Adaptive Neuro-PID Controller for Humidity

Despite the fuzzy PID controller being designed for indoor climate control, the temperature, humidity, and IAQ differ in physical parameters, and have different characteristics. Therefore, in order to further analyze the potential of using an improved management method to improve the quality of the indoor environment, it is necessary to conduct research and develop a new indoor humidity control strategy based on the difficulties of humidity control discussed in this section. The major difficulties of indoor humidity control include: time delay; personal preferences; the influence of temperature.

Consequently, the designed controller has to able to satisfy the following requirements: fast response, small overshoot, good adaptability, and an intelligent algorithm to determine if the temperature is hot, cold, or warm. An intelligent PID controller based on a NN of radial basis function (RBF) is introduced to control the room temperature in this section. In this study, the performance of the radial basis function neural network PID (RBFNN-PID) controller is checked by computer simulation, using Python. An intelligent PID controller based on an RBF neural network is introduced for indoor RH control. After a description, we will prove our approach by computer simulation, and experiments in experiment results section.

The control process of the RBFNN-PID control as presented in Figure 6 can be summarized as follows:

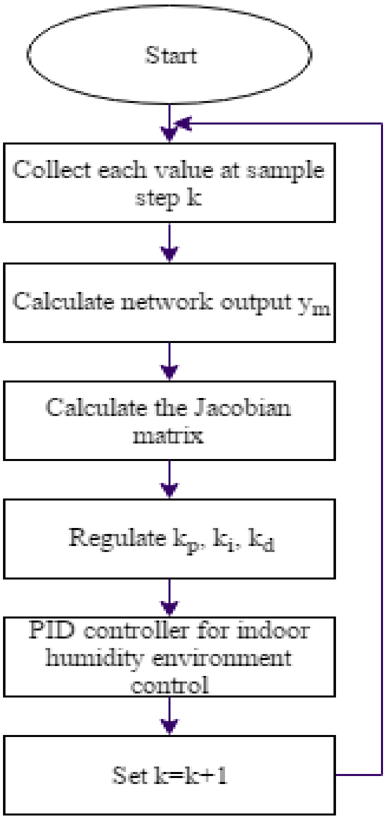


Figure 4.1 - Flow chart of RBFNN-PID controller

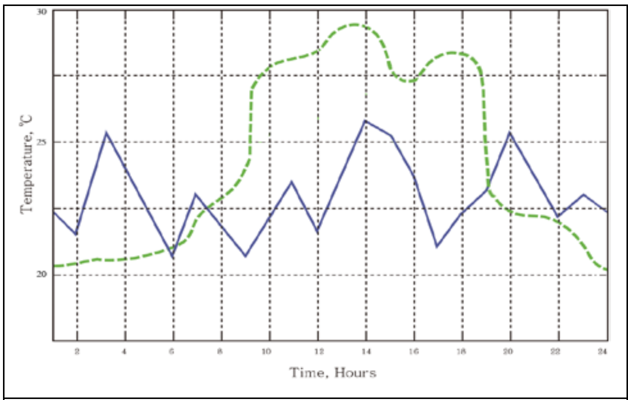
- Collect each value at sampling step k.
- Calculate the network output y_m, based on the collected data.
- Get the Jacobian matrix using the given equations.
- Tune the PID parameters for the PID controller.
- The controller sends a command to the HVAC equipment for humidity control, and since the indoor climate may change the control process should be continued.

Set k=k+1.

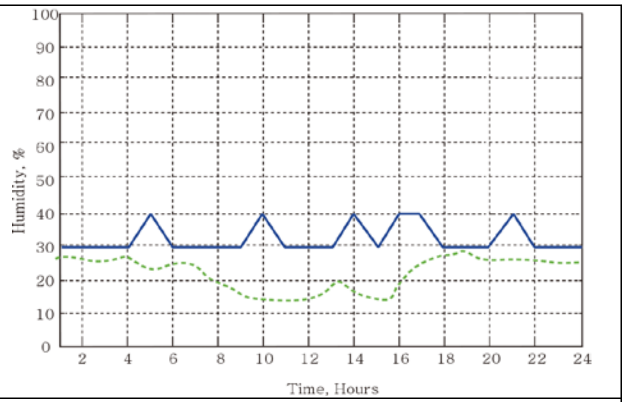
5 EXPERIMENT RESULTS AND DISCUSSION

As a case study, we consider the utilized mode. By performing experiments with utilized mode and measuring the required power, further, we can predict the capacity of the microgrid to supply the building with energy. In the simulation, the inhabitants' comfort ranges for the various control tasks are set as follows: Air Quality ranges between 400 and 8800 ppm, the temperature and humidity ranges are taken based on international standards and recommendations ISO/FDIS 7730 [5].

