Scientific Journal of Riga Technical University
Power and Electrical Engineering

2011
Volume 28

Power and Control Aspects in Integrated Building Management Systems with Event-based Control

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***Abstract* – The paper describes integrated building management system climate control principles based on event forecast with respect to minimization of energy consumption. The method uses appropriate control algorithm when environment events can be forecasted. Conference room control method is described in the example. Three different control models are compared in the paper: standard, event-based and event forecast. To compare model energy efficiency computerized models with various thermal and environmental parameters are used. System model research shows that event forecast method is the most energy efficient, but amount of energy economy is not significantly bigger comparing to other compared methods.**

***Keywords*: event-forecast, control, conference room, energy, efficiency, heating, occupancy, model, thermal, automation.**

I. INTRODUCTION

Building sector is one of the biggest energy consumers (see Fig. 1.) in the world. It uses approximately 40% of the produced energy. In conditions, when energy consumption continuously grows in the building sector [1] and production amount of nonrenewable energy still noticeably dominates over renewable energy amount, it is important to determine the common energy optimization approach to all building engineering systems.

Nowadays, most individual building engineering control systems are combined into few or even one common building control system. The guiding idea of event forecast control method is to use data from one building engineering system as a forecast for controlling another building engineering system. Topic objective is to describe an example of building engineering system control method based on event forecast with the goal to achieve maximum energy efficiency [3].

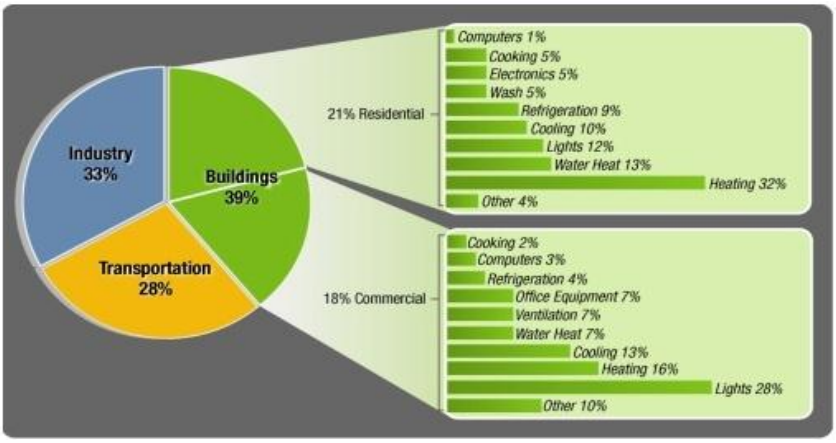

Fig. 1. Energy consumption by sector [2]

II. CONTROL METHOD OVERVIEW

Meeting room heating system control will be analyzed as an example. Three possible methods of room heating system control are compared [4]:

1. Standard. Two separate room setpoints (temperature that must be maintained indoors) are used: for night and day time.
2. Event-based. Three separate room setpoints are used: one for night and two for day time (reduced and comfort).
3. Event forecast. Three separate room setpoints are used: one for night and two for day time (reduced and comfort).

To compare these methods room thermal model will be used. It is created in MatLab Simulink software packet. This system models the outdoor environment, the thermal characteristics of the meeting room, and the meeting room heating system. Meeting room dimensional sizes are shown in Fig. 2.

