EasyChair Preprint

№ 5892

Temperature Evolution in Building Wall System with Dynamic Control of Heating Systems

Laszlo Garbai and Gergely Pacza

EasyChair preprints are intended for rapid dissemination of research results and are integrated with the rest of EasyChair.

June 23, 2021

Temperature evolution in building wall system with dynamic control of heating systems

Laszlo Garbai[1], Gergely Pacza[2]

[1] Department of Building Services and Process Engineering, Budapest University of Technology, Professor Emeritus, garbai@epget.bme.hu

[2] Department of Building Services and Process Engineering, Budapest University of Technology, PhD student, pacza@epget.bme.hu

Abstract

I focus on the dynamic control of heating systems, primarily district heating systems in this study. With the dynamic control of the heating system we can defined the temperature changing in the wall structure. The control of district heating systems is currently static. We set the primary flow temperature and the circulating hot water volume flow to the heat source with the estimation of the average daily temperature. These values are set empirically. The control of the thermal centre is similarly static. The secondary flow temperature and the circulating secondary hot water volume flow are set according to the estimated heat demand of the building, the control is choked. There is no exact practice currently on how to consider thermal inertia of boundary walls, the amount of heat stored in the walls and the damping effect. In our study, we present models in which we consider the damping and delaying effect of the walls and the heat storage in the walls. The model is of concentrated parameter and describes development over time regarding the air temperature of the habitation and the average wall temperature considering the outside temperature.

Keywords: District heating system, predictive control, instationary, Fourier-equitation

1 Introduction

The control of heating systems is still static these days. It is based on the calculation of so-called stationary operating points assigned to outside temperatures. We describe the relationship between interventions and outputs with an empirical function, i.e., what input characteristics are necessary for the required internal temperature in a stationary state at a given outdoor temperature. Previous studies have also delved into the question of what internal temperature is formed if there is a change or disturbance in the inputs compared to the theoretically required values and what correction of the inputs is necessary to restore the commanded air temperature. In this paper, we describe a transient description method that can be applied to model the effect of changes in external temperatures over time, the thermal storage capacity of walls, and the damping effect. Thereby, we can determine the time course of the intervention characteristics as precisely as possible by which the commanded value of the internal temperature can be kept with the smallest deviation. The logic of the control is as follows: as a result of the change in outside temperature, the change in heat loss occurs only delayed in the air of the dwelling, intervention from the primary side, increase or decrease in heat input has to reach the air of the dwelling by this time. This mode of control obviously and demonstrably results in energy savings. Due to this dynamic contor we could minimize the temperature fluctuation in the wall structure. We can reduce the dilation which can occur thermal stresses.

2 Single and double storage modelling of thermal inertia of a wall structure

The thermal inertia of the wall structure, the description of the instationary heat conduction in the wall can be obtained most accurately by the Fourier equation for the multilayer wall and its numerical solution. One of the graphical methods is called Schmidt editing. The temperature distribution in the wall is theoretically continuous, we disregard to define it. Instead, we apply concentrated parameter description. The parameters under study include the air temperature and the average wall temperature. If we disregard the description of the heat stored in the air and study only the change in heat stored in the wall, it is called the single-storage model, otherwise a two-storage model. In our study, we write the differential equations of both single and two-storage modelling.

2.1 Single-storage model

We set up a model for the evolution of the average temperature of a wall structure and for the calculation of the thermal flow through the wall during the cooling of the bounded space as a function of time. We defined two tasks:

- Mark the average wall temperature as tm. Our aim is to determine how the thermal flow density through the wall changes in the event of a sudden change in the outside temperature, from tk1 to tk2, i.e., to what extent we need to increase the input thermal flow if we intend to keep the air temperature at constant value.

- The outdoor temperature changes according to an arbitrary time function, namely decreases in the model. Consequently, the average temperature of the wall decreases as well, assuming the consistency of the indoor air temperature. This decrease in the average temperature of the wall is described by Equation (1), which results in the increase of the thermal flow through the wall compared to the stationary initial state. (Equation 2) As a result of the increased thermal flow, the internal air temperature must necessarily decrease, for the calculation of which another differential equation is set and solved at the end of the chapter.

2.2 Temperature change according to jump funciton

A further advantage of the control is that we can minimize the temperature fluctuations in the boundary structures and therefore the degree of dilatation and thermal stresses. We can reduce the risk of damage to the building structure and increase the lifetime of the building.

