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Information model of energy and economic efficiency of the capital construction object life cycle

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The potential of energy saving can be effectively realized by combining its tools with the methods of information modelling of the life cycle of a capital construction object, which determined the problem statement of this study. In this paper, the dependence of peak and average power of heating systems necessary to maintain comfortable temperature in the building on the climatic characteristics of the construction region is determined. For the dome part, the surface of which is realized in the form of a periodic sequence of elementary cells, the dependences of heat losses through the dome part of the building on the characteristics of the cells are calculated. The parameter describing the energy efficiency of space-planning solutions is determined, and its dependences on the geometric and thermophysical properties of enclosing structures are calculated. The total energy efficiency of the space-planning solution for the heating period is calculated. It is proved that energy optimization of the life cycle is possible only on the basis of heat flows through the surface of enclosing structures, linear and point thermally stressed elements (TSE) arising at the boundary of the dome part, the boundaries of the elementary cells filling the dome and on the structural elements of the triangular hemisphere or stratodesic dome. The formulated algorithms for describing all energy flows through the enclosing structures of the building made it possible to build an information model of the energy and economic efficiency of the life cycle of a capital construction object. The constructed vector information model of the energy and economic efficiency of the life cycle of a capital construction object allows solving the following practical tasks: to determine the dependence of energy costs on climatic parameters; to optimize the composition, terms of implementation and sequence of technical measures aimed at increasing the heat-insulating properties of enclosing structures and thermally stressed elements; to determine the profitability of these measures and their payback period.

Keywords: *information model, life cycle, efficiency, optimization, factors, capital construction object, thermally stressed elements*

INTRODUCTION

Taking into account the thermophysical properties of enclosing structures and climatic characteristics of the building localization allows to describe quantitatively the influence of the space-planning solution on the energy efficiency of the life cycle of a capital construction object. At the same time, it is necessary to take into account both energy flows through the enclosing structures proportional to the area of contact with the environment and the contribution of thermally stressed elements (thermal bridges) to heat losses.

However, in practice, the dome part of the enclosing structures is often structured and implemented in the form of a periodic sequence of elementary cells having the form of regular polygons. In this case, the boundaries of the cells and the points of their intersections represent additional TSE, generating additional heat loss. For buildings, the dome part of which has a radius of curvature much larger than the linear dimensions of the unit cell, individual parts of the dome can be locally considered flat, and the problem is reduced to the problem of regular parquet (mosaics) [1]. There are only three types of such parquet, the elements of which are regular triangles, quadrilaterals (squares) and hexagons.

Linear TSE occur at the interface of the structural elements of the dome part and the base, at the elements of the geodesic or stratodesic frame and at the boundaries of the parquet elements filling the surface of the dome part. The contribution of this class of thermal bridges is proportional to the extent of the corresponding boundaries. In addition, when the linear elements are coupled, additional point heat-stressed elements arise. For all regular parquet floors without gaps and overlays filling the surface of a domed building, the parameters of thermal bridges are determined by the geometric characteristics of the project, the number of sides and the size of the parquet unit cell. The parameters of the unit cell are determined by technological and economic factors, and the features of the architectural solution of the project.

Taking into account the climatic characteristics of the region where the project is implemented, the algorithm developed in this paper for quantitative description of heat flows through enclosing structures makes it possible to calculate both the peak capacities of the heating system necessary to maintain comfortable temperatures during the coldest periods and the total consumption of thermal energy during the heating period. These data make it possible to optimize space-planning and technical solutions at the design stage and calculate the dynamics of heating costs during operation. In particular, the implementation of technical measures to improve the thermal insulation properties of enclosing structures and thermal bridges can improve the energy efficiency of domed buildings, the compactness coefficient of which is far from optimal.

