Principles and Implementation of Energy Efficiency in Public Buildings

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ABSTRACT: *Energy efficiency in public buildings is a prime issue of research. We have studied the basic principles and implementation of energy efficiency in public buildings in this work. To do so, we have basically developed an algorithm with a sound architecture. The system implementation results are presented briefly.*

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1. Introduction

The monitoring and management of the energy efficiency in public buildings can be exanimated as composition of two parts – hardware and software devices for remote monitoring and control, and algorithms for decision making. The first part was designed and implemented by the research laboratory "Radio control and environmental monitoring" of the Department of Telecommunications at the Technical University in Sofia. It is designed to monitor and control certain parameters into buildings and send the measured data to the central management system. The commands are sendin order to control in real-time the energy efficiency in certain facilities, the following parametersare measured:

- Consumption of electricity
- Consumption of heat
- Indoortemperature
- Lighting in therooms
- Operation mode of the substation,
- Outdoor weather conditions;

• Measuring the overall power consumption and estimating thebalance of power consumption includingdetection of an unauthorized use of electrical instruments and etc.

Moreover, the system provides the following additional functions:

• Site security

• Detecting open doors and windows

• Automatically updated central clock and thermometer

• Can operate as school-bell

• Can alertemergencies

The second part of the system being developed at the Center for Energy analyzes byprof. Kaloyanov.

2. Block Diagramm and Hardware System

The system includes dispatcher station hubs, sensor modules, local controllers and automatic weather stations. The connection between the different modules is establishedvia wireless radio channels and / or by build in computer network.

The sensor modules are compact, low cost devices whichare placed in each room in the controlled building. They are battery supplied and does not require connection to anypower gridsor computer networks. The battery power ensures operation of the module for at least 10 years. Each sensor module measures the temperature, lighting in the room, opening the door/window and the status of its own battery. It has a low-powered transmitter in the range of 433 MHz, which transmits information to the hub, located in the corridor or in the immediate area. The information is transmitted in certain periods or in case of significant change in the measured parameters. The module is designed on the base of microcontroller ATmega-168, which operates inthe most of the time in sleep mode in order to reduce the power consumption of the module. The microcontroller periodically wakes up into active mode to conduct measurements and to transmit data.

The hubs are installed in hallways and large rooms. They have volume sensors, thermometer, sound detector, two displays,clock, inputs for measuring curren, a separate feeder highways to other facilities for receiving information from sensor modules, radio module and/or modem for GSM-GPRS data transmission /or cable input for connection with dispatcher station. On the display is indicated the astronomical time and the current temperature in a given point. They are powered from the main power grid and has backup battery power for that ensures operation for several days. At the request of the dispatcher center they transmit the measurements data and the data obtained from the sensor modules.

The local controllers have analog and digital inputs, as well as input for positioning data, analog and serial outputs for facilities management. Powered by an external rectifier 12 V / 1,6 A and a battery backup power supply. The local controllersare based on microcontroller Atmega- 168. All of their inputs and outputs are galvanically separated by optocouplers and defensive schemes. They are designed for remote control and monitoring of equipment relevant to the energy efficiency - substations for district heating, coolantflow controllers, power distribution boards, external infrared cameras to monitor heatradiation from different parts of the building and etc.

Automatic weather stations are usually installed on the roof of the observed buildingor complex of buildingsor near it. It provides information to the dispatcher station which aimsto optimize the energy system of the building and the individual spaces in it. The current version measures temperature, humidity, pressure, solar radiation and wind. The data is transmitted over a radio channel during the periodswithin 10 minutes or in case of substantial change.

The dispatcher station collects data automatically or manually, it manages energy efficiency, lighting, heating, start and end of school hours and / or working hours and breaks and etc. It includes standard PC modem, radio module with antenna, printer and redundant power supplies.

