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INFLUENCE OF THE OUTSIDE CLIMATE PARAMETERS ON THE SELECTION OF THE OPTIMUM COMBINATION OF THE ENERGY SAVING MEASURES

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Abstract. In this paper the influence of climatic parameters of building region on expedient depth of implementation of different ways of energy consumption decrease in civil buildings is reviewed. The data of multivariate calculations of power and technological efficiency of an adopted complex of energy saving measures for reference climatic zones of the terrain of Russia in modern economic conditions with allowance for discounting of costs are adduced. The analysis of the obtained outcomes is given and the guidelines are also offered at the choice of optimum combination of the solutions on a decrease of power inputs at exploitation of a building depending on the number of degree-days of the heating season, as well as on established prices for stuffs both equipment and fares on power supplies.

Keywords: energy consumption, energy saving, discounted payback term, thermal insulation, heat recovery, sustainable development and economy.

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1. Introduction

The construction industry is one of the largest in the world. The building sector consumes some 40% of the European final energy. This sector has great potentials for energy savings since much energy devoted to the built environment is not efficiently used. Most of the overall energy is required during the buildings' operational life and it primarily covers heat-

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ing and cooling, hot water and electricity demand (Institute … 2007). The necessity of a comprehensive approach to the implementation of energy and resource saving measures at designing, building and exploitation of buildings and, first of all, of systems of maintenance of their microclimate is not a subject to doubt and is conditioned mainly by the reduction of reserves of mineral raw materials and mineral organic fuel and, as a consequent, their constant rise in price.

Buildings' renovation could be developed by different ways considering sustainable development and economy (Kaklauskas *et al.* 2006; Martinaitis *et al.* 2007; Mickaitytė *et al.* 2008; Zavadskas *et al.* 2008a, b; Ginevičius *et al.* 2008). Taking into a view only economical and energy saving sides, that issue is not acceptable because of wide multipurpose role of civil engineering in our days. For the solution of the question about the selection of optimum combination of energy saving measures in public buildings, as well as depth and the sequences of their implementation multivariate calculations were conducted with the help of Excel spreadsheets that permit to recalculate automatically all power and overall economics of a building at a change of those or diverse data-ins (Samarin *et al.* 2007a).

2. Methods

Thus the technique of the National voluntary consensus building thermal protection standard developed by Russian Scientific and Technical Civil Engineers Organization (Rus. Sci. Tech. C.E.O.) (National … 2006) was utilized, in the mining of which one of the writers received direct participation, and its further development permits to evaluate economic efficiency of an adopted complex of engineering decisions, set up by the writer in a number of activities, including in (Samarin *et al.* 2007b). The purpose of calculations was an estimation of general padding capital costs I, RUR, indispensable on the implementation of a complex of energy saving measures, and conforming annual saving of expense on a thermal energy O, RUR/year, at a different degree of increase of heat-shielding properties of transparent and non-transparent enclosures and variable temperature efficiency of heat recovery devices. It enables to determine the relation of discounted term of payback T_d, years, for considered combination of engineering decisions from the depth of their implementation and to select thereby optimum version. Such term is determined under the formula (1) (Dmitriev *et al.* 2005):

$$T_d = \frac{-\ln\left(1 - pT_0/100\right)}{\ln\left(1 + p/100\right)} \quad , \tag{1}$$

where T_0 = I/O is the payback time without discount, years; p is the discount norm, %. In calculations it was taken equal to 11.5% annual pursuant to the bet of the Russian Federation Central Bank established since June 26, 2006.

