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RADOSŁAW GÓRZEŃSKI, ANDRZEJ GÓRKA, EDWARD SZCZECHOWIAK*

GUIDELINES FOR THE CONTROL ALGORITHM OF HEATING INSTALLATIONS IN LARS LOW-ENERGY SYSTEM

WYTYCZNE DOTYCZĄCE ALGORYTMU STEROWANIA INSTALACJAMI GRZEWCZYMI W NISKOENERGETYCZNYM SYSTEMIE LARS

Abstract

Automatic control systems in heating installations are presented. Different procedures for controlling circuit pump speed, supply temperatures and radiators valves' lifts are tested. As a conclusion, guidelines for an algorithm for the control of a heating system with electronically controlled valves are presented. It is concluded that the proposed algorithm facilitates higher efficiency than a typical PID control system. A heat and fluid flow simulation model, used for algorithm optimization, is presented.

Keywords: automatic control, heating systems, radiator valves, control algorithm

Streszczenie

W niniejszym artykule zaprezentowano systemy sterowania automatycznego w instalacjach grzewczych. Przetestowano różnorakie procedury kontroli prędkości pompy obwodowej, wytwarzanych temperatur oraz podnośników zaworów grzejnika. Zaprezentowano też wytyczne dotyczące algorytmu sterowania systemami grzewczymi z elektronicznie kontrolowanymi zaworami. Wyciągnięto wniosek, że proponowany algorytm pozwala uzyskać wyższą wydajność w stosunku do typowego systemu sterowania PID. Przedstawiono symulacyjny model przepływu ciepła i cieczy dla optymalizacji algorytmu.

Słowa kluczowe: sterowanie automatyczne, systemy grzewcze, zawory grzejnika, algorytm sterowania

* Dr inż. Radosław Górzeński, dr inż. Andrzej Górka, prof. dr hab. inż. Edward Szczechowiak, Instytut Inżynierii Środowiska, Wydział Budownictwa i Inżynierii Środowiska, Politechnika Poznańska.

1. Introduction

Automatic control systems play an important role in reducing final energy demand for heating systems. With decreasing heat demand in low-energy buildings, with no quality improvement in the field of control systems, the control and emission efficiency of a heating system is strongly reduced.

In low-energy buildings, low-temperature heat sources, such as condensing boilers, heat pumps or solar collectors, are used together with surface radiant heating systems. With low supply temperature, more precise temperature control is needed. An unjustified temperature increase results in lower heat generation efficiency, especially in the case of heat pumps and solar collectors. Higher temperatures also mean lower distribution and accumulation efficiency.

2. Control systems optimization

These considerations determine the necessity of improving water heating control algorithms. Apart from the already outdated boiler constant temperature control system, the representative room temperature controller and the weather adjusted regulation are in common use.

Representative room temperature controllers are often exposed to disturbing influences occurring asymmetrically in a building, such as internal gains or solar radiation. The rooms they are located in may not be always called representative. Only few of them allow the adjustment of the supply temperature in a boiler. The biggest disadvantage is usually the maintenance of excessively high supply temperature which reduces heat source generation efficiency and increases distribution heat losses.

A more advanced system is the weather adjusted regulation. This system, based on the ambient air temperature and a programmed heating curve, adjusts the boiler supply temperature. More sophisticated controllers additionally use internal temperature sensors for the automatic adjustment of the heating curve.

The weather adjusted control system is based on the relationship between room and ambient temperature difference and heating energy demand. This assumption is not valid for indoor areas, such as a bathroom. In low-energy buildings, solar and internal heat gains have a greater impact on the energy balance.

Another solution is the multi-zone control system with the use of electronic programmable radiator valves that make it possible to define an individual weekly temperature schedule. A disadvantage of this system is the need to make individual settings for multiple devices.

The solution of a central multi-zone control system has the biggest saving potential. A single heat source controller uses actual room air temperatures and temperature set values in each zone for controlling the supply temperature and pump speed. Water flow through radiators is controlled by means of electronically controlled radiator valves. Therefore, it is not required to specify a representative room – the controller sets the power and switching time of the heat source so as to meet the thermal requirements of all zones.

