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CHOOSING THE HEAT FLUX DENSITY NORM SIN CALCULATING HEAT SUPPLY PIPELINES CONSTRUCTIONS INSULATION WITH GIVEN GEOMETRICAL CHARACTERISTICS AND EFFICIENCY COEFFICIENT

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The article Investigates the relationship between thermal insulation surface density heat flux and thermal networkscoefficient of efficiency on the basis of its geometrical characteristics and power heat consumption for the residential development area.It also presents analytical and graphical dependencies, which allowto choose normalized heat flux density for designing insulation constructionwith an earlier pre-assigned thermal network efficiency coefficient value.

Introduction. Heat supply system efficiency is the ratio of the useful system effect to the total energy costs to acquire it. Energy spending in the heat supply system consists of the equipment actuator power consumption and the heat generation fuel consumption.

A heat supply system consists of a thermal energy source, adistribution network (heat network) and a heat consumer user-side. According to various estimates, the efficiency coefficient of the heat supply system elements under real conditions is: heat source – 80...96%, heat network – 60...92%, heat using plant – 80...95%. The energy source losses are caused by the imperfect fuel to thermal energy conversion. Energy losses in the heat networks occur due to the heat leaking into the environment and consumers' energy losses – due to the thermodynamic imperfection of the energy-consuming equipment.So, aheat supply system total coefficient of efficiency is a multiplication of the efficiency coefficients of each individual element andit ultimately equals40 to 85 percent. The weakest link of this chain is a thermal energy to heat networks transportation system.

A lot of research has been carried out to establish aplainrelationship between thethermal energy efficiency coefficient and its geometrical parameters. In particular, works [1–3] show the relationship betweenthe heat network geometrical parameters, its load and coefficient of efficiency, however a clearaccounting methodologyfor the thermal network coefficient of efficiency, when designing thermal insulation for newly created or assessing its state for existing heating systems, was not provided.

The aim of this work is to study the relationship between the efficiency of thermal insulation and a heat supplyload, connected to the source collectors, based on the geometrical characteristics of the heat network. The purpose of thermal insulation is to reduce heat losses from pipelines into the environment. The basic, most often used criteria of efficiency are the following:

- *normalized value of heat flux density;*
- *normative values of temperatures on the surface of the insulation;*
- *acceptable values of the coolant temperature drop along the length of the heat network.*

These criteria should at all timesremainin unitywith the efficiency of the whole heating system. This requires additional research, which this work is devoted to. As per tradition, let's call the efficiency of a heat supply system and its constituent elements a coefficient of efficiency (COE). Also let's take into account only its fuel component, connected to the generation of thermal energy, considering the heat source to be non-cogenerative, in regard to the area of residential development.

Theoretical substantiation and development of mathematical model study. COEof aheating network η_{mc} is the ratio of the amount of heat transmitted to consumers, $Q_{nomp,}$ to the amount of heat Q_{omn}, released into the heat network by the source:

$$\eta_{mc} = \frac{Q_{nomp.}}{Q_{omn.}} = \frac{Q_{omn.} - \Delta Q_{m.n.}}{Q_{omn.}} = 1 - \frac{\Delta Q_{m.n.}}{Q_{nomp.} + \Delta Q_{m.n.}}, \qquad (1)$$

ΔQ_{mn} is the difference between the released and consumed heat, which is equal to the heat loss in heat transport in heating systems from source to consumers.

Fig. 1 presents a graphical dependence of the network COE and theratio ofheat loss valueson the amount of heat energy released by the heat source.

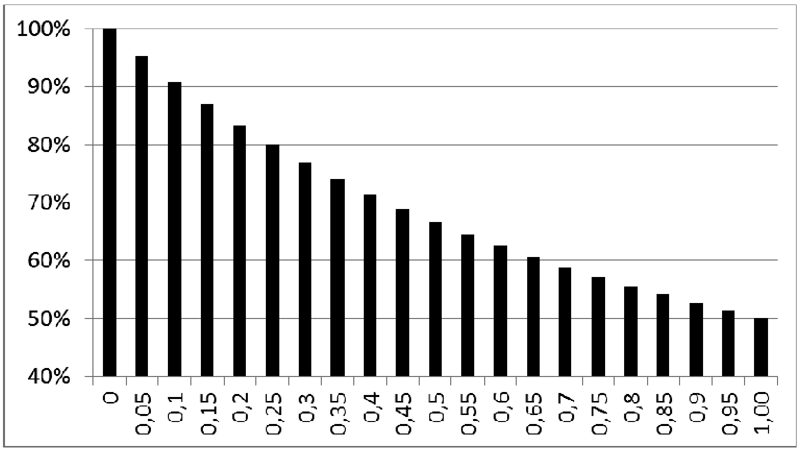

Fig. 1. Dependence of the network COE and the ratio
of heat loss values on the amount of heat energy released by the heat source.