MATERIALS AND METHODS

Studies have shown that it is impossible to describe the energy characteristics of buildings within the framework of a geometric model and requires additional consideration of the thermophysical properties of the elements of enclosing structures. The contribution of these effects to the energy efficiency of the building is reflected in the directive document SP 50.13330.2012[1] and for some spatial planning solutions is analyzed in [2–6].

The integral heat flow through the enclosing structures is determined by three physical mechanisms with qualitatively different dependence on the geometric parameters of the structure. Firstly, there is the heat flow, the value of which is proportional to the area of the enclosing structures and the average difference in indoor temperature and ambient temperature ΔT. In accordance with the law of thermal conductivity in the static approximation and the one-dimensional temperature distribution along the axis perpendicular to the boundaries of the orthotropic structure, the power of thermal energy losses determined by this part of the heat flow is described by the equation:

$$P = \kappa \cdot S \cdot \Delta T, \qquad (1)$$

were κ is the heat transfer coefficient of N-layer building structure, expressed in terms of layer thicknesses d_i (i = 1, 2, …, N) and the thermal conductivity coefficients of materials λ_i in the form:

$$\kappa = \frac{1}{\sum_{i=1}^{N} d_i/\lambda_i}. \qquad (2)$$

In the areas of sharp geometric and thermal inhomogeneities, the so-called TSE (in English-language literature — thermal bridges) arise, leading to the emergence of additional heat flows through external enclosing structures. TSE arise, first of all, in the areas of coupling of structural elements of the enclosing structure [7]. The presence of TSE leads to a decrease in the integral energy efficiency of the building [8–10]. In addition to reducing energy efficiency in the areas of TSE, the intensity of condensate formation on the inner surface increases, leading to the development of mold, which negatively affects the health of the inhabitants [11, 12].

A highly effective method of reducing the negative impact of TSE formed at the junctions of two outer walls and the interface of the outer and inner walls is based on the addition of local layers of thermal insulation (thermal pads) [13]. Heat flows through the TSE are proportional to the lengths of the interface areas of structural elements. In addition, additional heat losses are realized at the points of intersection of the interface areas, independent of geometric characteristics. The method of calculating heat flows averaged over the area of enclosing structures is formulated in SP 50.13330.2012[1]. Simila.rules are in EN ISO 10211[2] are mandatory in EU countries.

We present the developed method for calculating the total heat energy losses during the heating period of all types (including components proportional to the areas, linear characteristics of thermal bridges and independent of geometric parameters) through the enclosing structures of perspective buildings having the shape of a spherical segment, and methods of energy optimization of space-planning solutions of such buildings.

The total power of heat losses through the areas of the spherical segment and the circular base in accordance with [14, 15] is determined by the equation:

$$P_S = 2\pi\cdot R\cdot H\cdot\kappa_s\cdot\Delta T_e + \pi\cdot H\cdot(2R-H)\cdot\kappa_b\cdot\Delta T_g = \pi\cdot H\cdot\left[2\cdot R\cdot\kappa_s\cdot\Delta T_e + (2R-H)\cdot\kappa_b\cdot\Delta T_g\right]. \qquad (3)$$

were κ_S and κ_b are the heat transfer coefficients of the structures of the spherical segment and the base, respectively;

ΔT_e and ΔT_g represent the average temperature differences of the room and the surrounding air and soil during the description intervals (hour, day, week, decade).

Let us determine the power of heat losses through enclosing structures per unit of useful volume:

