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Thermal mode of a room with integrated regulation of microclimate systems

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Abstract. An air-conditioned room with automatic regulation of its microclimate systems using complex control algorithms is one of the most complex objects for calculating non-stationary thermal regime, so this mode is still insufficiently studied. At the same time, such facilities are typical for providing internal weather parameters in civil buildings. In this paper, we consider a simplified mathematical formulation and solution to the problem of changing the temperature of internal air in a room equipped with a back-ground supply ventilation system and automated local cooling systems under variable thermal effects. The main equations connecting the most important components of the heat flow in the room are analyzed, given we neglect the heat accumulation of the array of fences in the first approximation. The dependence on time for the deviation of the room air temperature from the setpoint and the expression for the moment of time at which the maximum temperature deviation is observed, when the heat flow changes abruptly and the equipment of local cooling systems is regulated according to the integral law are presented. Calculations were made to confirm the obtained analytical solution using a finite-difference approximation of the differential equations of heat balance and heat transfer, as well as by comparing the solution obtained by the author earlier, taking into account the spread of the temperature wave in fences, on the example of one of the currently existing residential buildings in the climatic conditions of Moscow. It is noted that the estimated value of the largest temperature deviation from the setpoint (dynamic control error) and the time for this deviation in the considered problem statement do not depend on the transmission coefficient of the regulator. The obtained relations are proposed to be used for an approximate assessment of the non-stationary thermal regime of an air-conditioned room served by local cooling systems controlled by the integral law, as well as for determining the required parameters of the regulator, including using multivariate calculations with changes in the parameters of the problem.

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1. *Introduction*

In the present paper, as an object of a study it is considered the behavior under the conditions of variable thermal effects of the internal air temperature in premises equipped with automated local cooling systems and background supply ventilation system.

The set of internal meteorological parameters in premises must be maintained within the limits determined first of all by the conditions of human comfort or the maintenance of technological process, which, in turn, are mainly associated with life safety requirements. In fact, the hygrothermal regime is stabilized mainly with the help of automatic regulation and control of engineering systems for microclimate maintenance allowing for building's own thermal capacity. At the same time, since the thermal effects on premises and their heat losses are almost always variable, this task turns out to be significantly non-steady.

The issues of calculating the temperature change in air-conditioned premises in the course of appearance of thermal disturbances have been studied for quite a long time. So, some simplified analytical solutions to this problem are even given in reference and educational literature. Of course, they mainly relate only to the thermal regime of insulated enclosures when cooling a building under the conditions of emergency shutdown of heat supply systems or on periodic changes in heat fluxes without taking into account the overall heat balance of premises. However, it can be noted that in recent years more complex papers have been published, in particular, [1, 2], but their results in many cases turn out to be complicated enough, at which point it is difficult to use them for engineering calculations. At the same time, numerical methods are more used for study non-steady regimes and their modeling. Therefore, publications [3, 4], for example, may be interesting in this respect, and especially approaches of this type are currently characteristic of foreign papers, among which there are quite typical studies [5–7]. However, a number of options for these solutions relate to objects of a specific type, operating in limited areas and under special conditions, for example, underground pipelines [8], or for ventilated facades combined with natural ventilation systems [9]. The work [10] is devoted to the non-stationary gas regime of a room with the release of harmful substances contained in building materials in it and the management of this regime, but the theoretical basis of the processes considered there and the results obtained can in many ways be extended to the thermal regime. Moreover, the authors of some studies in this area, on the contrary, solve the inverse problem – on determination of thermophysical characteristics of a material by studying temperature fluctuations [11–13] or using thermography methods [14]. Papers [15–19] are devoted to the modeling of processes in premises as a whole. Thus, in [15] it is presented a very detailed multiparameter numerical model of a simulation type, but it applies only to the cold season in the presence of heating. The publications [16–19] are also quite holistic, for example, in [16, 17] they talk about the use of the principles of fuzzy logic in organization of microclimate control, and [18, 19] are mostly based on the methods of automatic control theory, but their results are still quite difficult for use in engineering practice. Finally, there are studies concerning the general principles of the management of engineering systems of a building and the energy saving under these conditions, for example, [20–22], but due to their general nature, they also do not have specific dependencies of interest to us.