During the research, two tasks were defined as follows:

- average wall temperature test, and
- external temperature test

The geometric model of control is of paramount importance. The heated rooms in the building require constant internal temperature. In our modelling, we test how thermal flow out of the boundary structures changes with outside temperature and how much heating power is needed to keep the internal temperature constant. The geometric model is shown in Figure 1.

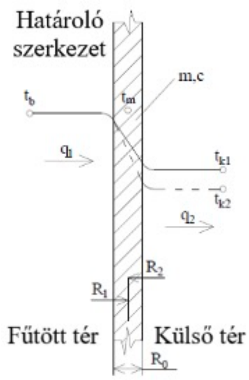

Fig. 1 Test model

The following equations can be applied for the thermal flow density leaving the wall:

$$\dot{q}_1 = \frac{t_b - t_m}{R_1} \quad (1)$$

$$\dot{q}_2 = \frac{t_m - t_k}{R_2} \quad (2)$$

Afterwards, we write the change in the amount of heat in the wall per unit of time, which will be equal to the difference in the increased thermal flow densities due to the decrease in the initial and outside temperatures, so

$$cM\frac{dt_m}{d\tau} = \dot{q}_1 - \dot{q}_2 = \frac{t_b - t_m}{R_1} - \frac{t_m - t_k}{R_2} \quad (3)$$

in an ordered way

$$M\frac{dt_m}{d\tau} = \dot{q}_1 - \dot{q}_2 = \frac{t_b}{R_1} - \frac{t_m}{R_1} - \frac{t_m}{R_2} + \frac{t_k}{R_2} \quad (4)$$

$$cM\frac{dt_m}{d\tau} = \left(\frac{t_b}{R_1} + \frac{t_k}{R_2}\right) - t_m\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \quad (5)$$

Introducing constants A and B.

$$cM\frac{dt_m}{d\tau} = A - t_m B \quad (6)$$

where,

$$A = \left(\frac{t_b}{R_1} + \frac{t_k}{R_2}\right) \text{ és } B = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

Divided by the thermal capacity of the wall and introducing constants A * and B *

$$\frac{dt_m}{d\tau} = \frac{A}{cM} - t_m\frac{B}{cM} \quad (7)$$

The obtained differential equation is a constant coefficient, linear, first order, homogeneous, which is a separable variable. After separating the variables, the differential equation can be solved by direct integration.

The ordered form of the differential equation by introducing new constants

$$\frac{dt_m}{d\tau} = A^* - t_m B^* \quad (8)$$

where,

$$A^* = \frac{A}{cM} \text{ és } B^* = \frac{B}{cM}$$

In an ordered way,

$$\frac{dt_m}{A^* - t_m B^*} = d\tau, \quad (9)$$

Marking integration,

$$\int \frac{1}{A^* - t_m B^*} dt_m = \int 1\, d\tau\,. \quad (10)$$

Performing integration,

$$-\frac{1}{B^*} ln(A^* - t_m B^*) = \tau + C, \qquad (11)$$

With further order,

$$(A^* - t_m B^*) = C e^{-B^* \tau} \qquad (12)$$

Finally,

$$t_m = \frac{A^*}{B^*} - \frac{C}{B^*} e^{-B^* \tau} \qquad (13)$$

The value of the integration constant C can be determined from the initial condition, according to which the average temperature of the wall at the initial time is a given initial value, i.e., if

$\tau = 0; \qquad t_m = t_{m,0},$

$$t_{m,0} = \frac{A^*}{B^*} - \frac{C}{B^*} \ , \qquad (14)$$

$$t_{m,0} = \frac{A^*}{B^*} - \frac{C}{B^*} \ , \qquad (15)$$

Replacing it into Equation (13), we get a formula describing the change in the mean wall temperature as a function of time:

$$t_m = \frac{A^*}{B^*} - \frac{(A^* - t_{m,0} B^*)}{B^*} e^{-B^* \tau}, \qquad (16)$$

heat flux density from heated space

$$\dot{q}_1(\tau) = \frac{t_b - t_m}{R_1} = \frac{t_b}{R_1} - \frac{1}{R_1}\left[\frac{A^*}{B^*} - \frac{(A^* - t_{m,0} B^*)}{B^*} e^{-B^* \tau}\right] \qquad (17)$$

3 Modelling the thermal inertia of a wall structure in case of the change of the outdoor temperature according to a continuous time function

The test model corresponds to paragraph 2 and Figure 1, however, as a fine-tuning of the model, the external temperature tk now does not change sharply, but changes according to some time function tk (τ). Discussing the tested phenomenon in this way is closer to reality and gives more accurate results.

