Comparison of PID and MPC control for a boiler room

S N Andriyashin¹, V A Elanakova¹, S V Myatezh¹, I L Popov¹

¹ Novosibirsk State Technical University, 20, Karla Marksa ave., Novosibirsk, 630073, Russia

E-mail: andrsn154@gmail.com

Abstract. Increasing efficiency will reduce costs for the building heating and will lead to energy savings. Efficiency of heating control systems depends on the implemented control algorithms. In this article, the comparison of PID and MPC control systems for a boiler room is presented. Model predictive control has shown to be more efficient in terms of accurate control of a building temperature. Moreover, MPC controller makes it possible to reduce fuel and power consumption.

1. Introduction

One of the most effective ways to save energy in Russia is directly related to energy heating savings since payments for energy heating are the large part of utility bills. At the same time, most of the heat energy consumed by the building is spent on its heating.

Automation of heating systems makes it possible to reduce costs of a building heating and increase its comfort. The efficiency of an automatic control system of heating delivery to the buildings depends on the implemented control algorithm. In modern heating controllers, a decrease in energy consumption and an increase in comfort is achieved mainly by regulating the temperature of the direct heat carrier. The temperature is regulated according to the temperature schedule (depending on the current outside temperature) and switching the system from an economical night heating mode to a comfortable day one. The control actions of such systems are carried out without taking into account the dynamic characteristics of the system along the disturbance and control channels. As a result, it can lead to long transient processes and an inevitable delay in the output information flow (control) in relation to a change in the input information flow (outdoor climate parameters).

Thus, synthesis of a feedforward control system of heating delivery to a building becomes an important and urgent issue. Such solution should be capable of increasing the efficiency of existing control algorithms.

2. Development of the mathematical model of a boiler room

Let’s represent a model of a boiler room in the form of a linear stationary model. This allows us to obtain the controlled object model in the form of an ordinary differential equation with constant coefficients or a transfer function. An analytical way of designing the model is used. The analytical method is based on the energy balance analysis of the object.

Let's consider a simplified structural control diagram of the air temperature inside the building (Figure 1). The boiler room is a control object and the detached building is a consumer. The outside air temperature acts as a disturbance.
Where $T_b'$ – the reference temperature; $\Delta T_b$ – the error in control system; $U$ – the control action; $T_{out2}$ – the temperature at the boiler room output; $T_{in1}$ – the input temperature of the water; $T_o$ – the disturbance; $T_b$ – the output temperature.

At the same time, a boiler room is a complex object consisting of many elements. Therefore, mathematical models of every individual element is required in order to further obtain a model of a whole object. The model being investigated in the article is a generalized boiler room-consumer model. The structural diagram of the boiler room as a control object is shown in the Figure 2.

The controlled object consists of the following structural parts, the mathematical models of which should be obtained:

- The air-fuel mixture supply system, i.e. mixtures of gas and air. Gas consumption $V_g$ is regulated by the degree of the control valves opening on the gas pipeline. Air is supplied to the burner by a blower fan, which drives an induction motor (IM). When the angular velocity of the motor shaft $\omega$ is changed, on which the fan impeller is fixed, the flow rate of air $V_a$ entering the burner is changed.
- In the rest of the boiler room model, various heat transfer processes take place. The heat carrier is heated by combustion products with temperature $T_c$. The water heated to the temperature $T_{in2}$ enters the heat exchanger, where it heats the heat carrier in the heating circuit. The heat carrier is heated from a temperature $T_{in2}$ at the heat exchanger inlet up to the temperature $T_{out2}$, and returns back to the boiler with temperature $T_{out1}$.

Physical simulation of building heating losses is the subject of extensive research. The developing models are becoming more and more accurate as well as complex. An individual boiler room does not require a very detailed and complex model, while simplified models used for large systems may not be sufficient for full research. The physical model used for heat consumers is as follows: the thermal model of the building calculates the change in indoor temperature; the heat flow coming from the boiler room.

**Figure 1.** Structural control diagram of the air temperature.

**Figure 2.** Structural diagram of coolant heating in the boiler room.

Where $V_g$ – the gas flow; $V_a$ – the air flow; $V_{g-a}$ – the difference between gas flow and air flow; $T_c$ – the combustor output temperature; $T_{in2}$ – the heat carrier input temperature; $T_{out2}$ – the heat carrier output temperature; $T_{out1}$ – the water temperature at the boiler input.
through the heating system, heat losses to the environment and the thermal resistance of the building are also taken into account.

3. Development of the building temperature control system

Nowadays automatic control systems are mainly designed on the basis of the traditional control theory. Therefore, traditional proportional-integral (PI-controller) and proportional-integral-differentiating (PID-controller) controllers are used. PI controllers are widely used in stabilization systems for various objects because of their structure simplicity and high reliability. However, their disadvantage consists in readjustment of the controllers when the operating points change due to disturbances. When such controllers are used at plants with a continuous operation mode, constant monitoring of the technological process is required. In addition, for processes with variable parameters, delay, significant nonlinearities, and significant noise, PI-controllers may be ineffective. In most cases PI-controllers are not able to operate in optimal mode because of their complex tuning.