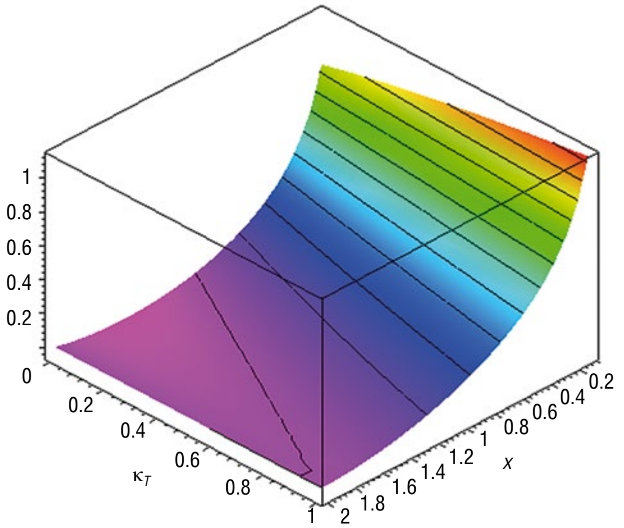
$$P_V = \frac{\pi\cdot H\left[2\cdot R\cdot\kappa_s\cdot\Delta T_e + (2R-H)\cdot\kappa_b\cdot\Delta T_g\right]}{\frac{\pi H^2}{3}(3R-H)} = \frac{3\kappa_s\cdot\Delta T_e\cdot\left[2+(2-x)\cdot\kappa_T\right]}{xR(3-x)}. \qquad (4)$$

In equation (4), the following notation of a dimensionless thermodynamic parameter is introduced:

$$\kappa_T = \frac{\kappa_b\cdot\Delta T_g}{\kappa_s\cdot\Delta T_e}, \qquad (5)$$

from a practical point of view, describing the ratio of flows through the base and the dome part.

Unlike the compactness coefficient, the position and value of the minimum of the heat loss function (5) is determined not only by the geometric characteristics of the space-planning solution, but also by the parameter κ_T. The graph of the dependence of the reduced power P_V on the geometric and thermophysical parameters is shown in Figure. The scale along the application axis is logarithmic. The beginning of the ordinate axis, from a practical point of



The dependence of the reduced power at R = 1 (the axis of the application) on the geometric parameter x (the axis of the abscissa) and the thermophysical parameter κ_T (the axis of the ordinate)

1 SP 50.13330.2012. Thermal protection of buildings (Updated version of SNiP 23-02–2009).

2 EN ISO 10211. Thermal Bridges in Building Construction: Heat Flows and Surface Temperatures. Detailed Calculations.

view, corresponds to negligible losses through the base of the building.

By appropriate choice of κ_T, which corresponds to achievement of necessary thermal insulation properties of the elements of enclosing structures, energy optimality can also be achieved for hemispherical dome part at $x = 1$. In this case, expression (5) is simplified and takes the form:

$$P_V(1) = \frac{3\kappa_s \cdot \Delta T_e \cdot (2 + \kappa_T)}{2R}, \quad (6)$$

minimized in the limit of small values of κ_T and large radii of curvature. The nature of the dependence of the specific power on the κ_T and the shape parameter x is reflected in Figure..

Dependencies (3)–(6) do not take into account losses through TSE. Now let us take into account the heat flows through thermal bridges. The interface area of the structural elements of the dome part and the base in the structure under consideration is a circle with a radius of:

$$r = \sqrt{H \cdot (2R - H)} \quad (7)$$

as a result, the power of heat losses through this linear element is determined by the equality

$$P_L = 2\pi \cdot \Delta T_g \cdot \kappa_L \cdot \sqrt{H \cdot (2R - H)}, \quad (8)$$

where κ_L is the linear coefficient of heat transfer TSE at the junction of the spherical segment and the base.

Summing up the heat loss capacities (6) and (8), we obtain the total capacity of the heating systems necessary to maintain a comfortable temperature in the building during the heating period:

$$P_{tot} = \pi \cdot H\left[2 \cdot R \cdot \kappa_s \cdot \Delta T_e + (2R - H) \cdot \kappa_b \cdot \Delta T_g\right] + \\ + \pi \cdot \Delta T_g \cdot \kappa_L \cdot \sqrt{H \cdot (2R - H)} = \\ = \pi \cdot H\left\{2 \cdot R \cdot \kappa_s \cdot \Delta T_e + \Delta T_g \cdot (2R - H) \cdot \left[\kappa_b + \frac{\kappa_L}{\sqrt{(2R - H) \cdot H}}\right]\right\}. \quad (9)$$

Formula (3) describes the parameters of the heating system of a building with homogeneous enclosing structures.