As above, thermal flow densities can be written.

$$\dot{q}_1 = \frac{t_b - t_m}{R_1} \qquad (18)$$

$$\dot{q}_2 = \frac{t_m - t_k}{R_2} \qquad (19)$$

$$t_k = t_k(\tau), \qquad (21)$$

$$cM \frac{dt_m}{d\tau} = \dot{q}_1 - \dot{q}_2 = \frac{t_b - t_m}{R_1} - \frac{t_m - t_k(\tau)}{R_2} = \frac{t_b}{R_1} - \frac{t_m}{R_1} - \frac{t_m}{R_2} + \frac{t_k(\tau)}{R_2} \qquad (21)$$

After ordering

$$cM \frac{dt_m}{d\tau} = \left(\frac{t_b}{R_1} + \frac{t_k(\tau)}{R_2}\right) - t_m\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \qquad (22)$$

Introducing notations A, B, and D, it can be written that

$$cM \frac{dt_m}{d\tau} = A - t_m B + D t_k(\tau), \qquad (23)$$

where

$$A = \left(\frac{t_b}{R_1}\right), B = \left(\frac{1}{R_1} + \frac{1}{R_2}\right), D = \left(\frac{1}{R_2}\right).$$

Divided by the thermal capacity of the wall,

$$\frac{dt_m}{d\tau} = \frac{A}{cM} - t_m \frac{B}{cM} + \frac{D}{cM} t_k(\tau) \qquad (24)$$

Introducing the modified notations A *, B * and D *, we obtain a linear, first-order, inhomogeneous differential equation with a constant coefficient.

$$\frac{dt_m}{d\tau} = A^* - t_m B^* + D^* t_k(\tau) \qquad (25)$$

where,

$$A^* = \frac{A}{cM}, \ B^* = \frac{B}{cM}, \ D^* = \frac{D}{cM}.$$

The canonical form of the equation, *(1)*

$$y' + X(x) y = -X_1(x), \qquad (26)$$

where,

$$X(x) = B^*, \qquad (27)$$

$$X_1(x) = A^* + D^* t_k(\tau)$$

The solution is as follows,

$$y = e^{u(x)}\left[-\int X_1(x) e^{-u(x)} dx + C_1\right] \qquad (28)$$

where,

$$u(x) = -\int X(x) dx = -\int B^* dx = -B^* x . \qquad (29)$$

Therefore,

$$y = t_m(\tau) = e^{-B^* x}\left[-\int (A^* + D^* t_k(\tau)) e^{B^* x} d\tau + C_1\right] \qquad (30)$$

After ordering, we get the differential equation describing the change of the average temperature of the wall, in case of the change of the outdoor temperature according to the time function

$$t_m(\tau) = e^{-B^*x}\left[-\int A^* e^{B^*x} d\tau - D\int t_k(\tau) e^{B^*x} d\tau + C_1\right] \quad (31)$$

Further simplified,

$$t_m(\tau) = e^{-B^*x}\left[-\frac{A^*}{B^*} e^{B^*x} - D\int t_k(\tau) e^{B^*x} d\tau + C_1\right] \quad (32)$$

Of which, the change in air temperature can be calculated with Equation (18).

3.1 Considering the combined heat storage and delay of air space and wall structure

In this subsection, we test transient processes in a system composed of air and wall structure. Our goal is to write the differential equation describing the transient, i.e., to determine what happens between two equilibriums.

The following balance can be written for the thermal balance of the air:

$$cm\frac{dt_{lev}}{d\tau} = \dot{q}_{rad} - \frac{t_{lev}-t_m}{R_1} \quad (33)$$

And the equations describing the thermal balance of the wall,

$$cM\frac{dt_m}{d\tau} = \frac{t_{lev}-t_m}{R_1} - \frac{t_m-t_k}{R_2} \quad (34)$$

$$cM\frac{dt_m}{d\tau} = \frac{t_{lev}}{R_1} - t_m\left(\frac{1}{R_1}+\frac{1}{R_2}\right) + \frac{t_k}{R_2} \quad (35)$$

From Equation (33):

$$t_m(\tau) = R_1 cm\frac{dt_{lev}}{d\tau} + t_{lev}(\tau) - \dot{q}_{rad}R_1 \quad (36)$$

Replace Equation (36) into Equation (35) to obtain the differential equation describing the change in tlev (τ).