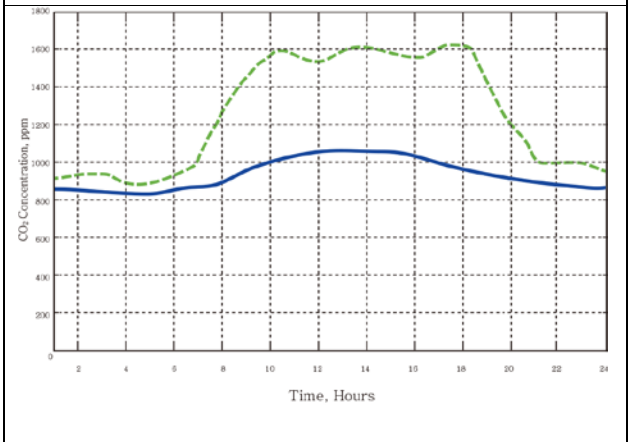
The optimization algorithm tools were used for the NN algorithms. The initial settings for the NN algorithm were selected as follows: temperature, relative humidity and CO_2 concentration (representing air quality) describe the comfort of the indoor environment. For a minimal rate of a comfort, the parameters were taken as the vector$\{19.5°C; 40\%; 800ppm\}$ and for a maximal rate of a comfort, the parameters were taken as the vector$\{26°C; 60\%; 1100ppm\}$.



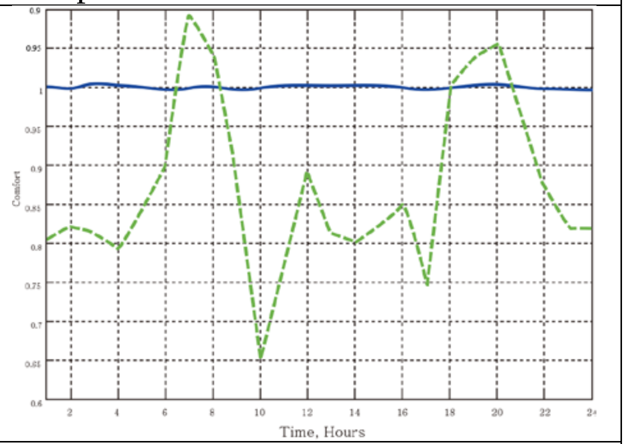
Temperature set points comparison



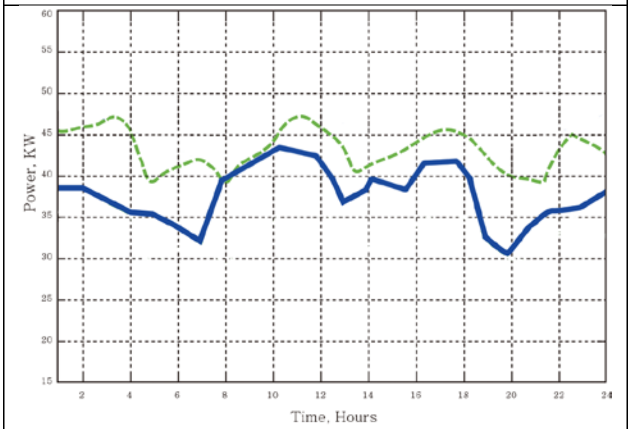
Relative humidity set points comparision



Air quality set points comparison



Overall comfort level set points comparision



Overall power consumption comparison

Figure 5.1 – Experiment results. Green line: casual system; Blue line: the proposed approach

CONCLUSION

This dissertation work was devoted to the creation of a comfortable microclimate using multi-agent technologies to ensure a comfortable microclimate inside the building. Models and methods for the development of Intelligent Energy based on Multi-Agent technology with the use of adapted neural networks were considered. The literature review carried out in the work shows that the problem is relevant, since energy saving and energy efficiency are important components in the heat power industry. In this regard, the dissertation work solved the problems of developing new approaches to assessing the comfort of the microclimate to reduce energy consumption while maintaining favorable conditions for people inside residential, public and administrative buildings, while saving the electricity used.

Currently used methods of assessing the comfort of the microclimate do not take into account the special risks inherent in non-industrial premises, as a result of which it can lead to a violation of favorable conditions for people inside. In this regard, in the proposed work, methods have been developed that take into account the impact of energy-saving measures on the microclimate, as a result of which it will not have a negative impact on people. One of the most suitable methods in the development of such a system is a multi-agent approach using adapted neural networks, in which a large number of interacting intelligent agents are modeled.

During the research, a qualitative review of the existing analogues of the system was conducted, among which the best ones were selected and analyzed to ensure a comfortable indoor microclimate. The paper investigated a mathematical model of thermal processes, the parameters of the indoor microclimate that affect its change, and the maintenance of a comfortable microclimate inside the building, as a result of which a mathematical model of thermal processes was modeled. In addition, it was studied how to manage heating, ventilation and air conditioning installations taking into account the temperature and humidity in the room and outdoors, and the issue of maintaining a constant comfortable temperature and humidity was also considered.

Thus, experiments conducted in laboratory conditions, analysis of the data obtained and testing showed that the multi-agent system of control and management of electricity proposed in this work based on mathematical models and methods using adapted neural networks is a necessary tool for creating comfortable conditions for people who are indoors and will make a great contribution to improving the country's economy in the future.

The following results were obtained in the dissertation:

1. A mathematical model of a comfortable microclimate of the Smart Grid model was developed with the participation of multi-agent technologies;
2. The architecture of a multi-agent system for monitoring and managing electricity was proposed;
3. Neural network models were adapted to ensure a comfortable microclimate inside the building;
4. Based on the developed mathematical modeling, it was found that the level of comfort of the microclimate depends on standard energy-saving mechanisms;

5. Data on the influence of energy-saving mechanisms on air exchange and microclimate parameters inside the building were obtained experimentally.

The reliability of the research results is confirmed by mathematical proofs and experimental studies.

The economic efficiency of the implemented work results is confirmed by the certificate intellectual property.

LIST OF PUBLICATIONS

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