BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Tomul L (LIV), Fasc. 1–4, 2004
CONSTRUCŢII. ARHITECTURĂ

103130

D.C. 699

THE OPTIMIZATION OF HEAT-INSULATION SOLUTIONS FOR SHUTTING-OFF AND DIVIDING THE LOW-TEMPERATURE FACILITIES

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A method concerning the optimization of heat insulation solutions for shutting-off the low temperature facilities is proposed and studied.

1. Introduction

Any human activity is subject to reaching previously set goals with the least human , financial, etc., effort.

When it comes to building design, regardless of their nature and utility, the main objective is to minimize the direct expenses in parallel with meeting the quality demands: durability and stability, safety in exploitation, fire protection, hygiene, health, renewal and protection of environment, heat insulation and energy saving.

To particularize, the main objective in shutting-off and dividing spacing the low-temperature facilities is to generate those construction designs that would best meet the operating requirements of such a facility in the circumstances of minimum real costs.

2. Optimization Criteria of Heat Insulation Solutions

In order to enhance the thermal resistance of a building block, which is the safe means to reduce the waste of heat, two aspects must be considered:

a) the careful choice of heat insulating material, with lowest values possible of conduction of heat and the correct spacing of these layers;

b) the adequate determination of the optimal thickness of heat insulation.

Therefore the composing multilayer structures emerged as consequence of calculations have to be efficient from the economic viewpoint as well. To this end following further studies, it has been concluded that the spacing of the optimal thickness of heat insulation of the thermal permeability, lead to economically optimal solutions for the building block as a whole.

The specialized literature indicates calculation relations regarding the optimization of the heat insulation for shut-off devices of the buildings equipped with heat installations, relations which, due to their manner of approaching the covering parameters, cannot be applied to the calculation optimization for these heat-insulating layers of heat-control rooms.

To conclude, as a result of the fact that the literature does not offer correct solutions but only relative and incomplete methods in the case of the optimization of heat insulation, the declared purpose of this paper is to determine an appropiate calculation procedure.

Under these circumstances, we propose to discuss, in a original way, the optimization of the heat-insulating thickness for shutt-off and spacing devices of inside temperature rooms below 10°C, fitted out with freezing plants that produce cooling (refrigeration) or the freezing of products down to -40°C.

The optinization of the heat-insulating thickness consists, in principle, in minimizing the total yearly expenses, made up of investment costs and exploitation costs, refered to 1 m^2 of heat insulation.

3. The Heat Intake *via* Limiting Devices (Opaque to Solar Radiation) of a Cooling Room

Let be a cooling room which has opaque shut-off and spacing devices; the heat flow input can be calculated with relation:

$$(1)\ Q_J = Q_E + Q_I = \sum_{j=1}^{n} S_j \left[k_E(T_{sm} - t_j) + \eta\alpha_j(t_s - t_{sm})\right] + \sum_{i=1}^{n} S_i k_I (t_{am} - t_i),\quad [\mathrm{W}],$$

where: Q_E and Q_I are the heat intake *via* external devices and inner ones, respectively, [W]; $j = 1$, $i = 1...n$ - the number of structural parts (inner and external) with temperature delay; S_j, S_i - the surface of the structural part considered, [m^2]; k_E, k_I - the overall coefficient of heat-transfer pertaining to the part, [$W/m^2.°C$]; t_s - the external equivalent calculation temperature (the temperature of sunny weather), [°C]; t_{sm} - the average external equivalent calculation temperature (the average temperature of sunny weather), [°C]; t_i - the inside calculation temperature for a cooling room, [°C]; t_{am} - the inside temperature of adjoining rooms, [°C]; $\nu = 1/\eta$ - damping factor representing the ratio between the oscillation amplitude of the equivalent calculation temperature of the external face of the shut-off device (wall, terrace) and the oscillation amplitude of temperature in the internal face of device, [°C]; α_i - the inside heat transfer coefficiennt, [$W/m^2.°C$].

4. The Necessary Annual Expenses to Exploit the Freezing Plant

The annual expenses are thought for 1 m^2 of shut-off device and 1 m^2 of heat insulation respectively, and have in view the average energy expenditure. This expenditure for an external part characterized by the number of degree-days of cooling, is defined as:

$$G_r = (t_{sm} - t_i)N, \quad [°C.s]. \tag{2}$$

where: t_{sm} and t_i have the above meanings: N – the number of cooling days, [s], (during a year).

There are also considered: i_{ex} – the utilization factor (wich brings the necessary correction depending on the actual conditions of utilization); c_{ex} – the specific exploitation/utilization cost, [lei/W.s].