3. Results and discussion

On Fig. 1 the continuous line shows the schedules for a Current at the change in the relation of resistance to heat transfer of non-transparent enclosures R_2/R_1 before and after additional thermal insulation in limits from 1.5 up to 3 in climatic conditions of Moscow. The degree of the increase in heat protection of the windows $(R_2/R_1)_w$ in relation to a floor adequate sanitary-hygienic requirements, was established at a rate of 1.25 (caplines), 1.5 (mean) and 2.0 (lower). The factor of temperature efficiency of the heat recovery devices k_{ef} in the given calculation was adopted greatest possible for vehicles with intermediate heat carrier, i.e. 0.5. The costs of automatic temperature controllers for heating devices were considered as constants, since for fullest usage internal heat ingress and on technological reasons the temperature regulators owe to set for each device, except for staircases and other similar putting. At the same time the number of heating devices, as against their power, is determined by a design of a system and, in the final accounting, design of a building, and practically does not depend on heat protection of enclosures. The consumptions on a padding thermal insulation were calculated with allowance for its depth and constant costs irrelevant with depth of a heat insulation layer, on a technique (National … 2006). The costs of a glazing replacement were adopted as a first approximation by proportional degree of increase of its resistance to heat transfer $(R_2/R_1)_w$, and the cost of the heat recovery equipment at change k_{ef} estimated by a linear interpolation, outgoing from value of minimum costs (at $k_{ef} = 0$), equal approximately 50% from as much as possible for $k_{ef} = 0.5$.

From Fig. 1 it is visible, that with the growth of heat-shielding properties of windows the term of payback monotonically decreases, therefore it is expedient to use windows with as much as possible better probable level of heat protection, accessible for designs of quantity

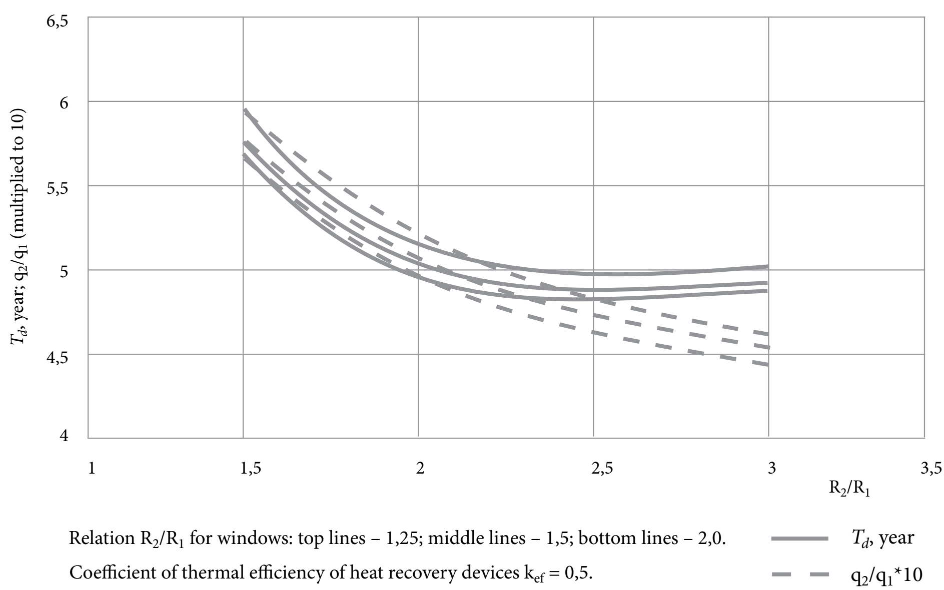

Fig. 1. Dependence of the discounted payback term for the combination of energy saving measures T_d and of relative energy consumption after their realization q_2/q_1 on the increase of thermal resistance of non-transparent enclosures R_2/R_1 for Moscow