$$cM\frac{d}{d\tau}\left[R_1 cm\frac{dt_{lev}}{d\tau} + t_{lev}(\tau) - \dot{q}_{rad}R_1\right] = \frac{t_{lev}(\tau)}{R_1} - t_m(\tau)\left(\frac{1}{R_1}+\frac{1}{R_2}\right) + \frac{t_k}{R_2} \quad (37)$$

$$cMR_1 cm\frac{d^2t_{lev}}{d\tau^2} + cM\frac{d}{d\tau}t_{lev} - cM\frac{d}{d\tau}\dot{q}_{rad}R_1 = \frac{t_{lev}(\tau)}{R_1} - t_m(\tau)\left(\frac{1}{R_1}+\frac{1}{R_2}\right) + \frac{t_k}{R_2} \quad (38)$$

After ordering, we get equation (39),

$$cMR_1 cm\frac{d^2t_{lev}}{d\tau^2} + cM\frac{d}{d\tau}t_{lev} - cMR_1\frac{d}{d\tau}\dot{q}_{rad} - \frac{t_{lev}(\tau)}{R_1} = -\left[R_1 cm\frac{dt_{lev}}{d\tau} + t_{lev}(\tau) - \dot{q}_{rad}R_1\right]\left(\frac{1}{R_1}+\frac{1}{R_2}\right) + \frac{t_k}{R_2} \quad (39)$$

Cases tested:

- qrad = const.

- qrad is a function of τ, therefore qrad = qrad (τ,)

$Ha\ \dot{q}_{rad} = constant$, for simpler use, we get equation (40) by introducing notations a0, a1, a2, a3 and a4:

$$a_0\frac{d^2t_{lev}}{d\tau^2} + a_1\frac{dt_{lev}}{d\tau} + a_2 t_{lev} = a_3 t_k(\tau) + a_4 \quad (40)$$

in which the constants a0, a1, a2, a3, a4 are as follows:

$$a_0 = cMR_1 cm \quad (41)$$

$$a_1 = cM + R_1 cm\left(\frac{1}{R_1}+\frac{1}{R_2}\right),$$

$$a_2 = \left(\frac{1}{R_1}+\frac{1}{R_2}\right) - \frac{1}{R_1} = \frac{1}{R_2},$$

$$a_3 = \frac{1}{R_2},$$

$$a_4 = -\dot{q}_{rad}R_1\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$$

The obtained differential equation is constant coefficient, linear, second-order, inhomogeneous, which can be solved by the method of varying the constants or by the method of probe functions.

The solution of Equation (40) by the method of varying the constants in matrix form is as follows:

We first solve the homogeneous part of the equation:

$$a_0\frac{d^2t_{lev}}{d\tau^2} + a_1\frac{dt_{lev}}{d\tau} + a_2 t_{lev} = 0. \quad (42)$$

Characteristic equation for the homogeneous part:

$$a_0\lambda^2 + a_1\lambda + a_2 = 0. \quad (43)$$

The characteristic equation can be solved by the general solution formula of the quadratic equation.

$$\lambda_{1,2} = \frac{-a_1 \pm \sqrt{a_1^2 - 4a_0 a_2}}{2a_0} \quad (44)$$

Solutions to Equation (43):

$$\lambda_1 = \frac{-a_1}{2a_0} + \sqrt{a_1^2 - 4a_0a_2} \quad (45)$$

$$\lambda_2 = \frac{-a_1}{2a_0} - \sqrt{a_1^2 - 4a_0a_2} \quad (46)$$

The homogeneous solutin

$$y_h = c_1 e^{\lambda_1 \tau} + c_2 e^{\lambda_2 \tau} \quad (47)$$

The constants c1 and c2 can be determined by the initial conditions.

Solving the particular part of the equation then, assuming that constants c1 and c2 are also functions of time

$$y_p = c_1(\tau) e^{\lambda_1 \tau} + c_2(\tau) e^{\lambda_2 \tau} \quad (48)$$

Using the method of varying the constants, an equation of the particular part can be created in matrix form.

$$y_p = \sum_{i=1}^{n} c_i(\tau) y_i(\tau)\ , \quad (49)$$

$$\begin{bmatrix} c_1' \\ c_2' \\ \vdots \end{bmatrix} = \begin{bmatrix} y_1 & y_2 & \cdots \\ y_1' & y_2' & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ f(\tau) \\ \vdots \end{bmatrix} \quad (50)$$