Therefore the relations regarding the freezing plant utilization are: a) *for external parts*:

$$C_{ex,e} = \frac{(t_{sm} - t_i)Ni_{ex}c_{ex}}{R_{iz}} = \frac{G_r i_{ex} c_{ex}}{R_{iz}}, \quad [\text{lei/m}^2.\text{year}]. \tag{3}$$

where R_{iz} is the resistance to thermal/heat permeability of the heat insulating layer, $[\text{m}^2.°\text{C/W}]$;

b) *for inner parts*:

$$C_{ex,i} = \frac{(t_{am} - t_i)Ni_{ex}c_{ex}}{R_{iz}}, \quad [\text{lei/m}^2.\text{year}]. \tag{4}$$

where t_{am} is the adjoining room inside temperature in case of inner parts: walls, ceilings, [°C], with $t_{am} > t_i$.

5. The Annual Expenses Regarding the Investiment in the Freezing Plant

The annual expenses regarding the investment in the freezing plant are the following:

a) *for external parts*:

$$A_{i,e} = \frac{(t_s - t_i)i_{ex}r_i}{R_{iz}}, \quad [\text{lei/m}^2.\text{year}]; \tag{5}$$

b) *for inner parts*:

$$A_{i,e} = \frac{(t_{am} - t_i)i_{ex}r_i}{R_{iz}}, \quad [\text{lei/m}^2.\text{year}]. \tag{6}$$

where: c_i is the specific cost of investment regarding the freezing plant, [lei/W]; r_i – the capital recovery factor depending on the average annual interest rate and on the freezing plant redemption as well as on the repair expenses.

6. The Anual Expenses (Annuity) Regarding the Investment in Heat Insulation

The annuity, A_c, related to 1 m^2 of shut-off device has the expression:

$$A_{iz} = d_{iz} r_{iz} c_{iz} = r_{iz} c'_{iz} \lambda_{iz} R_{iz}, \quad [\text{lei/m}^2.\text{year}]. \tag{7}$$

where: $d_{\rm iz}$ is the thickness of the heat-insulation, [m]; $r_{\rm iz}$ – the capital recovery factor depending on the average annual interest and on the wested capital redemption for heat insulation as well as on the repair expenses; $c_{\rm iz}$ – the specific cost of heat insulation, [lei/m^3].

7. The Determination of the Economically Optimal Resistance to Heat Permeability and of the Optimal Thickness of the Insulating Layer

The annual expenses referring to 1 m^2 of heat insulation are calculated whith relation:

$$C_{t,a} = C_{\rm ex} + A_i + A_{\rm iz}, \quad [\text{lei/m}^2\text{.year}], \tag{8}$$

where: $C_{\rm ext}$ is the necessary annual costs to utilize the freezing plant, [lei/m^2.year]; A_i – the annuity regarding the investment and the repairs of the freezing plant, [lei/m^2.year]; $A_{\rm iz}$ – the annuity regarding the heat insulation, [lei/m^2.year].

By adding relations (3), (5), (7) in relation (8) il result:

$$C_{i,o} = \frac{(t_{sm} - t_i)Ni_{ex}c_{ex}}{R_{\rm iz}} + \frac{(t_s - t_i)r_ic_i}{R_{\rm iz}} + \lambda_{\rm iz}r_{\rm iz}c_{\rm iz}R_{\rm iz}, \quad [\text{lei/m}^2\text{.year}]. \tag{9}$$

By replacing $R_{\rm iz} = d_{\rm iz}/\lambda_{\rm iz}$ into relation (9), it can be seen that, in the case of the first and second term, if $d_{\rm iz}$ tends from zero to infinity, the terms tend from infinity to zero, while the third term will rise from zero to infinity.

So, it follows that the overall annual costs referring to 1 m^2 of structural part of heat insulation, admit a minimum for a specific value of the tickness of the heat insulating layer, value that constitutes the economically optimal thickness.

This minimum occurs if the partial derivative of the function $C_{t,a}$ from relation (9) w.r.t $R_{\rm iz}$ or $d_{\rm iz}$ becomes zero:

$$\frac{\partial C_{t,a}}{\partial R_{\rm iz}} = \frac{(t_{sm} - t_i)Ni_{ex}c_{ex}}{R_{\rm iz}^2} - \frac{(t_s - t_i)r_ic_i}{R_{\rm iz}^2} + \lambda_{\rm iz}r_{\rm iz}c_{\rm iz} = 0. \tag{10}$$

It may be proved, at the same time, that the second derivative of $C_{t,a}$ w.r.t $R_{\rm iz}$ or $d_{\rm iz}$ is positive for $d_{\rm iz} = d_{\rm iz}^{\rm opt}$, which confirm that, for this value, $C_{t,a}$ is minimal.

