Ensuring the Comfort in the Heated Space by Controlling the Temperature in the Heating Installation of a Non-residential Building

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Keywords: Temperature Control, Nonlinear Control Systems, Modelling, Simulation, Building Automation, Civil Engineering.

Abstract: In this article is modeled, with the help of Simulink, the automatic system that controls the thermal agent temperature in a non-residential building chosen for study. It describes how the model has been drawn for the subsystem entitled HEATED SPACE in the building. There were used mathematical relationships which show how the indoor temperature is changing, depending on the heat input in building and the heat loss through building envelope. The other subsystems have been modeled in the articles specified in the bibliography. By simulation of the model for the automatic system is determinated his behavior during two days in the winter season. The evaluation of the thermal comfort in the heated space from the building, ensured by using the automatic system, is made by analyzing the graphs of the significant temperatures from the modeled system: indoor temperature, outdoor temperature and thermal agent temperature in the heating installation. At the end of the article are shown the main causes of low thermal comfort in the building, and also the reasons why this type of automatic system is preferred in many non-residential buildings.

1 INTRODUCTION

The comfort is defined in the Oxford Dictionaries as being „a state of physical ease and freedom from pain or constraint”. The comfort can be of several types: thermal comfort, visual comfort, acoustic comfort, olfactory comfort.

The quality of the built space in a building depends, among others, on the thermal comfort in building (Clements-Croome, 2011; Oancea and Caluianu, 2012; Frontczak et al., 2012). It can be evaluated using the indoor temperature perceived by the occupants of the building. This temperature can be maintained at the desired constant value only if is kept the balance between the input heat into the building and the lost heat through the building envelope.

The thermal comfort in building can be ensured only by using adequate automatic control systems for the heating installations.

In the case of automated systems commonly used in non-residential buildings there is no setpoint for the indoor temperature, because the indoor temperature is not controlled with an own control loop. It is used only the setpoint for flow temperature of the heating installation. This setpoint value can be established using the heating curve by selecting the gradient of circuit with valve, in correlation with the destination and the constructive characteristics of the heated building (Mira, 2010; Ilina, 2010).

The current systems used to automate heating installations in buildings are provided with various functions that improve the thermal comfort, save energy and protect the building against frost during periods when the building is unoccupied (Diematic, 2015). These functions are:

- adapting the time response of the systems to the building inertia factor;
- time programming of the heating installation in comfort period and reduced period;
- choosing the room temperature that activates the antifreeze function;
- choosing the outside temperature required for heating shut-off.

2 OBJECTIVES OF THE ARTICLE

The objectives are the following:

Popescu, D. and Borza, I.
Ensuring the Comfort in the Heated Space by Controlling the Temperature in the Heating Installation of a Non-residential Building.
In *Proceedings of the 5th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS 2016)*, pages 462-467
ISBN: 978-989-758-184-7

- modeling the automatic heating system of the non-residential building so that the model to represent with accuracy the physical characteristics of the real system;
- simulation of the functioning for the modeled automatic system and recording the evolution of the representative temperatures from the system.
- evaluation of the automatic system model by analyzing the records over time for the indoor temperature, flow and return temperatures in the heating installation, depending on the outdoor temperature changes.

3 PROCEDURE FOR MODELING, SIMULATION AND EVALUATION OF THE AUTOMATIC SYSTEM

The automatic heating system is decomposed into subsystems and then is modeled each subsystem. The subsystems represent the used automation equipments, the heating installation of the building, the thermodynamic system of heated space and the exterior environment of the building. There are created block diagrams in Simulink for each subsystem, based on mathematical equations, transfer functions or graphs according to which the subsystems work.

The evaluation of the model for the automatic system is done by simulation and recording of the evolution for representative parameters. The model will be declared valid if he represents with accurately the physical characteristics of the analyzed automatic system.

4 AUTOMATIC SYSTEM FOR TEMPERATURE CONTROL OF THE THERMAL AGENT IN NON-RESIDENTIAL BUILDINGS

The classical control loop with three-points regulator and three-way control valve is completed with HEATING CURVE subsystem. This subsystem is dedicated for automation of heating installations in buildings, because it determines the set point for the thermal agent temperature according to the outside temperature. The set point value must take into account the construction features of the building and also its destination. In the current practice of the automated heating installations for non-residential buildings, the HEATING CURVE subsystem is included in the automatic regulator.

Outside temperature evolution is modeled using the OUTDOOR TEMPERATURE subsystem.