3. Analysed control algorithms

The following control system algorithms were chosen and analysed, some of them by means of the simulation model described below.

3.1. Circuit pump control algorithms

3.1.1. ON/OFF control

In this variant, the pump operates at maximum speed. This solution, popular in older systems, is an uneconomical one with considerable power consumption.

3.1.2. Variable speed control

The pump operates continuously at variable speed while maintaining constant differential pressure between supply and return. In small systems, the continuous operation of the pump increases electricity consumption because the pump works even when all its valves are closed.

3.1.3. Variable speed with ON/OFF control

The pump operates in the same way as in the previous variant. However, the control system switches the pump off when all the valves are closed. In this variant, electronic radiator valves with a communication controller are needed.

3.1.4. Impulse control

In this control mode, each ON/OFF radiator valve is controlled by pulse width modulation as a function of energy demand. Impulse control can be used when a predictive model proves that it is possible to get shutoff times for all the valves longer than τ_{imp} at supply temperature not exceeding $t_{s.\text{imp}}$. $t_{s.\text{imp}}$ limit value should be calculated on the basis of the experimentally determined heated rooms inertia time constants. τ_{imp} value should be within the range of 30 to 120 minutes.

3.1.5. Variable speed with ON/OFF control and constant pressure difference

The pump operates in the same way as in the variable speed variant with ON/OFF correction. Although such pumps are available on the market, it would be difficult to use them in this algorithm. Its application would require further tests to determine the interdependence of the valve opening time and the pressure difference on the actual water flow through the radiator. In this aspect, to achieve energy savings, it would be better to lift the valves first and then change the pump speed.

3.2. Supply temperature control algorithms

3.2.1. Weather adjusted regulation

Weather adjusted regulation is a common control system for water heating systems. The idea of weather control is the relationship between heating demand on the external and internal temperature difference. However, this assumption is not true in many cases, e.g. for indoor areas, such as the bathroom. In low-energy buildings, solar and internal heat gains have a greater impact on the energy balance. As a result, supply temperature is often too high, especially in spring. Therefore, the weather adjusted mode is used only for comparative purposes in this analysis.

3.2.2. Minimizing supply temperature

The basic way to decrease heat demand in heating systems is to reduce supply temperature. Weather adjustment described before uses ambient temperature as the exclusive control parameter. As previously stated, this solution leads to overheating in low-energy buildings.

With the use of a simulation model, the following algorithm for determining supply temperature as a function of the valves' lift degree is proposed. This solution is possible in systems where the valve lift degree is adjusted using an electronic actuator that communicates with the central controller. Supply temperature changes to maintain set temperature in the rooms according to the following algorithm:

- if $h_{max} = 100\%$, then: $t'_z = t_z + \Delta t_{inc}$
- if $h_{max} < h_{gr,}$ then: $t'_z = t_z - \Delta t_{dec}$
- if $h_{gr} \leq h_{max} < 100\%$, then: $t_z = const$

where:

h_n – valve lift degree in room n [%],
$h_{max} = \max(h_i)_{i=1,\ldots,n}$ – highest lift degree among n valves [%],
Δt_{inc} – temperature increase gradient in heat source [K/min],
Δt_{dec} – temperature decrease gradient in heat source [K/min],
h_{gr} – limit value of valve lift degree [%],
t_z – supply temperature [°C].

3.3. Valve lift control algorithms

3.3.1. Proportional controller P

The basic and most common method of control is used in thermostatic radiator valves, with the dead band of 1K or 2K, but in real life it is smaller and depends on the initial setting of a valve. This solution is characterized by a continuous, non-correctable error of difference between actual and setpoint temperature which, in long-term use, may increase the operating costs (overheating).

3.3.2. PI and PID controller

PID controllers, used in more advanced electronic control systems, make the best solution if there is no accurate information about the controlled system. However, the simple application of a PID or PI controller is not effective. When a considerable change in setpoint occurs, the integral terms cause an overshooting error during the rise (the so-called integral windup). One of the correction method is to disable the integral function until the process variable moves to a controllable area. However, this increases the complexity of the algorithm.