The amount of heat loss is directly proportional the difference between thecoolant, τ_{cp}, and the environment, t_{oc}, average temperatures of the heat transfer surface and inversely proportional to the thermal resistance of the insulating structure, $R_{ик}$, averaged across the entire network, while the heat exchange surface is proportional to the length, l_i, and diameter, d_i, of the pipelines:

$$\Delta Q_{т.п} = \frac{(\tau_{ср} - t_{о.с})}{R_{и.к}} \cdot \pi \sum d_i \cdot l_i \, . \qquad (2)$$

Two complexes can be highlighted in the above expression:

$$q_F = \frac{(\tau_{ср} - t_{о.с})}{R_{и.к}} \text{ and } M = \sum d_i \cdot l_i \, . \qquad (3)$$

Here $q_f$is a heat flux density related to a singular material characteristic of the heat network, and M is a material characteristic of the network.

Performing substitution of equations (3) into equation (2) yields:

$$\Delta Q_{т.п} = q_f \cdot \pi \cdot M \, . \qquad (4)$$

The size of the heat consumption, $\Delta Q_{потр}$, included in equation (1), is defined depending on the area of the building territory, residential density, specific heat consumption values, duration of the heating period and other characteristics of district heat consumption.

In general terms, a magnitude of the accounted annual heat consumption applied to residential settlement construction can be expressed on the basis of the methodology represented in [4], as follows,$W\cdot h$:

$$Q^{год}_{потр} = a \cdot F \left[q_0 \cdot (1 + k_1 + k_1 \cdot k_2) \cdot \frac{t^p_в - t^{ср}_н}{t^p_в - t^p_{но}} \cdot n_0 + \frac{q_{гв}}{f} \cdot (n_0 + n_{но}) \right], \qquad (5)$$

and the calculated heat load [4] the following way:

$$Q^{расч}_{потр} = q_0 \cdot a \cdot F \cdot (1 + k_1 + k_1 \cdot k_2) + q_{гв} \cdot \frac{a \cdot F}{f} \, , \qquad (6)$$

q_0 and $q_{гв}$ – enlarged values of, respectively: the maximum heat consumption for heating of residential buildings at 1 m^2 of total space, W/m^2 and the average heat flow of the hot water supply for one person, W/person;

k_1 – coefficient that accounts for heat consumption on heating of public buildings;

k_2 – coefficient that accounts for heat consumption onventilation of public buildings; in the absence of specific data those are taken according to the requirements [4];

a – dwelling density, m^2/ha, taken on the basis of requirements [5];

F – gross building territory area, ha;

F – projected norm of total area per person, m^2/person;

$t^p_{но}$ $t^p_в$ $t^{ср}_н$ – the estimated internal, outdoor and the average air temperatures during the heating periodre-spectively,°*C*;

$n_{но}$ n_0 – duration of a heating and non-heating period, *h*.

Material characteristic of a thermal network when designing a mathematical model can be calculated on the basis ofthe known relations [6]

$$d_i = A_d \cdot \frac{G_i^{0,38}}{R^{0,19}};$$
$$M = \sum A_d \cdot \frac{G_i^{0,38}}{R^{0,19}} \cdot l_i; \qquad G_i = \frac{Q_{потр.,i}}{c \cdot (\tau_1^p - \tau_2^p)}; \tag{7}$$
$$M = \sum A_d \cdot \frac{Q_{потр.,i}^{0,38}}{R^{0,19} \cdot [c \cdot (\tau_1^p - \tau_2^p)]^{0,38}} \cdot l_i,$$

A_d – a coefficient dependent on the roughness of the pipes;

R – specific friction pressure loss, Pa/m;

τ_2^p, τ_1^p – calculated temperatures ofthe supplierin a supplying and reversed heating networks respectively, °C.

By generalizing equations 1–7 it is possible get a correlation between the thermal network COE, building density, normalized density of a heat flow from the surface of a thermal insulator and a physical characteristic of the network:

$$\eta_{тс} = 1 - \left\{ 1 + \frac{a \cdot F \left[q_o \cdot (1 + k_1 + k_1 \cdot k_2) \cdot \frac{t_в^p - t_н^{ср}}{t_в^p - t_{но}^p} \cdot n_o + \frac{q_{гв}}{f} \cdot (n_o + n_{но}) \right]}{q_F \cdot \pi \cdot M \cdot (n_o + n_{но})} \right\}^{-1} \tag{8}$$

The dependence following from this equation allows taking the magnitude of the normalized heat flow from the surface thermal insulation depending on the pre-assigned value ofthe heating network COE:

$$q_F = \frac{(1 - \eta_{тс}) \cdot a \cdot F \left[q_o \cdot (1 + k_1 + k_1 \cdot k_2) \cdot \frac{t_в^p - t_н^{ср}}{t_в^p - t_{но}^p} \cdot n_o + \frac{q_{гв}}{f} \cdot (n_o + n_{но}) \right]}{\eta_{тс} \cdot \pi \cdot M \cdot (n_o + n_{но})} \tag{9}$$

Study of the developed mathematical model. Based on equations 7–9, numerical investigations of the obtained mathematical model when changing its individual settings were carried out. Based on general theoretical notions, with heat loss per unit increasing and other parameters remaining constant COE of a thermal network should decrease. Increasing the length of a network and/or individual diameters of its segmentsis also expected to reduce the thermal COE of the network. Inversely, with residential density increasingand the physical characteristics of the network remaining unchanged the thermal network COEshould increase monotonically, asymptotically approaching its maximum value. The density of residential development in the model is a scale of useful heat consumption volume, whereas the density of the heat flow and physical characteristics of the network allowsto perceive the amount of heat loss into the environment.