The heating of the indoor space delimitated in the space of the Faculty of Building Services Engineering Bucharest is performed by means of a heating circuit independent from the other circuits which makes up the heating installation of the whole building (Popescu et al., 2008; Popescu and Ciufudean, 2008).

The block diagram of the automatic system is shown in Figure 1.

In the analyzed non-residential building, the heating installation is provided with radiators and the thermal agent is water. The boiler is the heat source that operates at a constant temperature of 800C.

The effect of the temperature control in the heating installation must be to maintain the indoor temperature in the heated space to a value as constant as possible.

The models for the subsystems OUTDOOR TEMPERATURE, HEATING CURVE, NONLINEAR CONTROLLER, THREE-WAY MIXING VALVE and HEATING SYSTEM were made in Simulink (Popescu et al., 2009).

5 MODEL OF THE HEATED SPACE FROM BUILDING

The heated space in the building is intended for offices. The constructive characteristics of the heated space are:

- walls without insulation applied to the outside;
- walls made of bricks;
- building with three levels (ground floor and two floors);
- dimensions 20m x 10m x 10m.

The heat input Q_{in} into the heated space by means of the installation is

$$\frac{dQ_{in}}{dt} = q_{ag} \cdot c_{ag} \cdot \Delta T \tag{1}$$

where

$$\Delta T = \frac{T_{flow} + T_{ret}}{2} - T_{indoor} \tag{2}$$

q_{ag} - volumetric flow of the thermal agent in the installation

c_{ag} - specific heat of the thermal agent

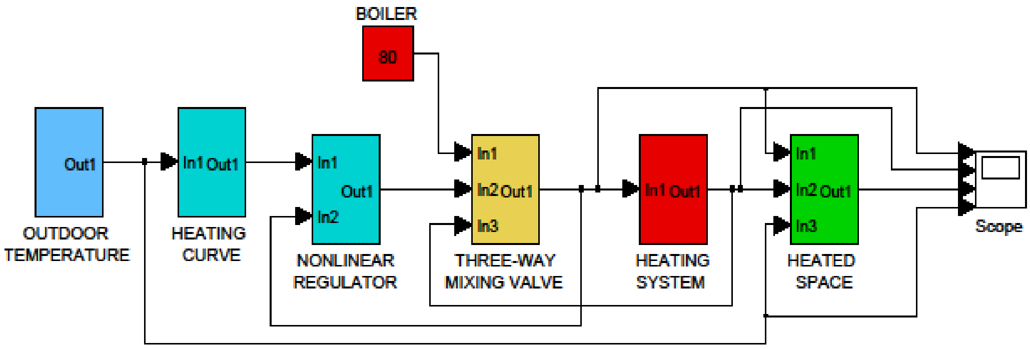

Figure 1: Block diagram of the automatic system modeled.

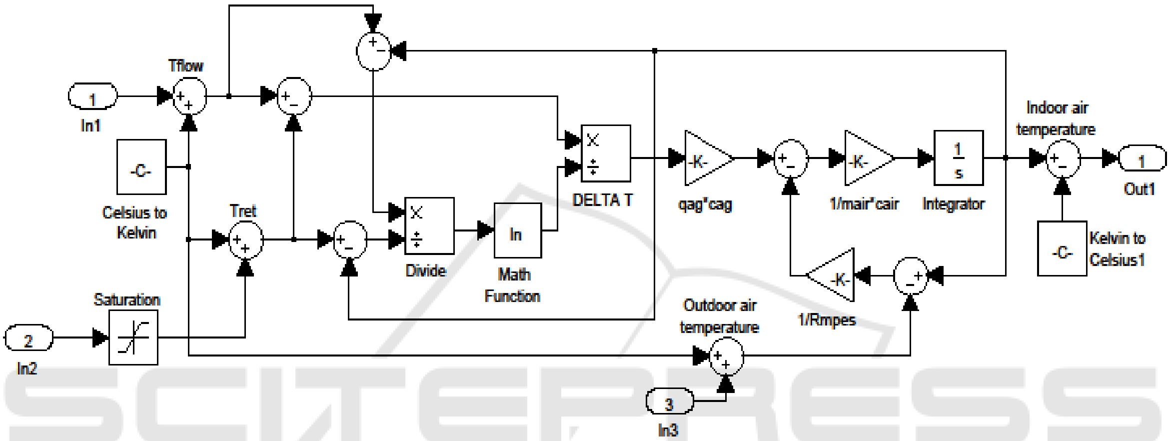

Figure 2: Simulink model for HEATED SPACE subsystem.