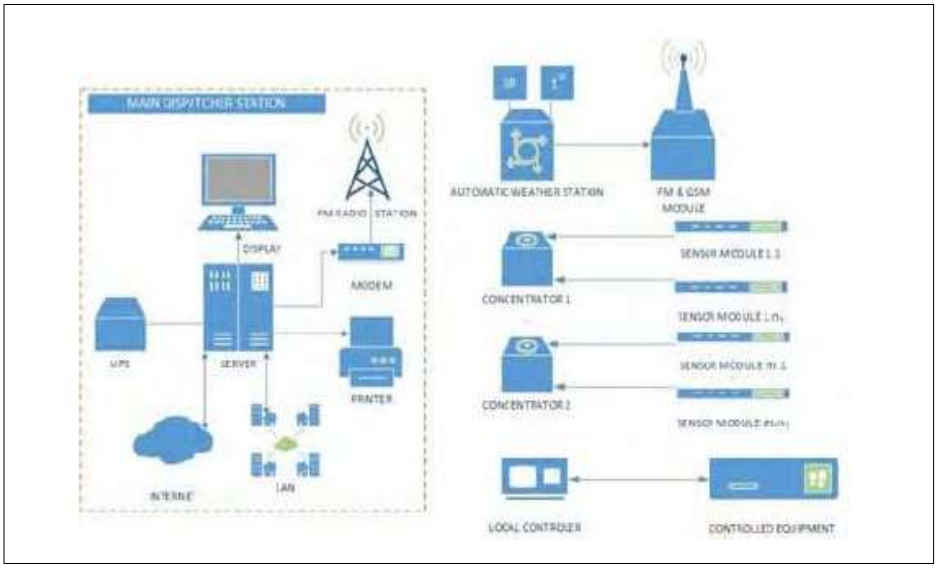

Figure 1. System architecture

Software for the dispatcher stations operates under OS Windows. It includes a several basic packages:

• Mnemonic editor.

• Software package for operational control and management, it consists of a data exchange application ("Server") and program operator interface ("Manager").

• Program for visualization and analysis of archive data.

The software supports the following features:

• A system for FM radio channel through an external modem with microcontroller connected via RS232, with the ability to relay data from each local controller or hub;

• Commanding of remote controllers via GSM-GPRS and Internet;

• In a mimic mode can be observed from different connectedcontrollers, without limitation in terms of the type of the objects and connection UHF, GSM or the Internet;

• Possibility to display mnemonicsdata as two different mnemonics schemes such group scheme or a separate site on PC with two monitors or monitor and TV;

• Can be set configurations for group call, for different types or for spatially separated groups of controllers;

• At the selected cyclean individual typecontrollers group can be called during the cycle without affect the cyclic call over a selected range of controllers and other groups;

• Directly from the application, the dispatcher can monitor graphics, change of individual parameters for the last 24 hours and etc. Without any need of additional applications. The graphics can be scaled,saved as picture, the values can be shown, the visualization parameterscan be changed and etc;

• Directly from the dispatcher program the data for an individual parameters and unitscan be examined including the response which comesafter call to a controller;

Preferential set of calibration coefficients for the analog parameters, supporting the work of dispatcher program without need ofrestarting the software;

• Possibility to connect multiple computers via the Internet, in order to monitor and even manage all or part of the periphery devices of the system. This can be done only through a radio station and a radio modem. For this purpose, one of the computers is used as radioserver which passes commands and data through the entire network. It can reaches to all other computers connectedvia LAN, and performs monitoring and management of the system;

• The system supports access levels and only certain users can perform management and setup of the system;

• Visualization with animation showing the operation of the equipment. The color of the lines can be programmed by the request from the customer;

• The "Server" can be used as a convenient test program to adjust initial start-up parameters of the facilities or for repair works or for change of the parameters;

• Upon receiption of trouble indication, the alert sound can be speech or just tone sound;

• Individual call a controller can be done by double clicking with the left mouse button on any unit of the mimic scheme, the program itself detects the controller to which the unit belongs and exchanges data with it;

• The "Archive" connected to the server and the dispatcher program, allows recording of data;

• Archived data can be seen in the mode of mnemonics in graphics mode. For both records, it can be choosen a different period of time and it is possible a simultaneously observe of individual records. One or more windows shows the program can backup data in the form of mnemonics, and therefore one or more windows showing data in a graph;

• Archive allows data export to Excel;

• Units that can be seen in a graphical window can be of different terminal stations;

• Possibility of direct printing the image data from the program to monitor the backup data;

• Automatic control units of the system, without the intervention of manager. The description of the algorithm is done directly by the administrator of the dispatcher station;

• Adjusting the astronomical clocks hubs. Adjusting the clocks can be done automatically in a user defined time;

• Dispatching station supports data loging function of the controller. This allows the controller to monitor parameters at short intervals, eg. in one minute and then to transmitt it in a packet to station dispatcher when a call from it occur;

• The presence of trouble events in the system are introduced with audio alarms for all units;

• Introduced a mode of operation in which some units are marked as idle (as if they are under repair) and thus automatically excludes the possibility to manage them;

• Windows and buttons in individual mode can display business information and transmits commands to reset service - signal level, recharge EEPROM, analog measured value of the voltage rectifier and battery, the number of board and microcontroller, the number of GSM modules Identification visualization programs on reboot and stuck in the transfer station command to send a test signal and etc.

• The system access levels and passwords are used for logging in, and the program is designed to administer passwords.

3. Communication System

The communication subsystem of the monitoring and management of energy efficiency system is developed for optimization of technical and economic parameters, as well as easy installation and maintenance. It combines three different technologies -VHF-radio, GSM-GPRS-channel and wire channels.

