

## **IMPROVING THE ACCURACY OF THE CALCULATION OF THERMAL CAPACITY OF HEATING SYSTEMS WHEN DESIGNING THE BUILDINGS WITH HIGH ENERGY EFFICIENCY**

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### **ABSTRACT**

This paper presents the theoretical basis of the matrix method direct-applied to determine the heat losses of the building and harmonized with the requirements very urgent regulatory documents. Matrix method consists in drawing up a series of matrices with geometrical and thermal characteristics and their subsequent multiplication by the rules of linear algebra. Matrix method is the most accurate way to determine the transmission heat losses and, consequently, the required heating power, because linear and point thermal bridges attached in Annex E SP 50.13330.2012 "Thermal performance of the buildings". The updated edition SNIP 23-02-2003 are taken into account. Tools of linear algebra allow to operate with a large data sets and take into account a number of different factors affecting the thermal balance of the building simultaneously. Matrix method is easily automated. Even the simplest tabular editors allow adapting them to write matrices and perform an operation of multiplication of matrices. In complex matrices using the opportunity to make up for the buildings detailed data array that is an information model of the thermal climate of the building is appeared. Approach realized by the matrix method corresponds the direction of development of science given at the federal level in Russian Federation - on energy saving and achieving maximal energy efficiency fully.

**Key words:** heating systems with high energy efficiency, reduced resistance to heat transfer, thermal bridges, elemental approach, matrix method

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### Introduction

All over the world technology development of engineering system aims to energy saving. At the same time, heating systems of buildings in the Russian Federation are vital engineering systems. So HVAC-engineers should exercise the utmost care, because each step of their calculations is an important task, the solution of which should be treated carefully. Today, in HVAC&R-engineering there are many problems. Firstly, regular updating of the market and appearance of the new equipment, of the new devices requires a high quality of mechanical works. In the conditions of our country these high standards is not always be guaranteed because of features of organization of construction and supervision, as well as the staffs' quality. Therefore, the increased responsibilities are assigned to the engineer when creating microclimate systems of buildings. So an engineer should detail of documentation as much as possible, take care of his calculations, try to predict the progress of the work and predict the technical problems that may occur when mounting, and try to solve them with the help of their decisions implemented in the project.

Second, the evolution of the enclosing structures, the transition to multi-layered elements of building shell require consideration of factors that existing methods of calculation are not able to reach. And, thirdly, achieve of the maximum energy efficiency of engineering systems and achieve of the perfect comfort requires a multifaceted and detailed calculation, which will accurately delineate the level of necessary expenses: and capital investments, and the cost of heat and electricity.

One of the most important components of a successful project is the calculation of the required power of the heating systems' of the building. It is the calculation that makes it possible to identify the required quantity of heat to be transferred to each room for its heating during the cold season. Without this calculation it is impossible to perform further calculations of heating systems, as well as assess the total level of costs for a whole building and for each room in it.

According to paragraph 6.22 [1], the thermal capacity of the heating system must take into account the following factors (1):

$$Q_{h.s} = Q_{tr} + Q_{inf} + Q_{mev} - \sum Q_{dom}, \quad (1)$$

where,

$Q_{h.s}$  - thermal capacity of the heating system, W;

$Q_{tr}$  - transmission heat losses through the enclosing structure of the building, W;

$Q_{inf}$  - heat consumption for heating the outside air entering the building due to infiltration or by organized inflow through window valves, vents, transoms and other devices for ventilation, W;

$Q_{mev}$  - heat consumption for heating the entering materials, equipment and vehicles, W;

$\sum Q_{dom}$  - heat flow coming regularly from electrical devices, lighting, technological equipment, piping engineering systems, people, and other heat sources lots, W.