One of the modern formalized approaches to the analysis and synthesis of control systems is the model predictive control (MPC) strategy. The model predictive control theory is based on the mathematical methods of optimization and is increasingly replacing PI-controllers.

The MPC main advantage is the relative simplicity of the basic feedback generating scheme. The latter circumstance makes it possible to control multidimensional complex objects, optimize real time process within the constraints on the control action and state coordinates and to take into account interval uncertainties in objects and disturbances settings. In addition, it is possible to take into account the delay and failures from the sensors of the measuring system, change the quality criteria during the control process.

The MPS is based on the model being controlled. The system performance forecast is made with the help of controlled model. Optimization is then used to find the best control signal. The controller consists of three different elements (Figure 3): the forecasting model, the cost function, and the control law. [9] The “optimizer” block consists of the cost function and the control law derivation. The cost function is defined from the forecasting model as something that should be minimized. The control law is what happens when the minimization was performed. The cost function analogue in PID control is the control error, which should be minimized.

The time frame for determining how far we want to see the future is called the prediction horizon, p (Figure 4). Sometimes reference values are not calculated for the entire prediction. Another period of time, called the control horizon, determines how many reference values should be calculated. Using a shorter reference horizon than predicted will save computational power. The system output is then calculated as if all control signals after the control horizon coincide with the last calculated signal. [2-10]

The operation principle of the temperature control system is as follows: the signal for setting the
required temperature in the room V is sent to the system input, then the error Δ is calculated and its value is processed by the temperature controller. It controls the hot water boiler by forming the control action U. Thus, the supply of the fuel-air mixture is regulated: the gas supply is regulated by changing the speed of the IM shaft, on which the impeller of the blower fan is fixed. By changing the air-fuel flow IMixture entering the burner, the water circulating in the boiler is regulated. The water released from the boiler passes through the heat exchanger, where it heats the coolant in the heating circuit and returns back to the boiler. The water heated in the heat exchanger is supplied to the consumer. The consumer is influenced by the disturbing effect F the ambient temperature. From the consumer, the heat carrier is returned to the heat exchanger along the heating circuit, where it is reheated. The room temperature Tb is recorded by a temperature sensor, the measured value is fed back to the error estimation, which is processed by the controller.

4. Comparison of systems with PID and MPC controller

The transients of the room temperature for PID and MPC controller are shown on the Figure 5. The setting time of the MPC system when a step control signal with a setpoint of 22 °C and a constant disturbance of -20 °C is applied is less than 6.5 hours. The setting time for PID controller is 26 hours. The deviation of the room temperature from the set value with a sinusoidal disturbance of the MPC system is less than 1 °C, which is 2 °C less than in the system with the PID controller.

![Figure 5](image_url)

It can be seen that the MPC system handles disturbances and control actions a way much better than the system with PID controller.

However, if there are no strict requirements for the quality of temperature control, the PID controller can also be applied. In addition to the quality of regulation, the economic effect from the implementation of more advanced control systems is extremely important. In this case, the cost of the generated heat energy is made up of the cost of the flared gas and the electricity consumed by the equipment. The volume of consumed gas Vg can be easily obtained from the developed mathematical model. It is more difficult to estimate the electricity costs, but specific figures are not important because the unreal object is being simulated.

Therefore, the main thing is to determine the overall trend. To do this, we will measure the total amount of heat energy at the boiler outlet, for the production of which a certain percentage of electricity is spent. According to the graphs (Figure 6) the MPC system consumed about 5 m³ of gas less than the system with the PID controller within 200 hours from the boiler starting point. In this simulation the constant setpoint was set at 22 °C, the weather changes by ±10 °C from an average temperature of -20 °C according to a sinusoidal law with a period of 60 hours. In this case, the heat flow is also lower.
in the MPC system by approximately 200 W.

![Graph](image.png)

**Figure 6.** Total gas consumption and the total amount of heat energy in the control system: 1 - with PID controller; 2 - with MPC controller.

5. Conclusions
In this study, the synthesis of predictive control algorithms for building temperature control with one manipulated variable has been carried out. As a result, a nonlinear control law was obtained, which at each step solves the problem of optimizing the trajectories of the object output signals under the conditions of restrictions on the control actions and output parameters of the controlled object.

The analysis of disturbances handling efficiency of the MPC system has shown high-speed response and lower temperature deviations from the desired one in comparison with the PID controller. The MPC system makes it possible to reduce a heat flow by approximately 200 W when starting up the boiler and during it operation for 200 hours. This, in its turn, leads to decrease in electricity costs for the production of heat energy.

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