The following studies of the mathematical model have been conducted:

1) determined the character of COE dependency on the residential development density with varying parameters of the overall network length, but with the value of pressure losses *R*, used to calculate the diameter of sections, remaining constant.

2) identified the character of the calculated heat flow values divided by the unit of material characteristics of the network from the surface of the thermal insulationinto the environment dependencyon the density of residential development at different network length and pressure losses Rremaining constant.

3) found a complex relationship between the COE of a thermal network density of residential development and normalized density of the heat flow from the surface of the insulation into the environment.

The results of numerical experiments conducted are presented graphically in Figures 2–4.

Fig. 2. Dependence of thethermal network COE on the residential development density, *a* with different values of total network sections length and *R* = const.

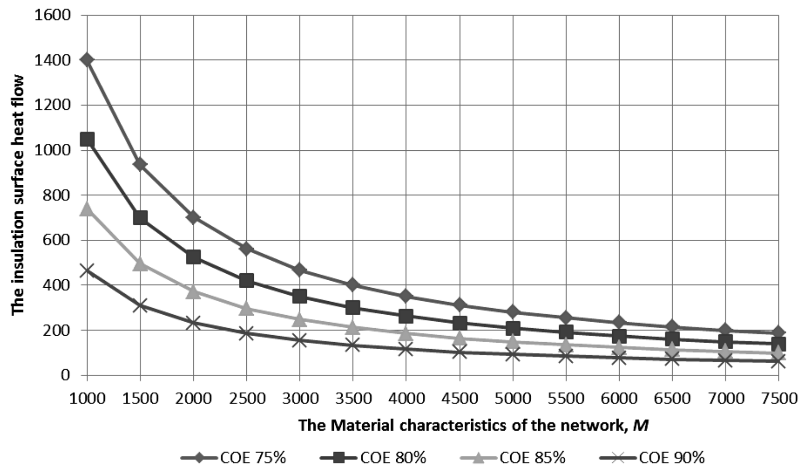

Fig. 3. Dependence of the insulation surface heat flow onthe material characteristics o f the network with different specific values of the heating network COE

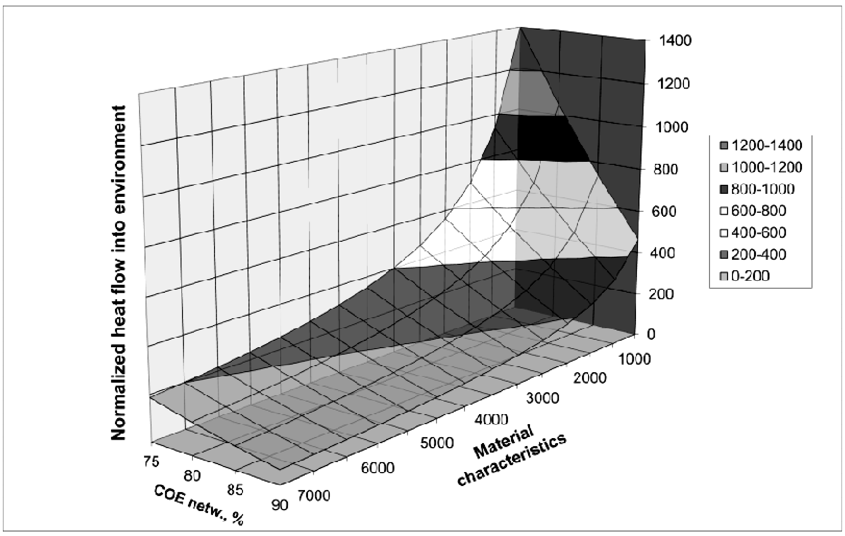

Fig. 4. Dependence of the normalized heat flow into the environment on the specificheating network COE and its material characteristics withresidential development density remaining constant

Conclusion. The results of the conducted studies show that in order to meet the requirements to the heating network COE residential development density has to be accounted for during the stage of insulation layer thickness selection. With residential development density decreasing, useful heat load of a network tends to drop as well; COE of thermal energy supply also decreases significantly. That is why values of the normalized heat flows given in [7] can only be used to a degree of finding a specific COE of the network. Thus, the COE of a heating network, along with the normalized heat flow, becomes an additional criterion which allows us to assess the quality and condition of the thermal insulation of existing conduits and an additional factor when designing newly created networks. The generalized graph provided in Figure 4 allows for adjustments to the calculations of the specific values of the normalized heat flow while taking pre-assigned COE into account.

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