On the basis of differential equation of the balance of convective heat for premises as a whole, the author in article [23] managed to find an analytical solution to the problem of the temperature drop in the event of emergency shutdown of heat supply. However, more complicated cases require additional consideration when such an equation is nevertheless amenable to integration. First of all, we are talking about regimes when the premises are serviced by standard systems for maintenance of internal microclimate, equipped with the appropriate equipment for their automatic regulation, which makes it possible to provide the required set of internal meteorological parameters under variable thermal effects. Therewith, in many cases, control algorithms with an integral component are preferable, when the control action is proportional to the sum of the accumulated deviation from the moment the thermal disturbance appears, and, therefore, the control process will be carried out until this deviation is completely eliminated. Thus, in contrast to simpler proportional controllers, this circuit is devoid of their main disadvantage, namely, a non-zero static control error.

However, it should be noted that in the engineering practice of recent years, the more typical situation is when the temperature of the air in premises and the temperature of surfaces of their enclosing structures is actually maintained at the required level, mainly due to local cooling systems, for example, of the “chiller-fancoil” type or split systems. They use complete recirculation of the air cooled and, therefore, do not take part in the overall air balance of premises. Another fairly common option is the installation of radiant panel cooling systems, the most common of which in recent times are chilled ceilings. In all these cases, the provision of the sanitary-hygiene requirements is accounted for a part of mechanical supply air system, namely, the maintenance of the necessary cleanliness of the internal air, and if at the same time it is provided the cooling of the inflow, then this process serves mainly to reduce, as far as possible, the heat load on the local cooling systems so that hot air does not enter the premises.

In publication [24], the author obtained a very general analytical solution to the problem of change of the temperature in the premises under these conditions using the integral law of climate system regulation. The corresponding dependence is written in the form of a fairly rapidly convergent series in powers of the independent variable, which is the square root of the time period elapsed since the appearance of the thermal disturbance. However, it is advisable to consider the possibility of some simplification of this solution on retention of its physical validity, which will expand the possibilities of its analysis and comparison with existing analogues, with the simultaneous identification of limits when such a simplification is permissible, and, thereby, with an evaluation of the degree of influence of various parameters of the problem on the behavior of internal temperature.

Therefore, the relevance of the proposed work consists in the need to search for simpler analytical dependences of the time variation of the internal air temperature in premises cooled by local automated systems, taking into account the amount of heat input, the thermal stability of premises and the characteristics of the controller, as well as the relationship of these characteristics with the maximum temperature deviation from a given value. These dependencies should be written in the form of final formulas acceptable for engineering use, but, at the same time, physically based, having satisfactory accuracy and allowing for evaluative multivariate calculations to analyze the behavior of the temperature in premises and synthesize the corresponding automatic control system. The application of the results achieved in this case will be possible for a very wide range of objects of a similar type.

The objective of the paper is to develop simplified analytical methods for calculating the non-steady thermal regime of premises served by local automated cooling systems in the presence of a background unregulated inflow. The tasks of the study are the following:

– setting up of a basic system of differential equations describing the heat balance and heat exchange in air-conditioned premises, taking into account the presence of automated systems for microclimate maintenance;
– obtention of an analytical solution of this system in the form of final formulas upon a jump-like thermal effect and regulation of cooling systems according to the integral law;
– construction of analytical dependencies for the maximum deviation of the air temperature in premises from the setpoint and for the moment in time when this deviation is observed, and their confirmation by comparison with the data of program generation;
– identification of limits when the introduced simplifications are acceptable, and evaluation of the degree of influence of the problem parameters on the thermal conditions of premises based on comparing the results with the general analytical solution obtained by the author in paper [24].