3.3.3. Predictive control with correction

Predictive control with correction based on the measured values of unpredictable disturbances (for example opening windows) is proposed to be used in the algorithm. This makes it possible to take advantage of the knowledge of the controlled object and consequently get a better control quality than a conventional PID controller.

For the proper operation of predictive control, it is important to know the parameters characterizing a room and its installation. The optimal solution would be the determination of these characteristics by a controller in an automatic way without interference from the installer and without major inconvenience to the user. Such measurements could be performed by the controller during the first nights after installation.

4. Simulation model

For the purpose of optimizing the algorithm, a modular heat-flow numerical model of a heating system integrated with the building and the automatic control system was developed by discretizing time and space, using the Finite Difference Method FDM. It was developed with National Instruments LabVIEW and corrected with the use of Microsoft Excel calculation spreadsheet.

The model consists of the following modules: climate, zone (along with the usage profile), external and internal wall, simple ventilation system, pipe with heating medium, circuit pump, radiator, heat source, radiator valve and central control system. Individual parameters for each of these modules can be defined. The configuration of a building is modelled by a combination of selected modules.

5. The simulation results

Generalized conclusions from the simulation with the proposed algorithms are presented in Chapter 6 Summary. Only two selected examples of the numerical simulation results for different supply temperature control algorithms are presented below. The results for weather adjusted regulation (the comparative variant) are shown in Fig. 1 and 2. The results for minimizing the supply temperature variant are shown in Fig. 3 and 4.

Calculations were performed for the following assumptions:

- *U*-values of external walls based on Polish regulations 2008,
- heating media pipes thermal insulation based on Polish regulations 2008,
- massive building construction,
- steel panel radiator,
- limit value of valve lift degree h_{gr} = 50%,
- temperature increase gradient in heat source Δt_{inc} = 2 K/min,
- temperature decrease gradient in heat source Δt_{dec} = -0.2 K/min,
- internal heat gains taken into account,
- radiators heating power based on Polish standard,
- inertia time constant of the valve: 25 min,

– day: December 26,
– climate data for Poznan, Poland.
– The following conclusions can be formulated for the minimizing supply temperature variant compared to the weather adjusted regulation algorithm.
– It offers the achievement of the desired room air temperature approximately four times faster after the step change of the setpoint,