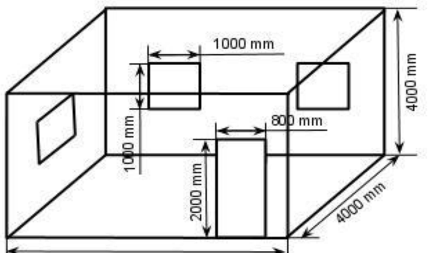

Fig. 2. Meeting room dimensional sizes

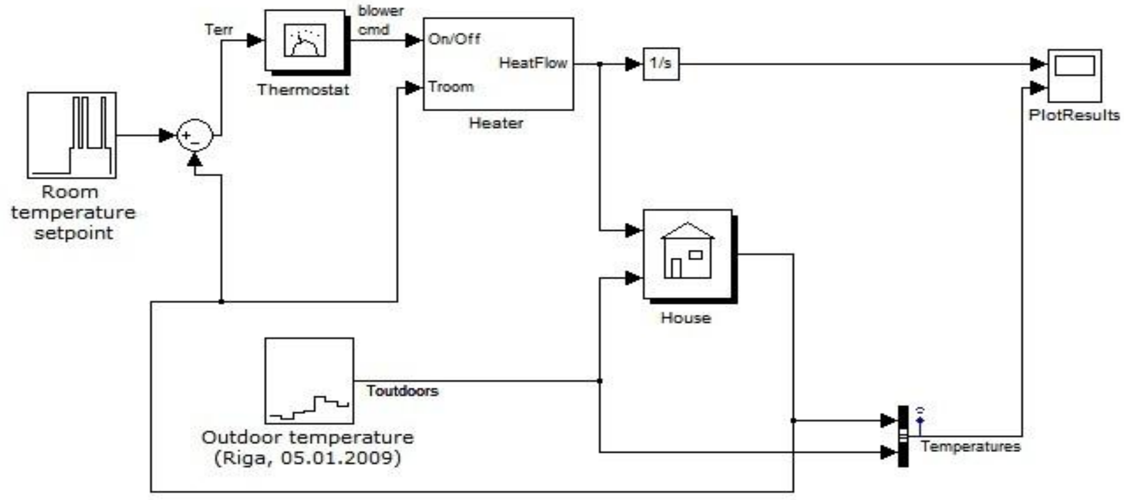

Fig. 4. Room thermal model created in Matlab Simulink software packet

Meeting room is occupied three times a day (8:00 to 9:00, 10:00 to 11:00 and 15:00 to 16:00). Occupancy graph is shown in Fig. 3 [3].

Fig. 3. Meeting room occupancy graph

Characteristics of the model are:
insulation thermal conductivity
K(wall)= 0.038 (W·m^{-1}·K^{-1});
K(window)= 0.78 (W·m^{-1}·K^{-1});
insulation thickness
L(wall)= 200 (mm);
L(window)= 10 (mm);
density of air at sea level
Ro= 1.2250 (kg·m^3);
room set-point temperatures
T(standard)= 16 (°C);
T(reduced)= 16 (°C);
T(comfort)= 16 (°C);
room initial temperature
T0= 16 (°C).
Outdoor temperature
T_{out}– metrological statistics for 5th January, 2009 in the Riga city.

Based on the above mentioned characteristics room thermal model (Fig. 4) is created.

III. MODEL DESCRIPTION

Model contains Heater for House, operation of the heater depends on Thermostat and current room temperature which operates as feed-back loop. Input of the thermostat is connected to summation junction in which room temperature set-point is compared with current temperature in the room. Heater's output is effecting on integrating junction results of the later represented energy consumption in system.

Junction House represents object of regulation and output of the junction represents current temperature in the room. Input of the junction depends on outdoor temperature and on output of the Heater.

Individual models of junctions are created using mathematical description of processes.

"Thermostat" (Fig. 5) is a subsystem that contains a Relay block. The thermostat allows fluctuations of 0.5 °C above or below the desired room temperature. If air temperature drops below 0.5 °C, the thermostat turns on the heater [5].

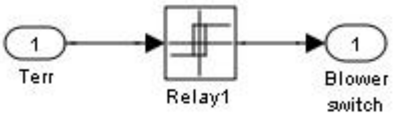

Fig. 5. Scheme of the thermostat model

"Heater" (Fig. 6) is a subsystem that has a constant air flow rate, "Mdot", which is specified in every example separately. The thermostat signal turns the heater on or off. When the heater is on, it blows hot air at temperature THeater (temperature of supply air, specified in every example separately) at a constant flow rate of Mdot. The heat flow into the room is expressed by

$$\frac{dQ_{heater}}{dt} = (T_{heater} - T_{room}) \cdot Mdot \cdot c\,, \qquad (1)$$

$\frac{dQ_{heater}}{dt}$ - heat flow from the heater into the room;

T_{heater}- temperature of hot air from heater;
T_{room}- current room air temperature;
Mdot- air mass flow rate trough heater (kg/hr);
c- heat capacity of air at constant pressure.