### Calculation of Transmission Heat Losses through the External Enclosing Structures of Buildings' Premises

The basic formula for determining the heat transfer coefficient with expression (E1) [2, 3] takes the form:

$$K = \frac{1}{R_o'} = [\Sigma(a_i \cdot U_i) + \Sigma(l_j \cdot \psi_j) + \Sigma(n_k \cdot \chi_k)] \quad (2)$$

When replacing the relative geometrical and quantitative characteristics of the elements of the structures  $a_i, l_j, n_k$  on the absolute values  $A_i, L_j, N_k$  formula is converted to the form (3):

$$H = K \cdot A = [\Sigma(A_i \cdot U_i) + \Sigma(L_j \cdot \psi_j) + \Sigma(N_k \cdot \chi_k)] \quad (3)$$

where,

$K$  - heat transfer coefficient of external enclosures,  $W/(m^2 \cdot ^\circ C)$ ;

$R_o'$  - reduced resistance to heat transfer of external enclosures,  $(m^2 \cdot ^\circ C)/W$ ;

$A$  - total area of external enclosures,  $m^2$ ;

$a_i$  - relative area of the flat structural element (of  $i$ -th type), accounting for the  $1m^2$  of enclosing structure,  $m^2/m^2$ ;

$l_j$  - relative length of the linear thermal bridge (of  $j$ -th type), accounting for the  $1m^2$  of enclosing structure,  $m/m^2$ ;

$n_k$  - relative amount of the point thermal bridge (of  $k$ -th type), accounting for the  $1m^2$  of enclosing structure,  $units/m^2$ ;

$A_i$  - area of the flat structural element (of  $i$ -th type),  $m^2$ ;

$L_j$  - length of the linear thermal bridge (of  $j$ -th type),  $m$ ;

$N_k$  - number of the point thermal bridge (of  $k$ -th type),  $units$ ;

$U_i$  - heat transfer coefficient of the uniform part(of  $i$ -th type) of the enclosing structure,

$W/(m^2 \cdot ^\circ C)$ ;

$\psi_j$  - specific heat losses through the linear thermal bridge (of  $j$ -th type),  $W/(m \cdot ^\circ C)$ ;

$\chi_k$  - specific heat losses through the point thermal bridge (of  $k$ -th type),  $W/^\circ C$ ;

$H$  - specific heat transfer of enclosure,  $W/^\circ C$ .

Thus, the traditional formula for calculating the transmission heat flow takes the form (4):

$$Q_{tr} = K \cdot A \cdot (t_{int} - t_{ext}) \cdot (1 + \Sigma \beta_i) = H \cdot (t_{int} - t_{ext}) \cdot (1 + \Sigma \beta_i), \quad (4)$$

where,  $t_{int}$  and  $t_{ext}$  - internal and external air temperature, respectively,  $^\circ C$ .

Multiplier  $(1 + \Sigma \beta_i)$  that takes into account different correction factors may be withdrawn as a result of adaptation of the correction factors. Then, transmission heat flow for each  $i$ -th premise can be calculated by the formula (5):

$$Q_{tr,i} = H_i \cdot (t_{int} - t_{ext}) \quad (5)$$

#### Forming Matrices with Thermal and Geometrical Characteristics of the Enclosing Structures of Building's Premises

For modern high-rise buildings calculation of the reduced resistance to heat transfer of enclosing structures, heat transfer coefficients and specific heat transfer by formulas (2) and (3), and then calculation of the transmission heat flow by the formula (5) for all rooms is a busy task that requires special care from an engineer. So for these calculations it is proposed to perform calculations using the matrix representation of input data (matrix method) [4].

The set of values of transmission of heat flow for all areas of the building can be represented as a vector-column (6):

$$Q_{tr} = \begin{pmatrix} Q_{tr1} \\ Q_{tr2} \\ Q_{tr3} \\ \dots \\ Q_{trn} \end{pmatrix}, \quad (6)$$

To get the matrix representing a column-vector (6), the coordinates of which are the transmission heat losses of building's premises, you must perform a matrix multiplication (7):

$$Q_{tr} = \Delta T \cdot H, \quad (7)$$

Number of rows in a matrix is the number of building premises, equal to  $n$ .