Let us consider an example of calculating the parameters of TSE of the dome part of the building with the area $S = 2\pi \cdot R \cdot H$ (3) for a parquet with an elementary cell in the form of a regular triangle with side a and area $S_3 = \sqrt{2}a^2/3$. The number of parquet tiles completely and without gaps covering the dome is equal to $S/S_3 = 3\sqrt{2}\pi \cdot R \cdot H/a^2$. The number of TSE points is equal to one third of the number of tiles, and the total length of linear thermal bridges is determined by half of the total perimeter of all tiles and, therefore, is equal to $9\pi \cdot R \cdot H/\sqrt{2}a$.

The results of calculations of the TSE parameters for all types of parquet are shown in Table 1.

The length of linear thermal bridges and the number of point TSE are normalized by multipliers $\pi \cdot R \cdot H/a$ and $\pi \cdot R \cdot H/a^2$, respectively. Linear thermal bridges and point TSE lead to additional thermal losses, the power of which is described by the equality:

$$P_{add} = \frac{\pi \cdot R \cdot H \cdot \Delta T_e \cdot (a \cdot L_i \cdot \kappa_1 + n_i \cdot \kappa_0)}{a^2}. \quad (10)$$

In equation (10) κ_1 and κ_0 are linear and point heat transfer coefficient, respectively, and the dimensionless normalized parameters L_i and n_i are taken from Table 1. Taking into account equation (3), the total power of the building's heating systems takes the form:

$$P_{tot} = \pi H \cdot \left\{R \cdot \Delta T_e \cdot \left[2\kappa_s + \frac{(a \cdot L_i \cdot \kappa_1 + n_i \cdot \kappa_0)}{a^2}\right] + \\ + \Delta T_g \cdot (2R - H) \cdot \left[\kappa_b + \frac{\kappa_L}{\sqrt{(2R - H) \cdot H}}\right]\right\}. \quad (11)$$

As can be seen from formulas (10) and (11), the contribution of linear and point TSE to energy loss decreases uniformly with the increase in the size of the unit cell and the number of sides. At the same time, the optimal cell size is limited by technological factors, and the number of sides, in addition to energy efficiency requirements, is determined by the features of the architectural solutions of the project.

The highest power is consumed in the coldest periods when the parameters ΔT_e and ΔT_g reach their maximum values. It is this capacity that should serve as a reference point in the design of engineering systems of the project. In addition, formula (11) makes

Table 1. Characteristics of the heat-stressed elements of the dome part of the building for parquet floors consisting of regular polygons with side a

Number of sides of the unit cell	Number of elementary cells	Unit cell area	Length of linear thermal bridges		Number of TSE points	
			General	Normalized	General	Normalized
3	$\frac{3\sqrt{2}\pi \cdot R \cdot H}{a^2}$	$\frac{\sqrt{2}a^2}{3}$	$\frac{9\pi \cdot R \cdot H}{\sqrt{2}a}$	$\frac{9}{\sqrt{2}}$	$\frac{\sqrt{2}\pi \cdot R \cdot H}{a^2}$	$\sqrt{2}$
4	$\frac{2\pi \cdot R \cdot H}{a^2}$	a^2	$\frac{2\pi \cdot R \cdot H}{a}$	2	$\frac{2\pi \cdot R \cdot H}{3a^2}$	$\frac{2}{3}$
6	$\frac{4\pi \cdot R \cdot H}{3\sqrt{3}a^2}$	$\frac{3\sqrt{3}a^2}{2}$	$\frac{4\pi \cdot R \cdot H}{\sqrt{3}a}$	$\frac{4}{\sqrt{3}}$	$\frac{4\pi \cdot R \cdot H}{9\sqrt{3}a^2}$	$\frac{4}{9\sqrt{3}}$

it possible to conduct an economic audit of the project, based, in particular, on the assessment of the cost of measures to increase the thermal insulation of the elements of enclosing structures and reduce the cost of consumed thermal energy.