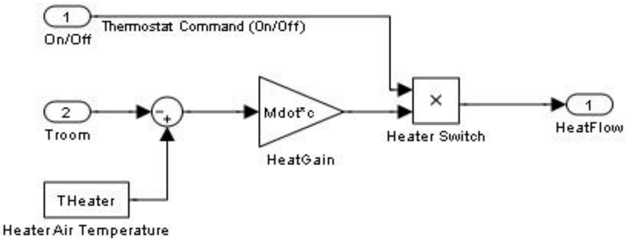

Fig. 6. Scheme of the heater subsystem

"House" (Fig. 7) is a subsystem that calculates room temperature variations. It takes into consideration the heat flow from the heater and heat losses to the environment [5]. Heat losses and the temperature time derivative are expressed by (2,3):

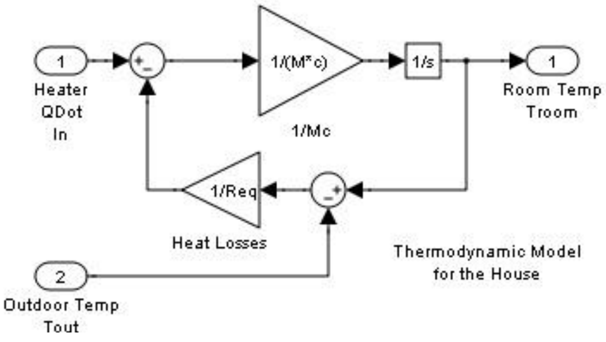

Fig. 7. Meeting room subsystem model

$$\frac{dQ_{losses}}{dt} = \frac{T_{room} - T_{out}}{R_{eq}}; \qquad (2)$$

$$\frac{dT_{room}}{dt} = \frac{1}{c \cdot M_{air}} \cdot \left(\frac{dQ_{heater}}{dt} - \frac{dQ_{losses}}{dt} \right); \qquad (3)$$

$\frac{dQ_{losses}}{dt}$ - heat losses to the environment;

M_{air}- mass of air inside the room;
R_{eq}- equivalent thermal resistance of the house.

IV. COMPARISON OF CONTROL METHODS

1. *Standard Control Method*

Method is shown in Fig. 8. the essence of the method is based on preset set-point temperatures. Heater parameters are:

air flow
Mdot=0.4 kg/s;
temperature of supply air
Theater=45 °C.

This heating system control method is most standard. For night and day time different set-points are used.

Total power usage for heating in 24 hours: 64.4 kWh.

2. *Event-Based Control Method*

Method is shown in Fig. 9. In this control method only comfort set-point is used at events existing in the room. Heater parameters are:

Mdot=0.4 kg/s;
temperature of supply air
Theater=45 °C.

In this example occupancy sensor or building security system motion sensor signal, which switches setpoint from reduced to a comfort level in case of occupancy or motion detection, can be used as event. From the graph (Fig. 8) we can see that in every occupancy phase there is under heating stage in the beginning and overheating stage in the end. It is so because thermal inertia temperature is always lagging behind setpoint. That creates uncomfortable environment in the beginning stage and wastes additional energy at the end stage. This heating control method is not widely used because of its