T_{flow} - flow temperature

T_{ret} - return temperature

T_{indoor} - indoor temperature

The temperature difference between flow and return of the heating installation, can be calculated with the relation

$$\Delta T = \frac{T_{flow} - T_{ret}}{\ln \dfrac{T_{flow} - T_{indoor}}{T_{ret} - T_{indoor}}} \qquad (3)$$

which shows the connection between the indoor temperature in the building and the water temperature in the heating installation.

The heat losses through the building envelope that correspond to the heated space, is calculated with the relation

$$\frac{dQ_{out}}{dt} = \frac{1}{R_{mPE}} \cdot (T_{indoor} - T_{outdoor}) . \qquad (4)$$

R_{mPE} - average thermal resistance of the building envelope

$T_{outdoor}$ - outdoor temperature

It is used the following simplifying hypothesis: heat losses are only through the exterior wall, that has the surface 20m x 10m = 200m^2.

The equation which models the heated space in the building is

$$\frac{dT_{indoor}}{dt} = \left(\frac{dQ_{in}}{dt} - \frac{dQ_{out}}{dt} \right) \cdot \frac{1}{m_{air} \cdot c_{air}} . \qquad (5)$$

m_{air} - mass of air in the heated space

c_{air} - specific heat of the air

The numerical values that need to be introduced in the equation of the heated space model are established further.

Mass of the air from the heated space

$$m_{air} = \rho_{air} \cdot V_{air} =$$
$$= 1{,}225 \frac{kg}{m^3} \cdot 20m \cdot 10m \cdot 10m = 2450kg \; .$$

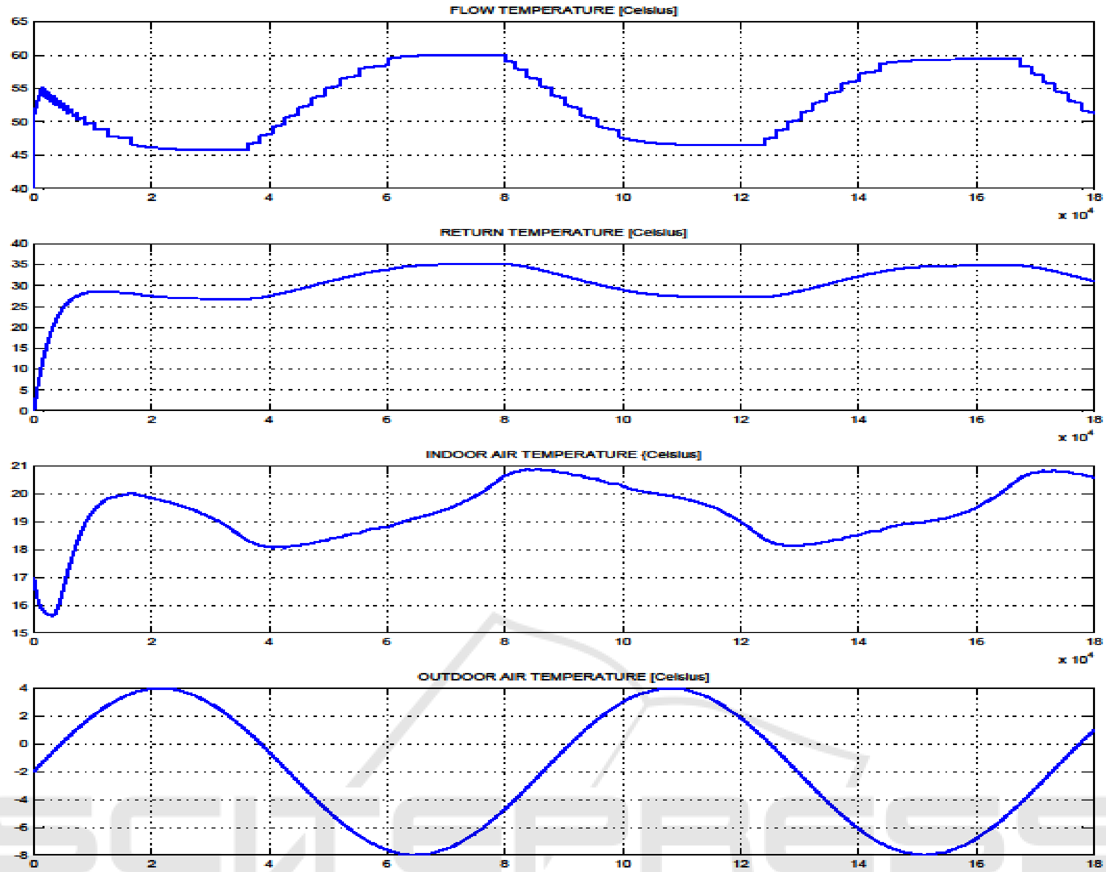

Figure 3: Results of simulation for the model of the automatic system.