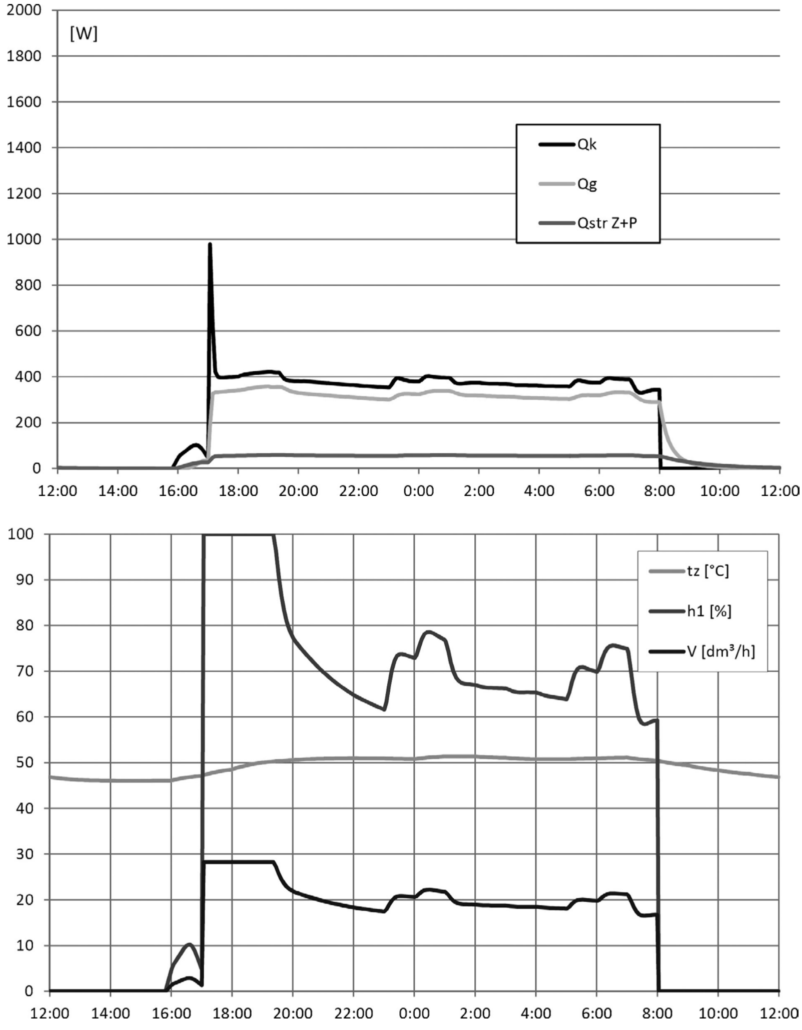

Fig. 1. Supply temperature t_z [°C], valve lift degree h_1 [%], heating media volume flow V [dm³/h] for weather adjusted regulation

Rys. 1. Wytwarzana temperatura t_z [°C], stopień podniesienia zaworu h_1 [%], intensywność przepływu mediów grzewczych V [dm³/h] dla regulacji dostosowanej do warunków pogodowych

– It is characterized by significant overregulation; it can be minimized by using a thermostat with a lower time constant (gas or electronic) or by using a PID controller,
– Heating system, except the starting period, operates at lower supply temperature which makes it possible to achieve better efficiency in heating systems with heat pumps and solar collectors.

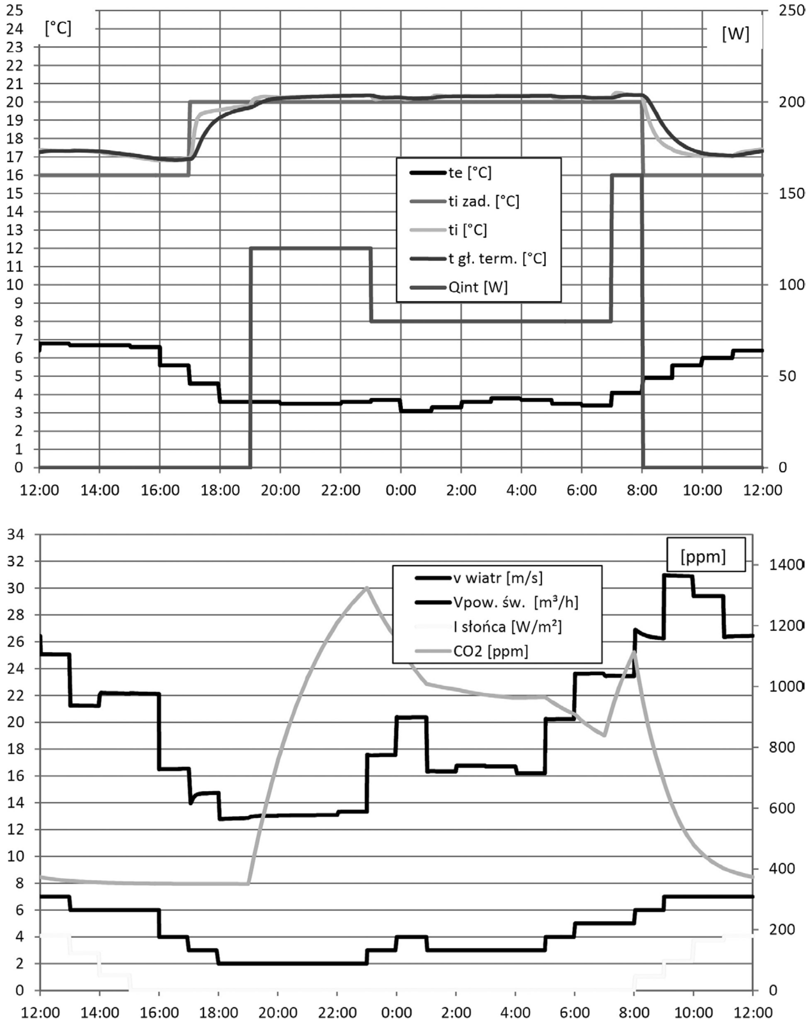

Fig. 2. Ambient air temperature t_e [°C], room air temperature: set $t_{i\ zad.}$ [°C] and actual t_i [°C], temperature measured at valves head $t_{gł.\ term.}$ [°C], internal heat gains Q_{int} [W] for weather adjusted regulation