production, down to $R_w = 0.8$ ($m^2 \cdot K$)/W. As to the heat recovery devices, it is possible to show, that the calculations at lower k_{ef} will give higher values a Current, and as with monotonic relation; therefore, here again it is necessary to receive best technically possible level $k_{ef} = 0.5$. The given outcome is explained to that the amplification of heat recovery and thermal resistance of transparent enclosures is fast and it essentially reduces power inputs at enough small padding investments. Besides, if we compute relative energy consumption of a building after the implementation of energy saving measures q_2/q_1, the value $q_2/q_1 < 0.5$, i.e. is easy to see, that is desirable for us. Decrease of power inputs not less than twice (National ... 2006), at $k_{ef} = 0.4$ and less, as a rule, is inaccessible. As if to a padding thermal insulation of transparent enclosures, on Fig. 1 there is a legible minimum a Current at (relation R_2/R_1, approximately equal 2.4 … 2.5, practically irrespective of value $(R_1/R_2)_w$. In conditions of Moscow for outside walls it corresponds to a level R_2 of the order 2.2 … 2.3 ($m^2 \cdot K$)/W for the buildings of the 1-st category of heat protection, and 1.9 … 2.0 ($m^2 \cdot K$)/W – for the buildings of the 2-nd category. As a whole it is close values obtained earlier at calculations for different buildings on a considered technique, and is significant (on 25–30%) below, than it is offered in the operational normative documents (Design code II-3-79*, 1998; Design code 23-02-2003, 2003), (3.15 and 2.7 ($m^2 \cdot K$)/W)).

However, there is essential concern, as the obtained conclusions in diverse climatic conditions will change, as in terrain of Russian Federation by virtue of its large expansion there are locales with parameters of an outside climate considerably distinguished from the reference for Moscow. For this purpose calculus is executed on the reviewed above technique for two cities of Russian Federation being the representative quotes of settlements, arranged in a zone of an Extreme North and South of Russia, namely Vorkuta and Krasnodar. The climatic parameters of these cities adopted pursuant to (Design code 23-01-99 2000), were already utilized by the writer in activity (Samarin 2004) at the analysis of the main errors of the document (Design code 23-02-2003 2003), therefore for unity both comparability of outcomes and received conclusions it is expedient to prolong calculus just for the conditions of the data of locales.

It is possible to make following conclusions by the analysis of the outcomes of the calculation for Vorkuta (Fig. 2). At first, the values a Current in all range of considered parameters appear much below than for Moscow, and even at $k_{ef} = 0.3$ (on the schedule are not shown) do not exceed 4–4.3 years, and at the greatest possible of heat recovery degree make approximately 3–3.2 years. At the same time optimum till a Current the ratio R_2/R_1 for non-transparent enclosures remains practically the same, as well as in the conditions of Moscow, and even it is less little, falling in an interval 2.1 … 2.3.

It corresponds to a level R_2 for outside walls of the order 2.45 … 2.7 ($m^2 \cdot K$)/W) for the buildings of the 1-st category on heat protection, and 2.3 … 2.5 ($m^2 \cdot K$)/W) – for buildings of the 2-nd category, and the gap that is offered in the operational normative documents (Design code II-3-79* 1998; Design code 23-02-2003 2003) (4.5 and 3.85 ($m^2 \cdot K$)/W)), it appears much more considerable than in central regions of Russian Federation and reaches 32–45%.

The obtained decrease of heat protection in comparison to the demanded in Design code 23-02-2003 (adopted in 2003) is near to low limit in 37% enabled Design code 23-02-2003 at limitation common energy consumption of a building for the heating season. Therefore, prob-