By solving relation (10) it is obtained the resistance to heat permeability of the heat insulating layer being part of shut-off device:

a) *for external structural members* (walls, ceiling-roogs):

$$R_{\rm iz}^{\rm opt} = \sqrt{\frac{(t_s - t_i)r_ic_i + (t_{sm} - t_i)Ni_{ex}c_{ex}}{r_{\rm iz}\lambda_{\rm iz}c_{\rm iz}}}, \quad [\text{m}^2.^\circ\text{C/W}]; \tag{11}$$

b) *for internal structural members* (walls, ceilings, non-heated floors):

$$R_{\rm iz}^{\rm opt} = \sqrt{\frac{(t_{am} - t_i)r_ic_i + (t_{am} - t_i)Ni_{ex}c_{ex}}{r_{\rm iz}\lambda_{\rm iz}c_{\rm iz}}}, \quad [\text{m}^2.^\circ\text{C/W}]. \tag{12}$$

The economically optimal values of thickness resulted for the cases in discussion, are:

c) *for external structural parts* (walls, ceilings roogs):

$$d_{\text{iz}}^{\text{opt}} = \sqrt{\frac{(t_s - t_i)r_i c_i + G_r i_{ex} c_{ex}}{r_{\text{iz}}\lambda_{\text{iz}} c_{\text{iz}}}\lambda_{\text{iz}}}, \quad [\text{m}]; \tag{13}$$

d) *for internal structural parts* (walls, ceiling non- heated floors):

$$d_{\text{iz}}^{\text{opt}} = \sqrt{\frac{(t_s - t_i)r_i c_i + (t_{sm} - t_i)N i_{ex} c_{ex}}{r_{\text{iz}}\lambda_{\text{iz}} c_{\text{iz}}}\lambda_{\text{iz}}}, \quad [\text{m}]. \tag{14}$$

8. The Overall Minimum Annual Cost for 1 m² of Heat Insulation, Shut-off Device

The overall minimum annual cost for 1 m^2 of heat insulation is calculated with the following relations, depending on the shut-off device:

a) *for external parts* (walls, ceilings-roogs):

$$C_{t,a}^{\min} = \frac{(t_s - t_i)r_i c_i}{R_{\text{iz}}^{\text{opt}}} + \frac{G_r i_{ex} c_{ex}}{R_{\text{iz}}^{\text{opt}}} + \lambda_{\text{iz}} r_{\text{iz}} c_{\text{iz}} R_{\text{iz}}^{\text{opt}}, \quad [\text{lei/m}^2.\text{year}]; \tag{15}$$

b) *for internal parts* (walls, ceilings, non-heated floors):

$$C_{t,a}^{\min} = \frac{(t_{am} - t_i)r_i c_i}{R_{\text{iz}}^{\text{opt}}} + \frac{(t_{am} - t_i)N i_{ex} c_{ex}}{R_{\text{iz}}^{\text{opt}}} + \lambda_{\text{iz}} r_{\text{iz}} c_{\text{iz}} R_{\text{iz}}^{\text{opt}}, \quad [\text{lei/m}^2.\text{year}]. \tag{16}$$

The overall minimum annnual cost for 1 m^2 of shut-off device with optimal thickness of heat insulation may be calculated with relation:

$$C_g^{\min} = C_{t,a}^{\min} + C_b, \quad [\text{lei/m}^2.\text{year}], \tag{17}$$

where C_s is the minimum annual cost of the basic structure that results from calculations.

In the basic structure there are included all the layers that constitute the shut-off device, including the heat insulation.

Received, December 14, 2003
Revised, May 15, 2004

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OPTIMIZAREA IZOLAŢIILOR TERMICE PENTRU ELEMENTELE DE ÎNCHIDERE ALE SPAŢIILOR CU TEMPERATURI SCĂZUTE

(Rezumat)

Termoizolaţia din structura multistrat a elementelor de închidere şi compartimentare ale spaţiilor cu temperaturi scăzute, costituie o componentă foarte importantă, care trebuie dimensionată nu doar pe criterii tehnice ci şi pe criterii economice, întrucât acestea au implicaţii deosebite în calculul costului instalaţiei frigorifice care se dimensionează pe baza aporturilor de căldură din exterior precum şi a costului exploatării care reprezintă consumul energetic necesar obţinerii şi menţinerii temperaturilor scăzute în spaţiile cu regim termic controlat.

Se sintetizează rezultatele unor cercetări privind optimizarea grosimii izolaţiei termice din structura elementelor de închidere şsi compartimentare a spaţiilor cu temperaturi scăzute