Rys. 2. Temperatura otoczenia t_e [°C], temperatura pokojowa: ustawiona $t_{i\ zad.}$ [°C] i rzeczywista t_i [°C], temperatura mierzona przy głowicy zaworów $t_{gł.\ term.}$ [°C], wewnętrzne zyski energii cieplnej Q_{int} [W] dla regulacji dostosowanej do warunków pogodowych

6. Summary

The following algorithms, based on the simulation results, were proposed. As an optimum circuit pump control, the **variable speed with ON/OFF control** algorithm was selected. The pump operates continuously at variable speed while maintaining constant differential pressure between supply and return. The control system switches off the pump when all the valves are closed. In this variant, electronic radiator valves with a communication controller are needed.

For controlling supply temperature, the **minimizing supply temperature** algorithm was selected. This solution is possible in systems where the valve lift degree is adjusted using

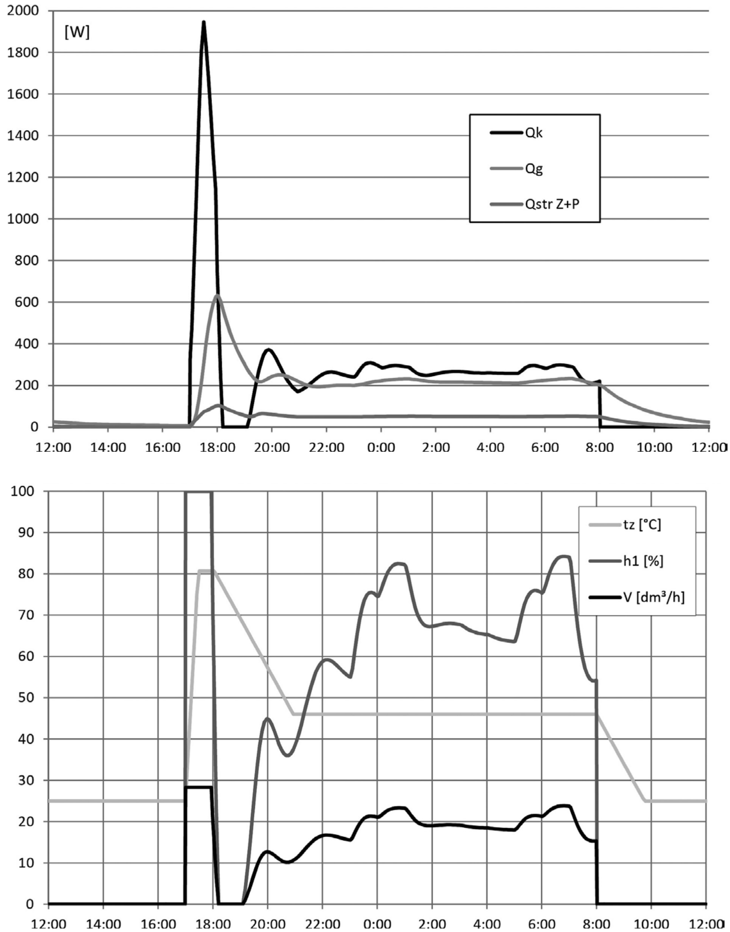

Fig. 3. Supply temperature t_z [°C], valve lift degree h_1 [%],
heating media volume flow V [dm³/h]
for minimizing supply temperature algorithm

Rys. 3. Wytwarzana temperatura t_z [°C], stopień podniesienia zaworu h_1 [%],
intensywność przepływu mediów grzewczych V [dm³/h]
dla minimalizacji algorytmu wytwarzanej temperatury