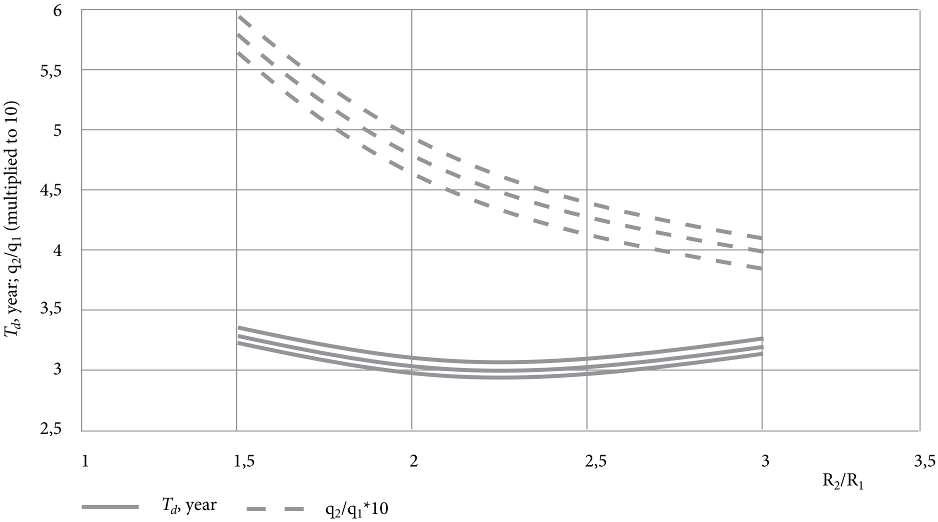

Fig. 2. The same to Fig. 1, but for conditions of Vorkuta

ably, reasonable level of heat protection of non-transparent designs, especially for northern regions, is just such – minimally permissible on Design code 23-02-2003.

The decrease of payback time of a complex of energy saving measures for the conditions of Vorkuta is uneasy to explain if to take into account that at the same depth of implementation of energy saving measures an absolute energy consumption decrease here will be higher than in Moscow because of more continuous heating season and its lower mean temperature. Annual saving of expense on thermal energy, therefore, increases as well. At the same time padding capital costs though will be increased but in a much smaller degree. The matter is that the consumptions on heat recovery depend basically on the output of the incoming and exhausting installations, i.e. on an air exchange in a building, which one is determined by assigning of an object and varies from region of building a little. The costs of replacement of a glazing at a given initial and final design of windows too are connected only to the area of windows. The cost of automatic temperature regulators depends on the number of heating devices, i.e. besides from the design characteristics of a building and its engineering systems, but not on their power. And only the volume and cost of a thermal insulation in northern regions will be somewhat more than in the center of Russian Federation, as the difference $(R_2–R_1)$ is augmented not too considerably. As to padding increase of capital costs, bound with the rise in price of stuffs and equipment in considered region as contrasted to by Moscow; it is compensated practically and even with a surplus for high rates on thermal energy.

Thus relative energy consumption for version with a complex of energy saving measures q_2/q_1 lies in the same ranges and varies approximately the same as for Moscow. It is connected just to the same adopted depth of the implementation of energy saving measures, owing to what the relative energy consumption decrease on each of components of balance will be save. However, descends to increase R_2/R_1 decreasing q_2/q_1 a little slower, basically because of smaller heat ingress from a solar radiation; therefore demanded level $q_2/q_1 < 0.5$ for $k_{ef} = 0.5$

is reached at a little bit higher ratio $R_2/R_1 = 2.1 \dots 2.5$. However, in any case, it almost coincides optimum range R_2/R_1 from the technological point of view obtained, outgoing from the minimization of value a Current. Therefore, most expedient degree of increase of heat protection of non-transparent enclosures ensuring in conditions of an adopted complex of engineering decisions a meeting the requirements as till a Current, and on q_1/q_2, is saved within the limits of 2.1 … 2.3. All other conclusions concerning necessity of the heat recovery device with as much as possible $k_{ef} = 0.5$, equipment of the greatest possible quantity of heating devices by temperature regulators and the installations of a glazing with the best resistance to heat transfer among mass designs for Vorkuta, and also concerning transportability of different energy saving measures save the force. In particular, with reduction k_{ef} an optimum level R_2/R_1 a little is augmented, and at $k_{ef} = 0.3$ it already makes about 2.2 … 2.5, though also these values lie in the same limits, as in the previous case.

If we address to the outcomes of calculations executed for the conditions of Krasnodar (Fig. 3), it is easy to see that on value of payback time of an adopted complex of engineering decisions they differ from the data for Moscow in the counter party. The lowest value the Current here makes 7–7.5 years, and it already makes about half of computational duration of exploitation of the equipment with a minimum term of a service, namely for heat recovery and automatic temperature controllers. The explanation here is the same as for Vorkuta, i.e. annual economies of costs on thermal energy because a shorter and milder heating season is reduced much stronger than padding capital investments. Apparently, there is a rather legible connection between a Current and computational climatic characteristics of an area of building, for example, degree-day of the heating season D_d, and it is possible to discharge their limiting value, since which one at an existing price level and fares the application of a complex of energy saving measures is expedient.