Energy efficiency of space-planning solutions is characterized by the specific power of heating systems per unit of useful volume of the building, and, in accordance with equations $V=\pi H^2/3\cdot(3R-H)$ [14] and (11), is equal to:

$$P_V=\frac{3}{H\cdot(3R-H)}\times\left\{R\cdot\Delta T_e\cdot\left[2\kappa_s+\frac{(a\cdot L_i\cdot\kappa_1+n_i\cdot\kappa_0)}{a^2}\right]+\right.$$
$$\left.+\Delta T_g\cdot(2R-H)\cdot\left[\kappa_b+\frac{\kappa_L}{\sqrt{(2R-H)\cdot H}}\right]\right\}. \quad (12)$$

Introducing the following designations for the specific loss capacities through all elements of the dome part of the enclosing structure and the base, occurring per one degree of temperature difference, we define:

$$P_C=\frac{3R}{H\cdot(3R-H)}\cdot\left[2\kappa_s+\frac{(a\cdot L_i\cdot\kappa_1+n_i\cdot\kappa_0)}{a^2}\right]; \quad (13)$$

$$P_B=\frac{3(2R-H)}{H\cdot(3R-H)}\cdot\left[\kappa_b+\frac{\kappa_L}{\sqrt{(2R-H)\cdot H}}\right]. \quad (14)$$

Let us express the indicator of the current energy efficiency of the space-planning solution in the form of:

$$P_V=P_C\cdot\Delta T_e+P_B\cdot\Delta T_g. \quad (15)$$

The total energy efficiency of the space-planning solution for the heating period can be obtained by summing up the values of current indicators for the intervals of determining average temperatures, in the form of:

$$Q_V=\sum_{t=t_b}^{t_f}\left[P_C\cdot(T_{in}-T_{out})+P_B\cdot(T_{in}-T_g)\right]=$$
$$=(P_C+P_B)\cdot\Delta t_{heat}\cdot T_{in}-\sum_{t=t_b}^{t_f}\left[P_C\cdot T_{out}+P_B\cdot T_g\right]. \quad (16)$$

The following notation is used in equation (16):

T_{in} — room temperature (for rooms of different purposes is determined by sanitary standards);

T_{out} — average outdoor temperature for the evaluation periods (hour, day, week, depending on the details of the description);

T_g — average ground temperature for the assessment periods;

t_b, t_f — the number of the period of the beginning and end of the heating season, respectively;

Δt_{heat} — duration of the heating season.

The formulated algorithms for describing energy flows through the building's enclosing structures allow us to build an information model of the energy and economic efficiency of the life cycle of a capital construction object. The composition, dimension and formats of the input data are determined by the technical content of the corresponding components and are given in Table 2 and 3.

In Table 2, the data format of the first row is whole, the rest of the data is valid. The data designations in lines 2–8 coincide with the designations in (1)–(5). The data contained in line 4 describe only heterogeneous dome structures.

Table 2. Technical parameters of the information model of space-planning solutions

Number	Content	Dimension	Class
1	The number of sides of the unit cell	Dimensionless	Geometric
2	R	m	
3	H		
4	a		
5	κ_S	W/sq. m×K	Thermophysical
6	κ_b		
7	κ_L	W/m×K	
7	κ_1		
8	κ_0	W/K	
9	Specific price of thermal energy	rub/W	Economic

In Table 3, parameter C is the unit costs (per unit of thermal power savings) for technical measures aimed at reducing energy consumption in the heating system. The data contained in co. 3 describes the specific cost of technical and technological measures carried out according to the results of an energy audit in the process of capital repairs or reconstruction and aimed at reducing the corresponding heat transfer coefficients of structures and energy costs (co. 2). Co. 5 shows the total duration of heating periods for the period of technical operation of the corresponding elements.