Writing Equation (47) in a matrix form:

$$\begin{bmatrix} c_1' \\ c_2' \end{bmatrix} = \begin{bmatrix} y_1 & y_2 \\ y_1' & y_2' \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ f(\tau) \end{bmatrix} \quad (51)$$

Replaced

$$\begin{bmatrix} c_1' \\ c_2' \end{bmatrix} = \begin{bmatrix} e^{\lambda_1 \tau} & e^{\lambda_2 \tau} \\ \lambda_1 e^{\lambda_1 \tau} & \lambda_2 e^{\lambda_2 \tau} \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ a_3 t_k(\tau) + a_4 \end{bmatrix} \quad (52)$$

When performing the matrix inversion:

$$\begin{bmatrix} c_1' \\ c_2' \end{bmatrix} = \frac{1}{e^{(\lambda_1+\lambda_2)\tau + (\lambda_2 - \lambda_1)}} \begin{bmatrix} \lambda_2 e^{\lambda_2 \tau} & -e^{\lambda_2 \tau} \\ -\lambda_1 e^{\lambda_1 \tau} & e^{\lambda_1 \tau} \end{bmatrix} \begin{bmatrix} 0 \\ a_3 t_k(\tau) + a_4 \end{bmatrix} \quad (53)$$

By performing the matrix multiplication and expressing the values of c1 'and c2', the constants c1 and c2 can be determined by integration.

$$c_1' = \frac{-e^{\lambda_2 \tau}}{e^{(\lambda_1+\lambda_2)\tau + (\lambda_2 - \lambda_1)}} (a_3 t_k(\tau) + a_4) \quad (54)$$

$$c_2' = \frac{e^{\lambda_1 \tau}}{e^{(\lambda_1+\lambda_2)\tau + (\lambda_2 - \lambda_1)}} (a_3 t_k(\tau) + a_4) \quad (55)$$

From Equation (54):

$$c_1(\tau) = \int \frac{-e^{\lambda_2 \tau}}{e^{(\lambda_1+\lambda_2)\tau + (\lambda_2 - \lambda_1)}} (a_3 t_k(\tau) + a_4)\, d\tau \quad (56)$$

From Equatuin (54):

$$c_2(\tau) = \int \frac{-e^{\lambda_2 \tau}}{e^{(\lambda_1+\lambda_2)\tau + (\lambda_2 - \lambda_1)}} (a_3 t_k(\tau) + a_4)\, d\tau \quad (57)$$

The solution of the initial equation (39) is the sum of the homogeneous and particular partial solutions, therefore:

$$y = y_h + y_p = c_1 e^{\lambda_1 \tau} + c_2 e^{\lambda_2 \tau} + c_1(\tau) e^{\lambda_1 \tau} + c_2(\tau) e^{\lambda_2 \tau}. \quad (58)$$

4 Summary, conclusions

The description of instationary heat conduction in a wall can be obtained most precisely by a numerical solution of a system of equations consisting of Fourier equations written for a multilayer wall structure. With the models in this paper, an approximation with different accuracy can be performed. In regular building engineering practice, the calculations described here have not used yet, but they may open the door to a new, predictive control of district heating systems. The mechanism of action of disturbance, which means a change in the outside temperature, is slow. The change of the thermal loss occurs only with a delay in the tested space, the intervention from the primary side, the increase or decrease of the heat supply or circulation only must arrive in the air of the dwelling by this time.

The formulas described in Section 2 can be used to calculate the time during which, in the event of a sudden change in the outside temperature, the change in air temperature takes place in addition to the constant heat input, which does not have a negative effect on our sense of comfort. The equation to be solved is linear, with constant coefficient, first order and homogeneous. (Equation 8) The problem can be further detailed by calculating the amount of excess heat that needs to be introduced so that the required internal temperature does not decrease with the change of the outdoor temperature. Alternatively, the decrease in internal temperature over a given period can be calculated. (Equation 38)

Section 3 discusses the thermal behaviour of the wall structure in the event of a change in the outside temperature as a function of time. Due to the change as a function of time, the equation thus written is already inhomogeneous (Equation 46). The equation (53) describing the change in the average wall temperature is thus much more complicated than that described in Section 2.

The combined behaviour of the system formed by the air and the wall structure was tested in Section 4. We have written a system of equations that is constant coefficient, linear, second order, and inhomogeneous. The system of equations can be reduced to a single differential equation by transformations.

We have described the theoretical course of the solution, which consists of a general solution of the homogeneous part and a particular solution of the inhomogeneous equation.