On Fig. 4 the graph of minimally possible value a Current from D_d under the data of calculus for the three reviewed cities as well as for Novosibirsk is adduced.

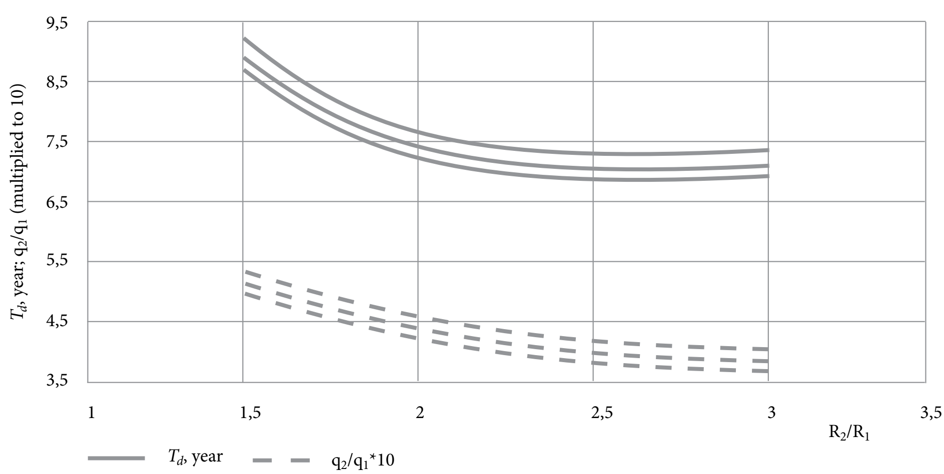

Fig. 3. The same to Fig. 1, but for conditions of Krasnodar

It is easy to see that with the increase of D_d, term of payback monotonically descends with some de-boosting in more northern regions. Thus, the curve on the schedule is well approximated by the following formula:

$$T_d = 10.4 - 1.4\left(\frac{D_d}{1000}\right) + 0.07\left(\frac{D_d}{1000}\right)^2. \quad (2)$$

Therefore, if we are interested in the circumstances when the adopted combination of engineering decisions is poorly wasteful and fast paid back, that the $T_d < 5$ years is determined by a condition, Fig. 4 gives quite a clear answer: for this purpose of D_d should be not less than 4500–5000.

As to optimum increase of resistance to heat transfer of non-transparent enclosures for the conditions of Krasnodar, here this value as a whole is in the same limits, as well as for other locales, that once again confirms justice of a used technique of optimization of heat protection. However, and in this case deviation (rejection) from outcomes obtained for Moscow appears inverse as contrasted by Vorkuta: the most expedient level of relation R_2/R_1 is moved in the party of higher values and lies in range 2.5 … 2.7. However, because of smaller basic value R_1 an absolute value R_2 remains all the same below demanded on to the operational standards (Design code II-3-79* 1998; Design code 23-02-2003 2003) and makes for outside walls about 1.9 … 2.0 $(m^2 \cdot K)/W$) in buildings of the 1-st category and 1.65 … 1.75 – for buildings of the 2-nd category. The documents (Design code II-3-79* 1998; Design code 23-02-2003 2003) give for these cases accordingly 2.35 and 1.9 $(m^2 \cdot K)/W$), i.e. the best value appears less existing normative approximately on 8–20%. But this decrease is not so notable as in the conditions of Moscow and, especially, of Vorkuta. To explain such behavior of relation R_2/R_1 it is possible, probably, just by a decrease of basic value R_1, owing to what absolute volume of a thermal insulation and, accordingly, the costs on thermal insulation of non-transparent enclosures will be rather small even at essential relative increase of resistance to heat transfer.