The information model also makes it possible to optimize not only the technical, but also the economic parameters of the project. At the design stage, summing up the cost of the energy carrier for the heating period:

$$G_{tot}=C_e\sum_{t=t_b}^{t_f}P_{tot}(t), \quad (17)$$

where C_e is the unit cost of the energy carrier, we will determine the total cost of heating for the season.

Similarly, the total economic efficiency of the space-planning solution of the object for the heating period is equal to the sum of the values of the current indicators of energy costs:

Table 3. Economic parameters of the information model of space-planning solutions

Number	Reduction of the thermophysical parameter	Unit cost of reduction	Dimension	Period of operation
1	$\Delta\kappa_S$	c_s	W/sq. m×K	τ_S
2	$\Delta\kappa_b$	c_b		τ_b
3	$\Delta\kappa_L$	c_L	W/m×K	τ_L
4	$\Delta\kappa_1$	c_1		τ_1
5	$\Delta\kappa_0$	c_0	W/K	τ_0
9	Unit costs of reducing power consumption	C	rub/W	τ_p

$$Q_V = C_e \sum_{t=t_b}^{t_f} \left[P_C \cdot \Delta T_e(t) + P_B \cdot \Delta T_g(t) \right]. \qquad (18)$$

Replacing the heat transfer coefficients in (5) with the corresponding specific reduction costs (co. 3 of Table 3) and adding the costs of improving the heating system, we obtain expressions for one-time costs for technical measures to improve the thermophysical properties of the project in the form:

$$C_{tot} = \pi H \cdot \left\{ R \cdot \Delta T_e \cdot \left[2\kappa_s + \frac{(a \cdot L_i \cdot c_1 + n_i \cdot c_0)}{a^2} \right] + \Delta T_g \cdot (2R - H) \cdot \left[c_b + \frac{c_L}{\sqrt{(2R-H) \cdot H}} \right] \right\} + ! . \qquad (19)$$

On the other hand, replacing the heat transfer coefficients in formula (5) with their reduction (co. 2 of Table 3) allows us to calculate the amount of reduction in heat consumption:

$$\Delta P = \pi H \cdot \left\{ R \cdot \Delta T_e \cdot \left[2\kappa_s + \frac{(a \cdot L_i \cdot \Delta\kappa_1 + n_i \cdot \Delta\kappa_0)}{a^2} \right] + \Delta T_g \cdot (2R - H) \cdot \left[\Delta\kappa_b + \frac{\Delta\kappa_L}{\sqrt{(2R-H) \cdot H}} \right] \right\}. \qquad (20)$$

Summing up the values of the reduction coefficients for the periods of operation of the corresponding elements:

$$\mathrm{K}_i = \min\left[\tau_p, \tau_i \right] \cdot \Delta\kappa_s. \qquad (21)$$

and substituting the result into formula (5), we get the total energy savings during the project implementation:

$$\Delta Q = \pi H \cdot \left\{ R \cdot \Delta T_e \cdot \left[2\kappa_s + \frac{(a \cdot L_i \cdot \mathrm{K}_1 + n_i \cdot \mathrm{K}_0)}{a^2} \right] + \Delta T_g \cdot (2R - H) \cdot \left[\mathrm{K}_b + \frac{\mathrm{K}_L}{\sqrt{(2R-H) \cdot H}} \right] \right\}. \qquad (22)$$

Formula (22) takes into account that the operating time of individual elements, the modernization of which is carried out during major repairs or reconstruction, may formally exceed the project implementation time.

The total savings from technical energy — saving measures are determined by the expression:

$$\Delta C_{tot} = C_e \cdot \Delta Q. \qquad (23)$$

Comparison of costs (19) and savings (23) determines the profitability of technical energy-saving measures and their payback period.