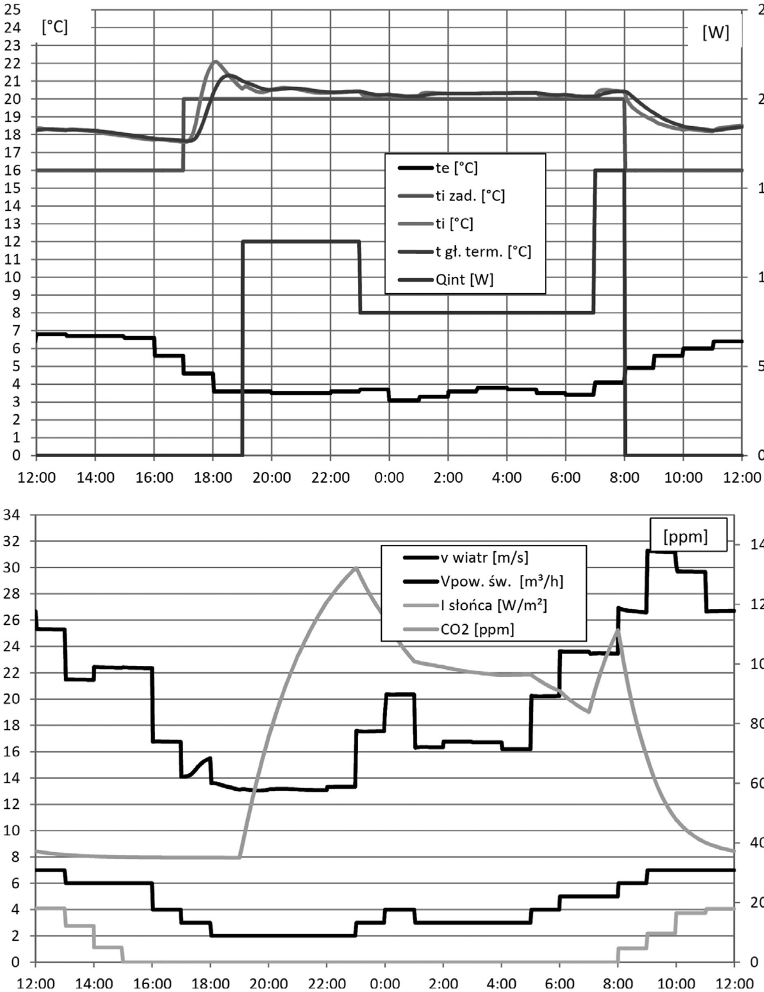

Fig. 4. Ambient air temperature t_e [°C], room air temperature: set $t_{i\ zad.}$ [°C] and actual t_i [°C], temperature measured at valves head $t_{gł.\ term.}$ [°C], internal heat gains Q_{int} [W] for minimizing supply temperature algorithm

Rys. 4. Temperatura otoczenia t_e [°C], temperatura pokojowa: ustawiona $t_{i\ zad.}$ [°C] i rzeczywista t_i [°C], temperatura mierzona przy głowicy zaworów $t_{gł.\ term.}$ [°C], wewnętrzne zyski energii cieplnej Q_{int} [W] dla minimalizacji algorytmu wytwarzanej temperatury

an electronic actuator that communicates with the central controller. Supply temperature changes are based on individual valves' lift degree h_n, assumed limit value of lift degree h_{gr} and temperature increase and decrease gradient in heat source $\Delta t_{inc}/\Delta t_{dec}$.

With the minimizing supply temperature algorithm chosen, a **PID controller** for controlling valve lift is recommended. Predictive control with correction is a promising research direction although at this stage of study cooperation with the minimizing supply temperature algorithm has not been fully investigated yet.

7. Conclusions

The proposed algorithms of the automatic control of a water heating system provides more precise temperature control as a function of real heat demand, hence the stable heat source operation at lower power. Combined with lower supply temperature, it may increase the efficiency of heating systems, especially those using heat pumps.

The presented solutions assume the use of communication between electronic radiator valves with a controller. The high cost of these devices limits the practical application of the presented algorithms. Therefore, the "Lars Low Energy – integrated control and measurement system for central heating systems" project with co-funding from the European Regional Development Fund was launched in collaboration with the Institute of Environmental Engineering, Poznan University of Technology, to develop a cheaper alternative for the existing expensive systems.

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