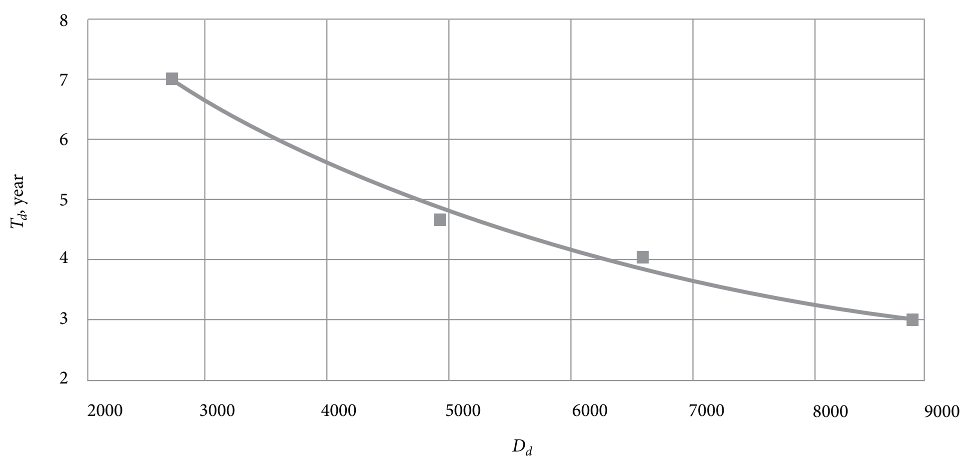

Fig. 4. Dependence of minimal value of T_d from D_d

But in southern regions in a larger extent general energy consumption of a building decreases, and desirable for us the value $q_2/q_1 < 0.5$ for $k_{ef} = 0.5$ is reached already at $R_2/R_1 = 1.6 \dots 1.8$, and even for $k_{ef} = 0.3$ it is possible to receive $q_2/q_1 < 0.5$ at not too large value $R_2/R_1 = 1.9 \dots 2.3$. It is explained by a higher lobe of heat ingress from a solar radiation in a general energy balance of a building. However, thus the gap between expedient ranges R_2/R_1, is chosen on conditions of limitation q_2/q_1 and minimization a Current increases, which once again testifies to considerable complexities in the feasibility report of an adopted complex of measures in milder climatic conditions.

On Fig. 5 the change of relation $R_{2.opt}/R_{2.cod}$ of optimum resistance to heat transfer of non-transparent enclosures for combination of energy saving engineering decisions on a condition of minimization a Current to demand in the operational normative documents (Design code II-3-79* 1998; Design code 23-02-2003, 2003) depending on D_d is shown. The continuous line falls into the buildings of the 1-st category on heat protection, dashed – to buildings of the 2-nd category. It is visible that the schedules on Fig. 5 visually mirror described above regularity of a gradual decrease with the increase of D_d optimum on technological reasons of heat protection as contrasted to normative. Thus in area $D_d < 8000$ such decrease lie within the limits of 37% enabled by the document (Design code 23-02-2003. 2003) for outside walls, and at further increase D_d it is stabilized at a level about 40% or hardly is less.

However, curves on Fig. 5 are actually related to any non-transparent enclosures and the calculations demonstrate that a divergence between relations $R_{2.opt}/R_{2.cod}$ for walls, covers and overlaps at the same D_d do not exceed line width on the schedule. Or else, the limitation of a decrease of heat protection for covers and overlaps by value all in 20% established in