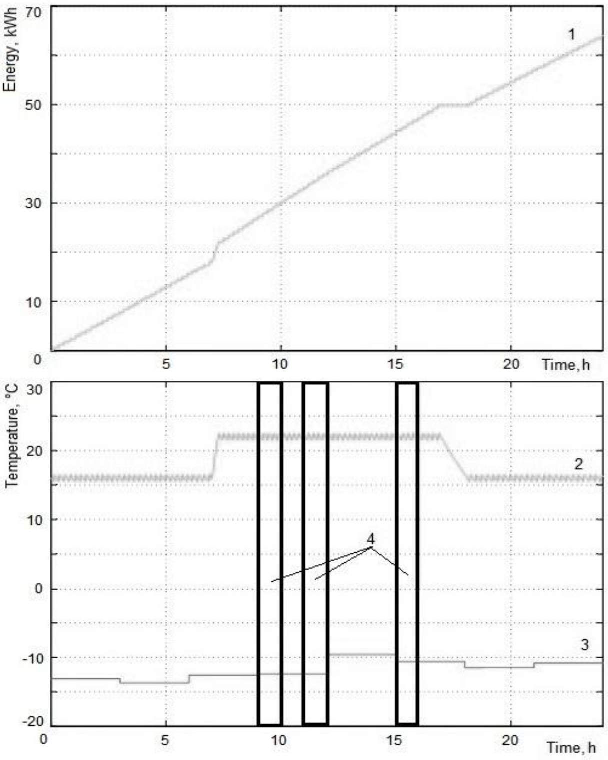

Fig. 8. Standard heating control method. 1- energy consumption (kWh), 2 - room temperature (°C), 3 - outdoor temperature (°C), 4 - room occupancy

disadvantages. Total power usage for heating in 24 hours: 61.6 kWh

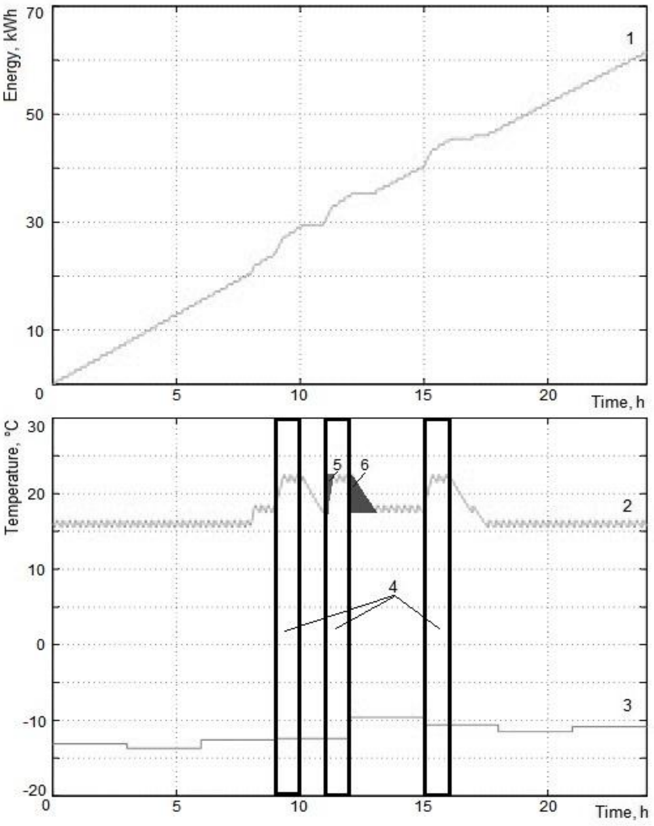

Fig. 9. Event-based heating control method. 1 - energy consumption (kWh), 2 - room temperature (°C), 3 - outdoor temperature (°C), 4 - room occupancy, 5 - under heating stage, 6 - overheating stage

To reduce under heating stage (Fig. 10) heater characteristics can be changed:

air flow

Mdot=0.5 kg/s;

temperature of supply air

Theater=50 °C.

Use of more powerful air heater at the beginning stage reduces under heating time (Fig. 10). Disadvantages are: increased noise level produced by bigger air flow and need to design a more powerful heating system.

Total power usage for heating in 24 hours: 61.8 kWh.

3. *Event Forecast Control Method*

Method is shown in Fig. 11. Heater parameters are:

Air flow

Mdot=0.4 kg/s;

Temperature of supply air

Theater=45 °C.

