Increasing buildings automation systems efficiency with real-time simulation trough improved machine self-learning algorithms

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Abstract. Energy savings with building’s automation is related to the functionality of the building’s automation system, equipment automation level, control algorithms and user-selected operating parameters. It is difficult and time-consuming process to customize each of these algorithms to a level, which would ensure the rational use of energy resources. To increase the adjusting quality that controls building’s engineering system it is necessary to implement new advanced methods, technologies and control algorithms within building’s automation system. This work presents the method of creating self-learning system, which is capable of detecting negative influences of different control algorithms. This self-learning system also provides error detection in engineering systems of the building. The system was designed in Matlab and Simulink programming environments. The article also describes the architecture of designing a complex wireless network system with real time (online) connection, including automatics and building’s engineering systems. This complex system is also capable of collecting data to perform an effective intellectual analysis.

Keywords: Self-Learning System, Matlab & Simulink, Wireless Sensor Network.

1 Introduction

There are problems with energy efficiency of buildings in Latvia. There is a necessity for algorithms and systems improving the situation. In order to achieve this goal and improve building’s energy efficiency it is necessary to develop self-learning algorithms based on the climate of Baltic region and building’s load in particular. Individually created algorithms using obtained data will be developed for each type of the building.

The main part of the task is to analyze operating conditions and energy efficiency of heating units. Determined necessary parameters of air supply and program calculated physical energy allows choosing correct configuration for operating parameters of heating units. Coincidences from parameter settings of air supply on heating units configuration and control system, should be investigated further. Necessary air supply can be adjusted to insure comfortable conditions. Adjustments
related to comfort zone, comparing to temperature adjustments with deadbands, requires control system of higher-level, but it gives the opportunity to calculate optimal air supply parameters, which requires minimum energy consumption. Developed heating energy calculation program can be supplemented with optimal air supply parameter calculations. This option will allow calculating potential energy savings, which can be achieved by control system of higher-level. Results can be used as key factors for better control system utility. To reduce consumption of energy resources it is necessary to create a wireless sensor system with self-learning algorithms, which will assist in energy efficiency and reveal weak points of systems exploitation. The goal of this work is to create a sensor network that determines energy efficiency in buildings according to the EN 15603 standard. The European EN 15603 standard sets the general structure of the assessment of general energy consumption in buildings, and also a technique, which should be used when determining the nominal power parameters.

One of main difficulties in creating a sensor data collection system is designing inexpensive and easily customized system, which will transfer data to the remote server (Cloud). The server should contain a database and quick assessment method for energy consumption of the building and create long-term forecasts of energy consumption. By using collected data from experimental objects it is necessary to create a database on different groups of building types and their operational parameters. The developed sensor system will help adjusting the system of existing buildings by providing deeper energy consumption analysis and comparison, assessing energy class and providing reliable data for possible buildings or its engineering system upgrades.

The research of building’s automation systems with different control algorithms is relevant for industry and academics. Analyses of control algorithm and energy consumption have been comprehensively disclosed in author’s various papers. They have made a great effort to develop different control algorithms.

Bo Chai [1] has described installation and temperature control algorithm depending on external temperature changes. The author describes the goal of energy control in office environment, by adjusting thermostat and minimizing maximum load. Developed models and simulations are accordingly implemented into Matlab to evaluate maximum load savings.

Per Lynggaard’s [2] promotion work is based on the combination of established theories. This work describes artificial intelligence of automated system based on analysis of building’s sensor database. The researcher analyzed methodology offering iteratively-based experimental research strategies.

Kumar Sandeep [3] describes analytical model of automated system which is knowledge-based system “KBS”. Based on this database the system can decide how to effectively control the building.

Amit Badlani’s [4] work describes smart home systems that decrease energy consumption by studying human behavior pattern.

The main contributions of this paper are Building Management System (BMS) with self-learning algorithms based on WSN of a heterogeneous network specified for
providing energy consumption analysis and estimating energy efficiency upgrading actions.

2 Overall system architecture

Multi-store buildings, which initially were not planned to integrate building’s control systems raises a complex problem condition for modernization. Installation of wired sensor system in such building becomes impractical or even impossible. Therefore, effective wireless sensor systems are necessary to be able to provide measurement delivery considering specifics of multi-store buildings.

Research direction, described in this work, leads to the creation of a wireless sensor data transmission network to ensure data collection from sensors and determine the loss of energy resources of the building. The specific task is to create the wireless sensor network in which the initial data flow concentrates in a special concentrator with further data transmission via high-speed channels to main network server. Such method is economically more effective comparing to systems without the concentrator. Although, despite the message being small in amount, there is a chance of electromagnetic incompatibility effect for channels. To reduce the noise, lines are separated in points of concentration, which do not cross the frequency of low channels and their throughput is defined by the sensor group. Data from developed sensor network is automatically transferred to Matlab and SQL (Structured Query Language) Database. The program written in Matlab has analysis algorithm for calculating the necessary heating power and work conditions of Heating systems. Calculation program for energy consumption is the first step for in developing a good climate control system for building areas. The program graphically analyzes the processes and gives information about the necessity to adjust. Power calculations of heating units show the necessary power requirements for different regimes. In this test bed of prototype architecture (see Fig. 1) the Sensor node senses the data from the sensor and the data received at the end base station (Raspberry Pi):