$\Delta T$  - diagonal matrix of temperature differences between external air and internal air of premises,  $^{\circ}\text{C}$  (8):

$$\Delta T = \begin{pmatrix} (t_{\text{int}_1} - t_{\text{ext}})_1 & 0 & 0 & \dots & 0 \\ 0 & (t_{\text{int}_2} - t_{\text{ext}})_2 & 0 & \dots & 0 \\ 0 & 0 & (t_{\text{int}_3} - t_{\text{ext}})_3 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \dots & (t_{\text{int}_n} - t_{\text{ext}})_n \end{pmatrix}, \quad (8)$$

$H$  - column-vector of the specific heat transfer through the external enclosure of the premise,  $\text{W}/^{\circ}\text{C}$  (9):

$$H = \begin{pmatrix} H_1 \\ H_2 \\ H_3 \\ \dots \\ H_n \end{pmatrix}, \quad (9)$$

Each coordinate of this vector corresponds to the room. So each specific heat transfer through the external enclosure of the premise is calculated using the formula (3). To determine the value of the specific heat transfer for each room, you must perform a matrix multiplication (10):

$$H = C_t \cdot F, \quad (10)$$

where,  $C_t$  - matrix of geometric and quantitative characteristics of flat, linear and point elements (surface of enclosures, thermal bridges) of external enclosing structures of building's premises (11):

$$C_t = \begin{pmatrix} A_{11} & A_{12} & \dots & A_{1m} & L_{11} & L_{12} & \dots & L_{1m} & N_{11} & N_{12} & \dots & N_{1m} \\ A_{21} & A_{22} & \dots & A_{2m} & L_{21} & L_{22} & \dots & L_{2m} & N_{21} & N_{22} & \dots & N_{2m} \\ A_{31} & A_{32} & \dots & A_{3m} & L_{31} & L_{32} & \dots & L_{3m} & N_{31} & N_{32} & \dots & N_{3m} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ A_{n1} & A_{n2} & \dots & A_{nm} & L_{n1} & L_{n2} & \dots & L_{nm} & N_{n1} & N_{n2} & \dots & N_{nm} \end{pmatrix} \quad (11)$$

Each row of the geometric characteristics' matrix is a set of geometric and quantitative characteristics of all types of elements corresponding to the  $n$ -th building premises.

$A_{nm}$  - area of  $m$ -th part of the surface of enclosing structure of  $n$ -th room,  $m^2$ ;

$L_{nm}$  - length of the  $m$ -th linear thermal bridge of  $n$ -th room,  $m$ ;

$N_{nm}$  - number of the  $m$ -th point thermal bridge of  $n$ -th room, *units*;

$U_m$  - heat transfer coefficient of  $m$ -th fragment of uniform enclosing construction,  $W/(m^2 \text{ } ^\circ C)$ ;

$\psi_m$  - specific heat losses through linear thermal bridge (of  $m$ -th type),  $W/(m \text{ } ^\circ C)$ ;

$\chi_m$  - specific heat losses through the point thermal bridge (of  $m$ -th type),  $W/^\circ C$ .

$F$  - column-vector of the specific heat flows through the corresponding elements (12):

$$F = \begin{pmatrix} U_1 \\ U_2 \\ \dots \\ U_m \\ \psi_1 \\ \psi_2 \\ \dots \\ \psi_m \\ \chi_1 \\ \chi_2 \\ \dots \\ \chi_m \end{pmatrix} \quad (12)$$

Specific heat flow through the windows and, accordingly, their geometrical characteristics are entered in the corresponding matrices (12) and (11) together with those for massive enclosures.

Window openings' fillings are considered as an integral part of the fragment enclosing structure.

The result of making matrices (8), (11), (12) and of the two operations of their multiplication (7) and (10) is a column-vector (6). This matrix is a set of transmission heat losses through external enclosing structures for each premise of the building.

#### Calculation of Transmission Heat Losses through the Internal Enclosing Structures of the Building's Premises

In addition to the external enclosures, it is necessary to take into account the possible heat losses through the internal enclosures for the correct calculation of the transmission component of the enclosing structures for each premise of the building. According to paragraph 6.22 [1], the heat losses through the internal construction shall be registered only if the temperature difference between the air of space under consideration and air of space divided with the considered location by calculated internal structure exceeds 3°C. Verification by calculation on concrete objects has confirmed the feasibility of this assumption.