Conclusions and prospects of research. Thus, the information model based on the data contained in Table 2 allows us to calculate and optimize the consumption of stored and non-stored resources necessary for the implementation of the project. The scope of applicability of the model can be significantly expanded with additional consideration of climate information describing the localization region of the project.

In this case, in accordance with formulas (3)–(6) and (10), the following tasks can be solved:

- at the design stage of engineering networks, the parameters of the heating system can be determined, which make it possible to guarantee comfortable temperature in standard climatic conditions and redundancy parameters in extreme conditions;
- the information model makes it possible to calculate the energy effect of using various types of elementary cells of the dome part of the enclosing structure;
- with additional accounting of the specific price of thermal energy, the information model allows you to calculate the dynamics of energy costs in both standard and extreme conditions;
- taking into account the data contained in co. 5 of Table 3, the model allows us to evaluate the energy efficiency of technical measures aimed at increasing the thermal insulation properties of all elements of enclosing structures, and optimize the composition, timing and sequence of these measures.

The information model also makes it possible to optimize the economic parameters of the project.

Supplementing the base of the information model with economic data makes it possible to expand the scope of its practical application. At the operational stage, the extended model allows us to calculate the dependence of energy costs on climatic parameters. At the stage of reconstruction, such information model makes it possible to optimize the composition, timing of implementation and sequence of technical measures aimed at increasing the heat-insulating properties of enclosing structures and thermally stressed elements, to determine the profitability of these measures and their payback period.

Further development of the information model involves the study of alternative methods of structuring the surface of the dome part. For this purpose, it is necessary to develop methods for describing heat-stressed elements for semi-regular and irregular parquet floors and rational methods for filling spherical surfaces with heterogeneous cells. In addition, it is necessary to develop methods for calculating losses through heat-stressed elements of the triangular hemisphere and stratodesic dome.

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Информационная модель энергетической и экономической эффективности жизненного цикла объекта капитального строительства

Потенциал энергосбережения может быть эффективно реализован при сопряжении его инструментария с методами информационного моделирования жизненного цикла объекта капитального строительства, что и определило постановку задачи данного исследования. В данной работе определена зависимость пиковой и средней мощности систем отопления, необходимой для поддержания комфортной температуры в здании, от климатических характеристик региона строительства. Для купольной части, поверхность которой реализована в виде периодической последовательности элементарных ячеек, рассчитаны зависимости тепловых потерь через купольную часть здания от характеристик ячеек. Определен параметр, описывающий энергетическую эффективность объемно-планировочных решений, и рассчитаны его зависимости от геометрических и теплофизических свойств ограждающих конструкций. Рассчитана полная энергоэффективность объемно-планировочного решения за отопительный период. Доказано, что энергетическая оптимизация жизненного цикла возможна только на основе учета тепловых потоков через поверхность ограждающих конструкций, линейные и точечные термонапряженные элементы (ТНЭ), возникающие на границе купольной части, границах элементарных ячеек, заполняющих купол, и на конструктивных элементах триангулярной полусферы или стратодезического купола. Сформулированные алгоритмы описания всех энергетических потоков через ограждающие конструкции здания позволили построить информационную модель энергетической и экономической эффективности жизненного цикла объекта капитального строительства. Построенная векторная информационная модель энергетической и экономической эффективности жизненного цикла объекта капитального строительства позволяет решить следующие практические задачи: определить зависимость затраты на энергоносители от климатических параметров; оптимизировать состав, сроки реализации и последовательность технических мероприятий, направленных на увеличение теплоизолирующих свойств ограждающих конструкций и термонапряженных элементов; определить рентабельность этих мероприятий и срок их окупаемости.