Fig.1. Test bed prototype
Base station with MQTT (Message Queuing Telemetry Transport) protocol sends all data to the Web cloud to Matlab. We managed to integrate it into building’s old automatic equipment by using Matlab and OPC (Open Platform Communications) standard. We used Matlab machine learning toolbox and weather forecast. OPC is the interoperability standard for secure and reliable exchange of data in industrial automation area. By analyzing next day’s weather forecast and the database with data from wireless temperature sensors, a self-learning algorithm was created that allows adjusting automatic equipment of the building.

Using PID control for Building Management System (BMS) is not effective method to control the heating system. Thus, a considerable change in set point occurs. Integral terms cause an overshooting error during the rise [5].

For the purpose of optimizing the control algorithm, a modular heat flow numerical model of a heating system integrated with BMS was developed by discrditing time using Finite Difference Method in self-learning model. It was developed in Matlab & Simulink (see Fig.2). To calculate the supply temperature we use the following parameters in this algorithm:

- Temperature increase/decrease gradient.
- Supply temperature compared to the weather forecasted.
- Inertia time constant of valve.
- Limit value for heating circuit power.
- Comparison of consumption energy with supply temperature.
- Adjustment of control algorithm based on the analysis of data archive.

![Fig.2. Self-learning implementation scheme](image)
3 Wireless Sensor Network Design

The Wireless Sensor Network (WSN) was implemented by using a topology in beacon mode where sensors collect data and deliver it to the base station which is the concentrator of the network. Offered WSN design is shown in Fig. 3. This system works in 25 meter range from the base station and it is suitable for monitoring [6,7,8]. The IEEE 802.11 devices are capable of transmitting data for long distances by passing them through intermediate devices reaching longer transmission range for the data. The main feature of ESP-8266 technology is the fact that at small energy consumption it supports not only simple network topologies, but also self-organized and self-recovering mesh topology with the retransferring and routing of messages [9].

We designed a system for collecting and analyzing the data from sensors. This system includes the base station (Raspberry Pi), the router (ESP-8266) and sensors (see Fig. 3).

Fig. 3. WSN toolbox software Overview

The dynamic structure of the network allows eliminating accidents quickly by laying out new paths of data transfer bypassing the faulty section. 16-bit addressing allows using more than 65 thousand nodes [10].

4 Test bed Results

At the beginning of our experiment we analyzed the regularity of thermal energy consumption depending on outside temperature over the 5 year period. The results show that the approximation of stored experimental data leads to a conclusion that this dependence is a linear function, see Fig. 4:
During next stage we carried out following actions:

1. Dividing heating unit into northern and southern part. Thus, by using the valve we had a chance to control southern and northern heating units separately (see Fig. 5) [11,12].

**Fig.4.** Thermal energy consumption depending on outdoor temperature over the 5 year period

**Fig.5.** Additional temperature sensors for heating center
2. To optimize the heating unit we had to add temperature sensors. We did it by choosing wireless ESP controllers and sensors connected to them. This system allows establishing sensors quickly and integrates them with existing BMS [13].

3. By using the Matlab machine learning toolbox and weather forecast a self-learning algorithm was created, which allows controlling pumps and heating unit valves more effectively and correctly [13-16].

As a result of our actions we managed to optimize the heating unit and decrease the consumption of thermal energy by $\approx 38\%$ as you can see in Fig. 6.

![Graph showing energy consumption](image1)

**Fig.6.** Heat energy consumption

5 Conclusion

The proposed self-learning system in this paper is designed with wireless sensor network and Raspberry Pi as the base station, and also ESP-8266 as the sensor node. This type of wireless sensor and self-learning algorithm control system improves the effectiveness and the efficiency of consumed heating resources. Described Self-learning system was developed and successfully tested. The main and major advantage of this system lies in the integration of the gateway node of wireless sensor network into Matlab & Simulink and traditional Building’s Management System.
Research results will be applied on energy-efficiency exploitation of engineering networks in existing buildings, which will help to increase energy-efficiency. Based on this research, recommendations will be made for the building owners about the possibilities for exploiting existing engineering systems and constructing buildings more efficiently.

Future’s plan is to address all above-mentioned problems included in this research by providing following solutions:

- The problem of ensuring the wireless network throughput and delays could be solved by the method of queuing theory of closed systems. Developed optimal assistant path for data transmission in wireless sensors system.
- When using the number of nodes (wireless controllers) >300, network’s goodput falls to unacceptable level due to increasing traffic service. In future the program – the simulator, could solve this problem. Simulators demonstrate how the performance was influenced by configuration of wireless sensors systems.
- To create an algorithm in Matlab & Simulink optimizing the work of ventilation based on specifics Baltic climate.

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