Whether higher accuracy and solution of this model is undoubtedly justifies its application can be decided by further studies. Of course, the same applies to the application of the Fourier-equation, which gives the most accurate description of the transient thermal conduction processes and the definition of the temperature field in complex wall structures. Regarding the application of the Fourier-equation, it is worth mentioning that due to the complicated initial and boundary conditions, there is only a numerical solution to the problem. In addition, Fourier-equation with different characteristics must be applied to each wall layer, and a quadratic (contact) boundary condition to be written for the contact of the layers appears, according to which the temperatures at the points of contact are the same.

References

[1] Garbai, L.: District heating (in Hungarian), 2012. ISBN: 978-963-279-739-7

[2] Jasper, A.: Optimization of district heating system design and operation (in Hungarian), PhD dissertation, 2017.

[3] Garbai L, Jasper A: Analysis of steady states in district heating systems. In: Nyers József (szerk.) Internationale symposium "EXPRES 2016" Subotica: 8th International Symposium of Renewable Energy Sources and Effectiveness. Konferencia helye, ideje: Szabadka, Szerbia, 2016.03.31-2016.04.02. Szabadka: Visoka Technicka skola strukovnihstudija u Subotici, 2016. pp. 81-83. (ISBN:978-86-85409-96-7)

[4] Nyers J., Nyers A.: "Hydraulic Analysis of Heat Pump's Heating Circuit using Mathematical Model". 9rd ICCC International Conference" Proceedings-USB, ISBN 978-1-4799-0061-9 pp 349-353, Tihany, Hungary. 04-08. 07. 2013.

[5] Nyers J.: "COP and Economic Analysis of the Heat Recovery from Waste Water using Heat Pumps".International J. Acta Polytechnica Hungarica Vol. 13, No. 5, 2016, pp. 135-154. DOI:10.12700/APH.13.5.2016.5.8.

[6] Szánthó Z: Determining the optimal schedule of district heating, Periodica Politechnica Ser. Mech. Eng. VOL.44 No. 2. Pp.285-300. (2000.)

[7] Dr. Erdősi István, Dr. Kajtár László Távhőszolgáltatás változó tömegáramú hőhordozóval (in Hungarian) ÉPÜLETGÉPÉSZET 1985:(2) pp. 49-55. (1985)

[8] Kajtár László, Erdősi István, Barna Lajos: A kombinált szabályozás alkalmazási lehetőségei forróvíz távhőrendszerekben, 11. Távhő Konferencia: 5. Távhőrendszerek. 155 p. Konferencia helye, ideje: Hajdúszoboszló, Magyarország, 1985.09.25-1985.09.27. Budapest: ÉTE, 1985. pp. 101-114. (ISBN:963-8041-67-6)

[9] Kajtár László, Erdősi István: Távhőrendszer mennyiségi és minőségi szabályozása, számítógépi program, 11. Távhő Konferencia. Konferencia helye, ideje: Hajdúszoboszló, Magyarország, 1985.09.25-1985.09.27. Budapest: Energiagazdálkodási Tudományos Egyesület, 1985. pp. 50-51. (ISBN:963-8041-61-7)

[10] Garbai L, Jasper A: Dynamic Contorlling Of District Heating Systems. In: Nyers József (szerk.) Internationale symposium "EXPRES 2019" Subotica: 11th International Symposium of Renewable Energy Sources and Effectiveness. Konferencia helye, ideje: Szabadka, Szerbia, 2019.04.11-2019.04.13. Szabadka: Visoka Technicka skola strukovnihstudija u Subotici, 2019. pp. 49-52. (ISBN: 978-86-919769-4-1)

List of notations

$\dot{m}$	mass flow	kg/s
p	pressure bar	
c	isobar specific temperature	kJ/kg°C
t	temperature	°C
q	specific heat consumption	-
y	primerenergia felhasználás	-
Q	heat energy	J
k	heat transfer coefficient	W/m2K
A	area	m2
kA	heat loss factor	W/K
n	air exchange number	1/h
V	volume	m3
$\dot{Q}$	heatflow	W
$\dot{W}$	heat capacity current	W/K
M	radiator indes	-
n	performance indes (1+M)	-
ln	natural logarithm	-
M	mass	kg
ϕ	Bosnjakovic coefficient	-
η	efficiency	-
τ	time	s

δ	thickness (wallthickness)	cm, m
Δ	change	-
λ	heat conduction coefficient	W/mK