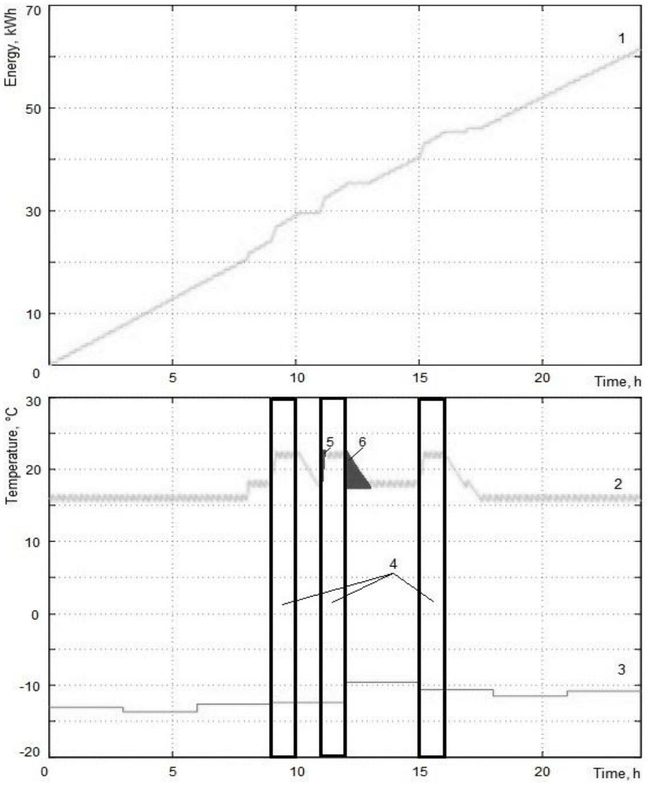

Fig. 10. Event-based heating control method with changed heater characteristics. 1- energy consumption (kWh), 2- room temperature (°C), 3- outdoor temperature (°C), 4- room occupancy, 5- under heating stage, 6- overheating stage.

In this example meeting room reservation system can be used as event forecast. Nowadays most modern buildings are using it in one or another form. For example, that can be online web-based service with possibility to reserve a meeting room and send a schedule of meeting room use to a building management system. From graph (Fig. 11) we can see that system has no under heating stage, and overheating stage is significantly reduced. The system can be used as event-based in case a meeting was not scheduled.

Total power usage for heating in 24 hours: 60.7 kWh.

If not scheduled meeting opportunity is not used, it is possible to use only two setpoints (reduced setpoint all time and comfort setpoint in meeting time), and that would give additional minor economy.

CONCLUSIONS

1. Standard model of heating control system is not efficient enough and can be optimized.

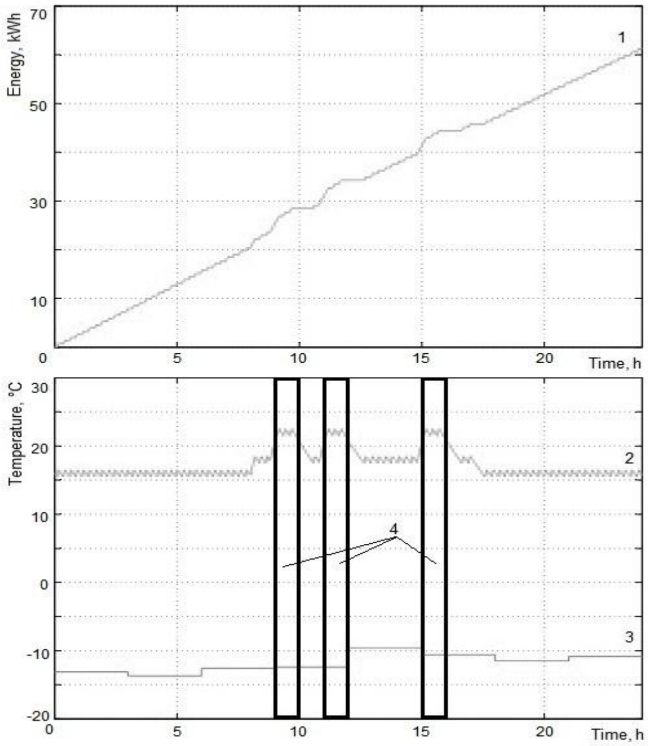

Fig. 11. Event forecast heating control method. 1- energy consumption (kWh), 2- room temperature (°C), 3- outdoor temperature (°C), 4- room occupancy.