2. Methods

Let's write the equation of the balance of convective heat for the air in premises within the framework of its one-zone model in the following form:

$$Q_{in} + G_s c_a \left(t_s - t_{in}\right)/3600 - Q_c - \Lambda\left(t_{in.0} - t_{in}\right) = V_r c_a \rho_a \frac{dt_{in}}{d\tau}, \qquad (1)$$

where Q_{in} is the delivery of sensible heat to the air of premises from sources, W; Q_c is the amount of regulated heat flow, W, from local cooling systems, which is designed to compensate for heat gain; V_r is the volume of premises, m^3; τ is the time interval, s, from the moment of the variable thermal effect; G_s is the mass flow rate, kg/h, which is usually considered equal to the value of the exhaust flow rate G_{ex} due to the almost instantaneous stationarity of the air balance of premises in comparison with the thermal; c_a = 1005 J/(kg·K) is the air specific heat; ρ_a = 1.2 kg/m^3 is its density; t_{in} is the temperature of internal air in the premises, °C; t_s is the inflow temperature, °C; $t_{in.0}$ represents the controlled level t_{in}, or the so-called setpoint; Λ is the total index of convective heat transfer on surfaces in the premises, W/K. It is calculated as $\alpha_m \sum A_i$, where α_m is the average coefficient of convective heat transfer, which in the first approximation can be taken in the amount of 3.7 W/(m^2·K), and $\sum A_i$ is the sum of the areas of surfaces of the enclosing structures facing the room, m^2. It is assumed that the initial temperature of these surfaces is averagely equal to $t_{in.0}$. Thus, the equation (1), in comparison with the one presented in [24] in the last term of the left side, takes into account only the flow of convective heat due to heat transfer on the surfaces of enclosures, and does not consider the temperature change of the structure material itself. But on the right side there is a complex representing the amount of heat that goes for change in the temperature of the volume of air contained in premises. Further, it will be shown that in this case, neglecting it in the considered formulation of the problem can lead to incorrect results. At the same time, as in [24], it is assumed here that t_s = const, since regulation is still carried out due to local cooling systems.

If the level t_{in} is automatically maintained by a controller in which a continuous integral law is realized by means of the necessary change in Q_c value, it is easiest to write the additional coupling equation in the following form:

$$\frac{dQ_c}{d\tau} = K_c\left(t_{in.0} - t_{in}\right). \tag{2}$$

Here K_c is the equivalent transfer coefficient of an automated system, W/(K·s), via the channel "t_{in} → derivative of Q_c". Using the concept of excess temperature $\theta_{in} = t_{in} - t_{in.0}$, and term-by-term differentiating (1) with respect to τ for the possibility to plug there the expression (2), we write (1) in the canonical form:

$$\frac{d^2\theta_{in}}{d\tau^2} + A\frac{d\theta_{in}}{d\tau} + B\theta_{in} = 0. \tag{3}$$

Parameters A, s^{-1}, and B, s^{-2}, can be determined here by the following formulas:

$$A = \frac{G_s c_a/3600 + \Lambda}{V_r c_a \rho_a}, \quad B = \frac{K_c}{V_r c_a \rho_a}. \tag{4}$$

It is easy to see that the differential equation (3) refers to linear homogeneous equations of the 2nd order with constant coefficients, as a result of which the simplest operational solution method can be applied to it. The characteristic equation for (3) will have the following form:

$$p^2 + Ap + B = 0, \tag{5}$$

where p is the Heaviside operator. In fact, in this case, the premises are treated as a second-order linear inertial link. From (5) we get:

$$p_{1,2} = \left(-A \pm \sqrt{A^2 - 4B}\right)\Big/2, \tag{6}$$

and finally write down the general solution in the following form:

$$\theta_{in} = C_1\exp\left(p_1\tau\right) + C_2\exp\left(p_2\tau\right), \tag{7}$$

where C_1 and C_2 are constants that can be obtained from the initial conditions. Obviously, that at τ = 0 and θ_{in} = 0, whence C_1 = $-C_2$. From (1) it can be found that in this case there is a relation $V_r c_a \rho_a \dfrac{dt_{in}}{d\tau} = -Q_{in}$, whence we have:

$$\theta_{in} = -\frac{Q_{in}}{V_r c_a \rho_a \sqrt{A^2 - 4B}}\left[\exp\left(p_1\tau\right) - \exp\left(p_2\tau\right)\right]. \tag{8}$$