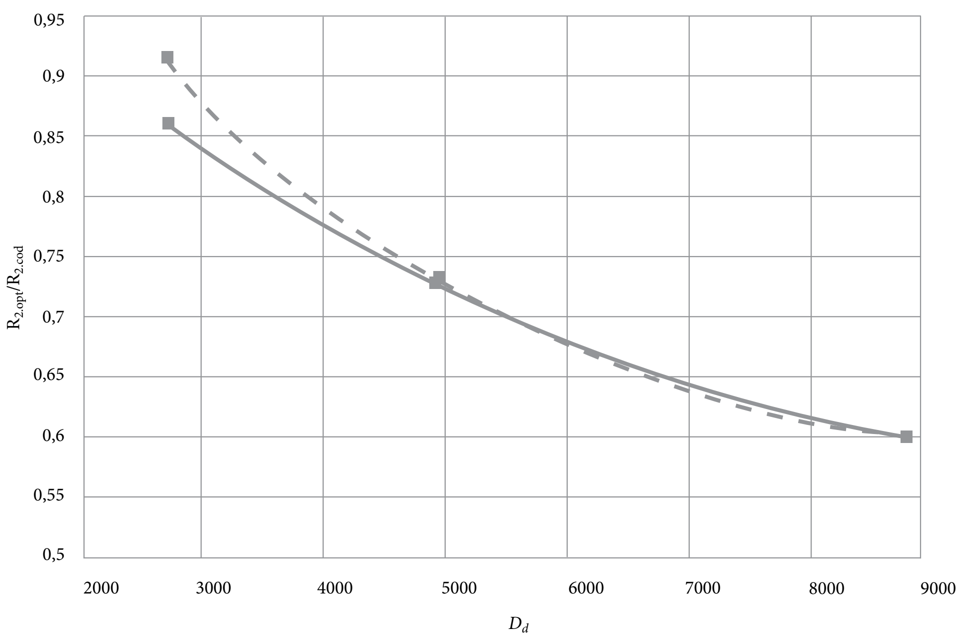

Fig. 5. Dependence of relation $R_{2.opt}/R_{2.cod}$ from D_d.

Design code 23-02-2003, from the technological point of view is unjustified, and from the point of view of thermal safety is needless, as even after a decrease the heat protection will be essential to exceed a sanitary-hygienic level. Moreover, Fig. 5 demonstrates that an essential difference in this problem between buildings of the 1-st and 2-nd category, and only at $D_d < 3000$, which in Russian Federation takes place only in Krasnodar region, the straddling reaches 5%. But it also lies in the limit of accuracy of customary engineering calculations and that is why is unessential.

4. Conclusions

We can confirm that climatic parameters of the greater part of terrain of Russian Federation, except for the regions lying in a southwest from a line "St.-Petersburg–Smolensk–Voronezh–Saratov", let arrive the payback term of the considered energy saving measures less than five years.

Therefore, at a meeting requirements of thermal safety the problem on selection of a concrete level of heat protection should be decided by extremely technological calculation on the basis of integrated estimation of power and economical efficiency of all complex of the adopted engineering solutions, and any predetermined limits of a permissible decrease of resistance to heat transfer, except for flowing out from sanitary-hygienic conditions do not have to be applied.

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KLIMATO IŠORĖS PARAMETRŲ ĮTAKA OPTIMALIAM ENERGIJĄ TAUPANČIŲ PRIEMONIŲ DERINIUI

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Santrauka

Straipsnyje išnagrinėta statybos rajono klimato parametrų įtaka tikslingam įvairių energijos taupymo būdų taikymui visuomeninės paskirties pastatuose. Pateikiami energetinio ir techninio-ekonominio skirtingų energijos taupymo priemonių komplekso variantų, charakteringų Rusijos teritorijos klimato zonoms šiuolaikinėmis ekonominėmis sąlygoms, įvertinant sąnaudų diskontavimą, skaičiavimo duomenys. Atlikta gautų rezultatų analizė ir pasiūlytos rekomendacijos, kaip pasirinkti optimalų energijos sąnaudų mažinimo derinį eksploatuojant pastatus, priklausomai nuo šildymo periodo dienolaipsnių ir galiojančių medžiagų, įrengimų ir šilumos tiekimo tarifų kainų.

Reikšminiai žodžiai: energijos vartojimas, energijos taupymas, diskontuotas atsipirkimo laikas, šiluminė izoliacija, šilumos atgavimas, darni plėtra.

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