FM-radio in the ISM bands is optimal communication solution for the channel between the sensor modules and hubs. Where distances in these cases do not exceed 20-30 meters in almost direct view. The use in this case the UTP cable creates inconvenience during installation and depence on the network. For better diffraction was selected frequency range of 433 MHz,when installing the sensor modules inside the doors. Used standard modules - hybrid schemes transmitters.

For FM radio station and transmission between hubs, local controllers and automatic weather station was originally selected frequency range of 50 MHz PMR technology in order to achieve higher power output, respectively, more coverage link. Later, after several test and prototypeswe decide to implement this connection within the ISM 433 MHz. The main benefits in this case are two - more compact antennas and use of a single receiver for signals from the sensor modules. Were constructed special transceivers based on standard modules with high power transmitters.

Connection via GSM-GPRS technology was developed in the modem based on the GSM-module QUECTELM-12. It is a single printed circuit board and includes four plug through to the main board. Powered by unregulated 12 V has its own two-stage stabilizer - first pulse and linear stabilizer. On the board is installed a SIMholder and PCB antenna. There is also a place to mount the external antenna connector. Modem connection to the host microcontroller is with RS232 signals RxD and TxD. In a separate signal is carried inclusion and exclusion of the basic modem controller. Dispatcher station connects to GSM-GPRS GSM-GPRS system.

Organization of VHF-radio exchange in the connection between the hub and sensor modules is unidirectional and asynchronous, as is done with very little coefficient filling the relatively small number of devices. To a hub signals reach no more than a hundred sensors modules. Each module transmits an average of once every T = 10 minutes long message about t = 100 ms. So the probability of simultaneous transmission of two modules will be not more than:

$$P = 100 \text{ x } t2 / T = 100 \text{ x } 0{,}12 / 10 \text{ x } 60 = 0.00167, \quad (1)$$

i.e. will lose no more than one in 600 messages, which is perfectly acceptable.Since FM-radio station and transmission between hubs, local controllers and automatic weather station is carried on the same radio frequency, the probability forlost messages rises, but not with much because of the small number of the hubs. The channel data is transmitted only upon request by dispatcher station and in case of error, the request repeats.

For the exchange of data for all routes were developed simplified protocols. These include Noise source address header, relay instructions, type the command that is executed or to be performed or to be performed and guidelines for the length of the message.

4. Algorithm for Dispatching Station and Energy Efficiency Management

Technical and software features offered by the system allow the management of the energy performance of buildings in real time by sending commands to the appropriate facilities: substations for district heating, electricity boards, regulators, flow of coolant and etc., The system provide also and sending of messages to employees. To achieve the high economies of heat and electricity through the system in the building is appropriate to install additional devices for power.

The system can significantly enhance energy efficiency and consequently to realize savings from the first heat by maintaining optimal thermal regime in any room of the building. In this regard, it should solve the following problems:

- Identify the optimal temperatures and tolerances of these for every room in the building at every hour of the week according to the activities in the room and his employment, the number and type of personnel and etc.;

- The program of the dispatcher station must set limits on the temperature for each room of the building at all hours of the week off to trigger the automatic maintenance of thermal regime and / or to alert the operator on duty;

- To establish a procedure algorithm and the operator and the program automatically maintain the thermal regime of the exit temperature regime outside specified limits, taking into account the possible causes of distortion mode - reduced heating and high or low ambient temperatures, reducing or increasing of fuel sources in a room, UNAUTHORIZED opening of windows and / or doors, impact on ventilation equipment and etc.

- Special attention should be given to the algorithm and the technical implementation of remote heat supply substations for data reporting to the measurement of the internal temperature, weather conditions, infrared cameras to monitor heat loss, etc.

To manage power consumption ofindoorlights and current in the power lines are observed in order to group rooms. Saving money on electricity, it is appropriate to solve the following problems:

- Identify optimal light levels and consumption in individual lines and their tolerances for each room of the building every hour of the week according to the activities in the room and its employment, the number and type of personnel, etc.;

- The program of the dispatcher station to set the limits of luminance and current in individual lines for each room and through the building every hour of the week off to inform the operator on duty;

- To establish a procedure algorithm and the operator for exit lighting level and consumption outside the specified limits, taking into account the possible causes of distortion mode - interruption of electricity supply in certain lines, low or high levels of external light, leaving the room from staff UNAUTHORIZED include heating and / or equipment, etc.

For efficient use of the system should be implement in the software and set in the dispatcher station, a schedule of automatic feeding beeps, start hours and / or work time alerts in case of fire or other disaster, and TP. Security system, which is included in the basic system can operate independently or in conjunction with other security system. Its use should be made relevant procedures and instructions for action.