It should be noted that, by virtue of relations (4) the equation (3) does not admit asymptotics at $V_r \to 0,$ and in the case of eliminating the corresponding term from the right side of (1), it is easy to show that then the variables become separable, and the resulting solution will have an absolutely exponential form. This does not correspond to the physical meaning of the problem under consideration, since when using the integral control law, the controlled value, as it is known, passes through a maximum and then tends to zero – either monotonically or in an oscillatory manner, depending on the parameters of the object and the controller (oscillations will obviously be observed at $A^2 < 4B$). That is why, in this case, taking into account the V_r is mandatory, even given that this complicates the solution to a certain extent, although due to the constancy of the coefficients in (3), this is not critical at all.

3. Results and Discussion

For the sake of clarity, it is advisable to give an example of calculating the t_{in} value according to expression (8) in the premises with parameters A = 0.0059 s^{-1} (which corresponds to V_r = 42 m^3,

$\sum A_i$ = 49 m², G_s = 430 kg/h) and K_c = 0.25 W/(K·s), whence B = 4.9·10⁻⁶ s⁻². In the course of calculations, the initial $t_{in.0}$ value was taken equal to +20 °C, and the value of heat gain jump Q_{in} = 500 W. The corresponding graph is shown in Fig. 1 as a solid curve. For comparison, the dotted line shows the results of numerical modeling upon the same initial data using the computer software developed by the author, which is based on the direct solution of the system of differential equations of non-steady heat transfer in enclosures and heat transfer on their surfaces [23]. The dash-dot line shows the dependence of the internal temperature on time, obtained using an analytical solution that takes into account the heat capacity of the near-surface layer of the enclosing structures facing the premises [24].

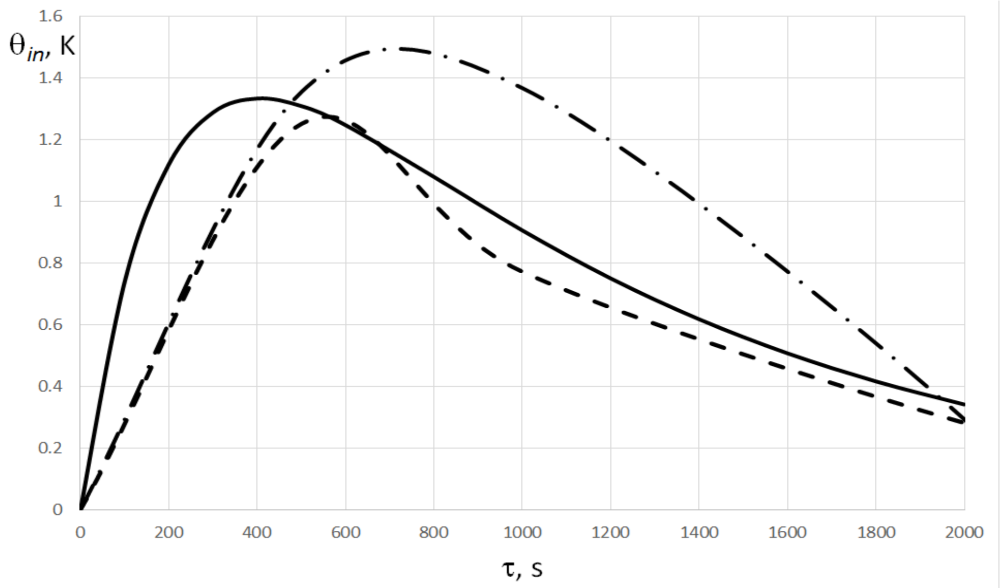

Figure 1. Dependence of θ_{in} on time for the premises under study (solid line – according to formula (8), dotted line – numerical calculation, dash-dotted line – analytical solution [24]).