Reducing the accuracy of the calculation of the heat balance of the building in the absence of accounting redistribution of heat flows through the internal enclosures, if the temperature difference between the airs of premises under consideration is equal to 3 °C or less, however, is not more than 1%.

To calculate transmission heat losses through the internal enclosing structures make up similar matrices  $\tilde{C}_i$ ,  $\tilde{F}$ ,  $\tilde{H}$ ,  $\Delta\tilde{T}$ , to matrices (6), (8), (9), (11) and (12) respectively.

For internal enclosures is acceptable to ignore thermal bridges, because there are small values of temperature pressures.

Matrix of geometric characteristics (13), matrix of the specific heat transfer (14) and the temperature differences' matrix (15) for internal enclosures look like:

$$\tilde{C}_i = \begin{pmatrix} A_{11} & A_{12} & \dots & A_{1m} \\ A_{21} & A_{22} & \dots & A_{2m} \\ A_{31} & A_{32} & \dots & A_{3m} \\ \dots & \dots & \dots & \dots \\ A_{n1} & A_{n2} & \dots & A_{nm} \end{pmatrix}, \quad (13)$$

$$\tilde{F} = \begin{pmatrix} U_1 \\ U_2 \\ \dots \\ U_m \end{pmatrix}, \quad (14)$$

$$\Delta\tilde{T} = \begin{pmatrix} (t_{\text{int}_1} - t_{\text{int}_a})_1 & 0 & 0 & 0 & 0 \\ 0 & (t_{\text{int}_2} - t_{\text{int}_b})_2 & 0 & 0 & 0 \\ 0 & 0 & (t_{\text{int}_3} - t_{\text{int}_c})_3 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & (t_{\text{int}_n} - t_{\text{int}_d})_n \end{pmatrix}, \quad (15)$$

Then total transmission heat losses will be represented by the sum of matrices of transmission heat losses through the external and internal enclosing structures (16).

$$Q_{tr,\Sigma} = Q_{tr} + \tilde{Q}_{tr}, \quad (16)$$

### Results of Testing

Existing building and its heating system was taken to test presented method for calculating the thermal capacity of the heating system. The object is a two-storey public building with a cellar. Comparison of calculations of transmission components using existing and matrix methods showed differences in the values of the transmission heat losses. This discrepancy is caused due to the averaging of linear and point thermal bridges over the area of the enclosure. Moreover, there is some loss of accuracy of the calculation that occurs when using the traditional method. For some premises deviation of the existing method from the proposed is about -9.45% in the direction of overheating. And for some another premises this deviation is 47.50% in the direction of subcooling. High percentage discrepancy is typical for areas with a little area of the external enclosures. This high percentage discrepancy is caused by a large number of linear and point thermal bridges, especially when there is of heat exchange processes with internal enclosures [4].

Also, this method allows calculating ventilation heat losses. To do this, you must make special matrices and perform their multiplication. It is possible to take into account the real pressure on the enclosures of the each premise that is important for taking into account the infiltration component. We can take into account heat costs for



heating the air entering as the result of the work of natural ventilation systems, if it is required.

### Conclusion

The developed method increases the accuracy of the calculations to determine the thermal capacity of the heating system for a whole building (little) and for each of the rooms (much). This method takes into account all specific character of modern enclosing structures, the presence of thermal bridges and the effect of ventilation systems. Matrix representation of the data provides a basis for the calculation of all supported modes of HVAC-systems with changing parameters of the environment. This corresponds to the best European trends in the area of energy saving. Matrix method is the action to increase energy efficiency by itself. Matrix method is important step towards BIM calculations of heating and cooling systems of the building.

The proposed approach for determining the heat loss of the building helps:

- to upgrade methods of determining of the thermal capacity on the heating systems in accordance with established practice, with features of modern building enclosures, with modern methods of calculation of the reduced resistance to heat transfer of buildings' enclosing structures and with requirements of standard documents.
- to improve the calculation accuracy by maximizing the integration of thermal bridges.
- to automate the work of the HVAC-engineer (the engineer does not need to perform any computing operation, so only data collection in matrices and choice of parameters, data representation).
- Now we need development and implementation of the developed method for calculating of the thermal capacity on the heating system. The first work in this direction is [4].

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