Ключевые слова: *информационная модель, жизненный цикл, эффективность, оптимизация, факторы, объект капитального строительства, теплонапряженные элементы*

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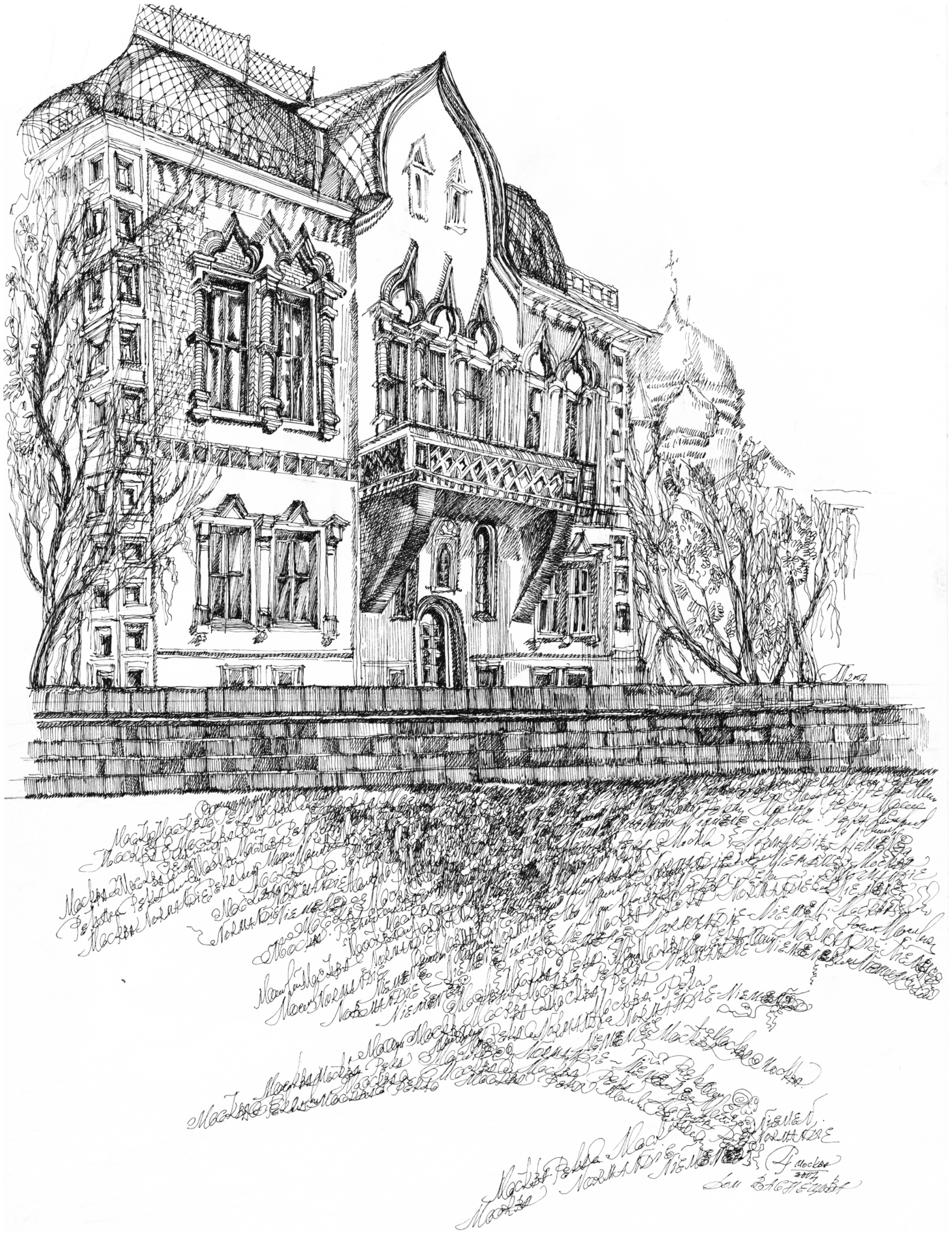

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