It can be pointed out that the numerical calculation data show a fairly satisfactory coincidence with an expression (8), especially for large τ values, in any case, from the point of view of the value of the maximum deviation t_{in} and the time when it occurs. Moreover, this coincidence turns out to be even closer than with the results of analytical calculations, with which the maximum proximity manifests itself, on the contrary, in the initial period, at the stage of temperature deviation increase. Apparently, this is related to the fact that the analytical solution [24] still gives a better asymptotic behavior at $\tau \to 0,$ while at higher τ prevails the fact that, up to a certain limit, when the penetration of the temperature wave into the thickness of the material of enclosures already becomes significant, the simplified equation (3) describes quite well the real process of regulation of the temperature in premises. In any case, the solution (8), on the one hand, shows its physical validity and suitability for rough estimates, taking into account its relative simplicity and the possibility of carrying out necessary operations to find the maximum and solving other problems of analysis, and on the other hand, it also confirms the sufficient reliability of more exact analytical solution [24].

The expression for the moment in time $\tau_{\max}$, s, at which it is observed the maximum temperature deviation from the setpoint, can be obtained from the condition $d\theta_{in}/d\tau = 0,$ whence, bearing in mind that in real conditions for stable automatic control systems, the ratio of the parameters A^2/B is much greater than 1 (in particular, for the example under consideration, it is equal to 7.16), and neglecting the small terms, we can write down the approximate formula:

$$\tau_{\max} = \frac{\ln\left(A^2/B\right)}{A}. \quad (9)$$

In our case, the $\tau_{\max}$ value turns out to be equal to 332 s, while the graph in Fig. 1 gives a value of about 380 s, i.e., the error is about 13 percent, but taking into account the simplicity of dependence (9) and its deliberately estimated character, this can be deemed quite satisfactory. However, both the numerical calculation and the analytical solution [24] lead to higher $\tau_{\max}$ (about twice). This is physically more justified, since these options already take into account the influence of heat inertia of the array of enclosing structures, which leads to a shift in the moment of a maximum temperature deviation to a later term. Nevertheless, within the framework of the problem under consideration, the expression for $\tau_{\max}$ is auxiliary, necessary for estimation of the maximum level θ_{in}, i.e. $\theta_{\max}$ that interests us the most. Plugging (9) to (8) and, neglecting once again small terms, we obtain:

$$\theta_{\max} = \frac{Q_{in}}{G_s c_a / 3600 + \Lambda}. \tag{10}$$

It is easily seen that this expression has a very simple physical meaning, namely, it turns out that within the model used, and the maximum temperature deviation from the setpoint is determined by the heat-assimilating ability of the air in the background ventilation system and the resulting heat flux due to heat transfer on the surfaces of enclosures. In our example, the $\theta_{\max}$ value according to formula (10) will be equal to 1.66 °C, which is 25–30 percent higher than directly according to the dependence graph (8) and according to the calculation data for the rest of the options in accordance with Fig. 1, so the relation (10) gives the result with a certain margin due to neglect of the influence of the thermal inertia of enclosures. It should also be said that for the general nature of the dependence (8) depicted in Fig. 1, one can find a significant similarity with the relations that lead, for example, to the authors [15] and [16] under similar initial conditions, and the observed temperature deviations from the initial values generally correspond to the level that is noted in [25] under close regimes. In addition, Fig. 2 shows a comparison of the calculation results according to expression (8), shown earlier in Fig. 1, with the data of full-scale measurements of the non-stationary thermal regime of a room serviced by an automated air heating system under similar control conditions given in [26] (dotted line), after normalization by the magnitude of the maximum temperature deviation. It can be seen that, up to the moment of maximum and even somewhat further, experimental measurements give a similar nature of dependence, which further confirms the theoretical provisions of the proposed work. The dash-dotted line represents the change in the relative concentration of harmful impurities in the room air C_r according to [10] also under similar control conditions after bringing to the appropriate deviation scale and time. Although the equations describing the gas regime differ somewhat from those considered here, the simplifications adopted in the derivation (8), namely the neglect of heat accumulation of the structural material, bring (8) closer to the result that can be obtained for changing the concentration, which is confirmed by Fig. 2.