The pump chosen for the circulation of the thermal agent in heating installation has the volumetric flow $q_{ag} = 2{,}5\frac{m^3}{h} = 0{,}694\frac{l}{s} = 0{,}694\frac{kg}{s}$.

Specific heat of the air $c_{air} = 1005{,}4\frac{J}{kg \cdot K}$.

Specific heat for thermal agent (water) $c_{ag} = 4190\frac{J}{kg \cdot K}$.

Average thermal resistance of the building envelope (exterior wall) has been chosen $R_{mPE} = 0{,}3\frac{m^2 \cdot K}{W}$. A building envelope whose average thermal resistance is 0,3 ... $0{,}5\left[\frac{m^2 \cdot K}{W}\right]$ corresponds to uninsulated buildings. The reference buildings are characterized by thermal resistance with values of $0{,}6...0{,}7\left[\frac{m^2 \cdot K}{W}\right]$ and the energy efficient buildings are characterized by thermal resistance values of $1...1{,}2\left[\frac{m^2 \cdot K}{W}\right]$.

The thermal resistance of the exterior wall with surface S is $R_{mPES} = \frac{R_{mPE}}{S} = \frac{0{,}3\frac{m^2K}{W}}{20m \cdot 10m} = 0{,}0015\frac{K}{W}$ and $\frac{1}{R_{mPES}} = \frac{1}{0{,}0015\frac{K}{W}} \approx 670\frac{W}{K}$.

The Simulink model for the subsystem called heated space from the building is shown in Figure 2.

The heated space model allows recording the indoor temperature, the main parameter which evaluates the thermal comfort in the built space.

6 SIMULATION AND EVALUATION OF THE MODEL

The model of the automatic system shown in Figure 1 represents the current situation in the building which belongs to the Faculty of Building Services Engineering Bucharest.

The simulation of the model for the automatic system is performed in a time interval that lasts 180,000 seconds, that is to say 50 hours. Time interval for simulation was chosen large enough compared with the values for the time constants of the processes of heating in buildings and with the transitory regime for an automatic heating system.

Through simulation were recorded the evolutions for the temperatures from the heating system, indoor temperature and outdoor temperature. The graphs are shown in Figure 3 and represent the behavior of the automatic system in winter days with normal temperatures for Romania.

After passing the transitory time, caused by the putting into service of automatic heating system, it is found the correct correlation between flow temperature from the heating installation $T_{ft}[K]$ and outside temperature $T_{ot}[K]$, according to equation

$$T_{ft}[K] = -1{,}5 \cdot T_{ot}[K] + 732{,}87K \ . \qquad (6)$$

This equation has been used for modeling the subsystem HEATIG CURVE.

7 CONCLUSIONS

The model can be validated because, according to the results of the simulation, it accurately represents the actual physical characteristics of the automatic system analyzed.

The variations obtained for the outside temperature and the thermal agent temperatures in the heating installation, as well as the correlations between them, are in accordance with the requirements for correct operation of the heating installation in the non-residential building. In the conformity assessment we must take into account that the precision of choice for the slope of the HEATING CURVE depends on the degree of knowledge of the characteristics of the building.

A poor result was obtained for indoor air temperature of the heated space. There are noted maximum temperature variations $\Delta\theta_{indoor} = 20{,}8^0 C - 18{,}2^0 C = 2{,}6^0 C$, which can be felt as a discomfort by the building occupants.

The low thermal comfort arises because the indoor temperature does not have an own control loop. The indoor temperature in the heated space is maintained approximately constant only by controlling the thermal agent temperature in the heating system depending on outside temperature. In the temperature control of the thermal agent are cumulated imprecisions that come from the non-linear control, from the choice of the slope value in HEATING CURVE and from the experimental determination procedure of the mathematical model for the heating installation.

The buildings and heating processes in non-residential buildings are characterized by large and very large thermal inertia, which is why the building indoor temperature changes very slowly; these variations of the indoor temperature represent a minor thermal discomfort for the building occupants. Are thus evident the main reasons for what the traditional heating automation in buildings is based on the non-linear control. An additional reason is the low price for nonlinear automatic systems.

Local control of the indoor temperature in each room of the building may be the ideal solution for ensuring the thermal comfort of all building occupants, but his high cost would allow rarely its application.

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