2. Comparing four described heating control examples, the most efficient by criteria of energy consumption, comfort level and investment price (in case system is modern and uses integrated building management system) is event forecast control method.

3. The use of event forecast control method can reduce heating energy consumption compared to traditional control method by about 6% not lowering common comfort level.

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Bartkevičš Dmitrijs. Integrēto ēkas vadības sistēmu ar notikumu orientētu regulēšanu jaudas un vadības aspekti
Ēku energoapgādes sektors strauji attīstās un pašlaik tas aizņem gandrīz 40% no visa pasaules energopatēriņa. Tāpēc energoefektivitātes pētījumi ir sevišķi svarīgi, un vismazākais efektivitātes palielinājums var dot lielu absolūto energoietaupījumu. Publikācijā ir aprakstīti ēku vadības sistēmu klimata kontroles principi, kuru pamatā ir notikumu (piemēram, cilvēku skaita izmaiņu publiskajās telpās u.c.) prognozēšana attiecībā uz enerģijas patēriņa samazināšanu. Šādas ēku integrētās vadības sistēmas pašlaik plaši pielieto sabiedrisko ēku jomā ar nolūku uzlabot ēku energoefektivitāti. Aplūkotas 3 vadības metodes – standarta, pēc esošajiem notikumiem, ar notikumu prognozēšanu. Pēdējā metode ietver sevī atbilstoša vadības algoritma izmantošanu gadījumā, ja apkārtējās vides notikumus ir iespējams prognozēt. Konferenču telpas vadības algoritmi ir aprakstīti visos trijos piemēros. Rakstā ir salīdzināti energoefektivitātes aspektā trīs dažādie vadības modeļi: standarta, notikumu orientēta un notikumu prognozēta. Vadības modeļu enerģijas efektivitātes salīdzināšanai tika izmantota datorizēta simulācija uz MATLAB-SIMULINK programmas bāzes ar dažādiem siltuma un vides parametriem. Izmantojot diferenciālvienādojumus, izstrādāti atsevišķu sistēmas posmu modeļi, kā arī formulēti ēku elementu aprēķinu un konstruktīvie parametri. Sistēmas simulācijas pētījumi liecina, ka notikumu prognozes metodes pielietojums dod enerģijas ekonomiju, taču enerģijas ekonomija nav ievērojami lielāka, salīdzinot ar citām metodēm. Modelēšana uzrāda, ka šis ietaupījums var sasniegt tikai 6% salīdzinot ar standarta vadības algoritma modeli.

Барткевич Дмитрий. Аспекты энергии и управления интегрированных систем управления зданий с ориентированным на события управлением.
Сектор энергоснабжения зданий занимает видное место в балансе энергетических ресурсов, используя в настоящее время почти 40% от всемирного энергетического потребления. Поэтому даже малейшее повышение энергоэфективности может обеспечить большой абсолютный энергоэффект. Рассмотрены три способа автоматизации энергоуправления зданиями – стандартный, по существующим событиям, по прогнозированию событий. Статья описывает принципы управления климатом на основе прогноза событий в интегрированных системах управления зданий с целью минимизации потребления энергии. Метод заключается в использовании подходящего алгоритма управления в ситуации, когда события окружающей среды могут быть предсказаны. В статье сравниваются указанные три различных модели управления: стандартная, ориентированная на события и ориентированная на прогноз события. Для сравнения эффективности используются компьютерные модели, разработанные в среде MATLAB-SIMULINK, с различными тепловыми и внешними параметрами. На базе дифференциальных уравнений разработаны модели отдельных элементов системы автоматизации, а также сформулированы исходные параметры элементов систем. Исследование моделей системы показывает, что ориентированная на прогноз событий модель является самой энергоэффективной, но количество сэкономленной энергии незначительно больше, в сравнении с остальными методами. Компютерное моделирование показало, что метод управления с прогнозированием событий может обеспечить экономию энергии в обьеме 6% по сравнению со стандартным методом управления.