5. System Implmentation and Testing

The monitoring and management of energy efficiency is constructed as a prototype, which includes dispatching station, 10 hubs, 100 sensor modules, two local controllers and one automatic weather station. Dispatching station is located in block 3 of the Technical University - Sofia, and hubs and part of the sensor modules are installed in blocks 1, 2 and 3. The other sensor modules, local controllers, automatic weather station and GSM-GPRS and cable connection now are tested in the laboratory in Block 3.Previous tests of the system have made it possible to verify hardware and software solutions as part of algorithms to automatically manage energy efficiency. Also working in real conditions allow to remove some unforeseen problems, and make some improvements. Issues were solved with the perturbation of radio frequency between 433 MHz and hubs sensor modules inverters DC-DC in the hub, the issue of same radio frequency antennas, precision and setting the clock, relay the signals from the remote concentrators to the dispatcher station, the passage of between the radio station and dispatcher hubs within 433 MHz instead of 50 MHz to obtain the received data from sensors and the other modules.

6. Conclusion

Developed systems for monitoring and management of energy efficiency is able to monitor and control processes and related energy efficiency of large public buildings such as universities, schools, hospitals, office buildings and more. The system is tested in real conditions and is improved on the base of the tested results.As a result of these a robust and efficient operation in all weather seasons is ensured. For future work we foresee a mounting of other modules and testing in real conditions a GSM-GPRS communication.

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References

[1] Aghemoa, C. & Virgoneb, J. GVFracastoroa, A. Pellegrinoa, n, L.Blasoa, J. Savoyatb, "Management and monitoring of public

buildings through ICT based systems: Controlrules for energy saving with lighting and HVAC services" Kevyn Johannes ba Politecnico di Torino, Energy Department, 24 Corso Ducadegli Abruzzi, Torino10129, Italy bCETHIL, UMR5008, Universit _e Lyon1, INSA-Lyon, Bat. Sadi Carnot, 9 rue de la physique, Ville urbanne Cedex 69621, France Received 27 October 2012; accepted 12November 2012.

[2] Dubois, M.C. & Blomsterberg, Å. (2011) Energysaving potential and strategies for electric lighting in future NorthEuropean, low energy office buildings: Aliterature review. *Energy and Buildings*, 43, 2572–2582.

[3] Guo, X., Tiller, D.K., Henze, G.P. & Waters, C.E. (2010) Theperformance of occupancy-based lighting controlsystems: *A review. Lighting Research and Technology*, 42, 415–431.

[4] Mardaljevic, J., Heschong, L. & Lee, E. (2009) Daylight metrics and energy savings. Lighting Research and Technology, 41, 261–283 .

[5] Reinhart, C.F. & Breton, P.F. (2009). Experimental valid action of 3ds Maxs design 2009 and Daysim 3.0. *In: Proceedings of the 11th International IBPSA Conference*. 27–30 July 2009, Glasgow, Scotland, pp. 1514–1521.

[6] Ryckaert, W.R., Lootens, C., Geldof, J. & Hanselaer, P. (2010). Criteria for energy efficient lighting in buildings. *Energy and Buildings*, 42, 341–347.

[7] Cardei, M., Thai, M.T., Yingshu, L. & Weili, W. (2005). Energy-efficient target coverage in wireless sensor networks. *Proceedings of the IEEE. 24th Annual Joint Conference of the IEEE Computer and Communications Societies, Vol. 3, On page (s). Infocom*, pp. 1976–1984, March 2005.

[8] Cardei, M. & Du, D. (2005). Improving wireless sensor network lifetime through power aware organization. Wireless Networks, 11, 333–340.

[9] Zhang, H., Wang, H. & Feng, H. (2009) *A distributed optimum algorithm for target coverage in wireless sensor networks Asia and the Pacific Conference on Information Processing*.

[10] Cardei, M. & Wu, J. (2006) Energy-efficient coverage problems in wireless ad-hoc sensornetworks. *Computer Communications*, 29, 413–420..

[11] Meguerdichian, S., Koushanfar, F., Potkonjak, M. & Srivastava, M.B. (2001). *Coverage Problems in Wireless Ad-Hoc Sensor Networks. IEEE Publications Infocom*, pp. 1380–1387.

[12] Bai, X., Yun, Z., Xuan, D., Lai, T., Jia, W. (2008) Optimal patterns for four-connectivity and full coverage in wireless sensor networks. *IEEE Transactions on Mobile Computing*.

[13] Hill, J., Szewczyk, R., Woo, A., Hollar, S., Culler, D. & Pister, K. (2000) *System architecture directions for network sensors*. ASPLOS, 93–104.