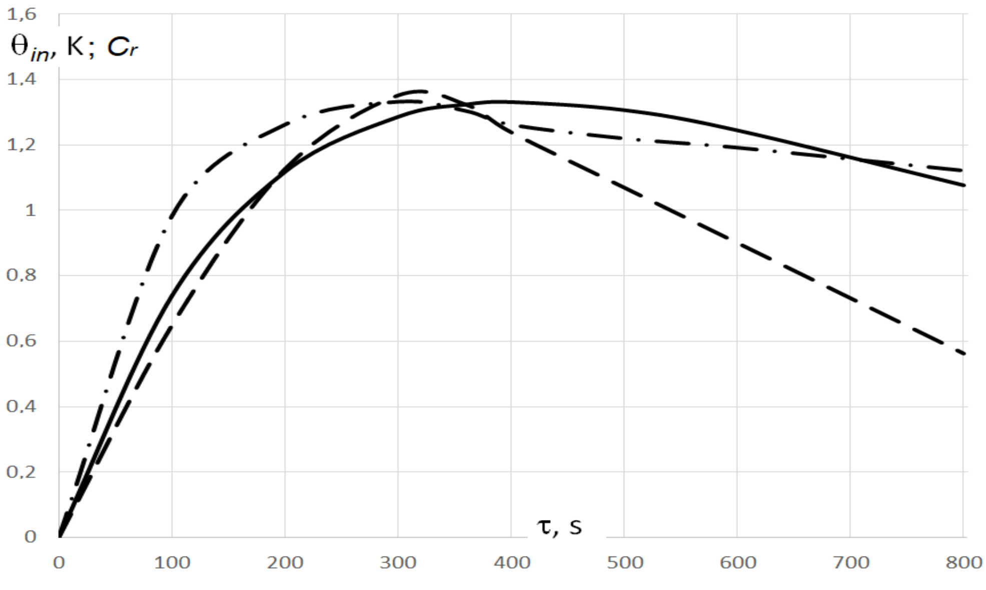

Figure 2. Dependence of θ_{in} on time for the premises under study (solid line – according to formula (8), dotted line – full-scale measurements [26], the dash-dotted line is the same according to [10] for the relative concentration of the harmful substance C_r).

4. Conclusion

1. It is shown that the simplified analytical solution obtained in the paper, which describes the change in t_{in} value in premises served by a background uncontrolled inflow and automated local cooling systems, subject to their control according to the integral law, for an abrupt change in heat input, it satisfactorily describes the real process of heating or cooling, at least at not too small τ values.

2. It is noted that the discovered dependence for t_{in} is expressed explicitly through exponential functions of τ and allows to easily analyze the problem and the subsequent synthesis of the automatic control system by varying the numerical coefficients in the solution.

3. It was confirmed that, as in other versions of the problem statement, the maximum deviation of t_{in} from the setpoint (dynamic control error) is proportional to the value of thermal disturbance, however, in the considered embodiment, the estimated level of this deviation and the moment in time, for which it is observed, are not directly related to the value of the controller gain.

4. It is proved that, all other things being equal, the simplified solution gives the maximum coincidence with the data of numerical calculations for the moments in time, starting with the maximum deviation t_{in}, since the analytical solution [24] still gives better asymptotics at $\tau \to 0$.

5. It is shown that the results obtained additionally confirm the reliability and practical applicability of the previously found analytical solution [24], which takes into account the thermal stability of the enclosures of premises in the course of propagation of a temperature wave in the material of the enclosing structures.

6. It is noted that the obtained simplified solution is quite successfully confirmed by the nature of the dependencies discovered by a number of authors by experimental measurements under appropriate conditions, including for changing the concentration of harmful impurities, which in physical sense should be described by equations similar to (8).

7. It is proposed to apply the relations obtained in the paper for an approximate analytical assessment of the non-steady thermal regime of air-conditioned premises served by local cooling systems equipped with an automation system with an integral control mode, to check the conditions for human comfort and safety of his life, as well as to determine the required parameters of the regulator, in particular using multivariate calculations with change in task parameters.

References

1. Rafalskaya, T.A. Reliability and controllability of systems of centralized heat supply. Eastern European Scientific Journal. 2016. 2. P. 228–235. DOI: 10.12851/EESJ201604C06ART10
2. Rafalskaya, T.A. Simulation of thermal characteristics of heat supply systems in variable operating. Journal of Physics: Conference Series. XXXV Siberian Thermophysical Seminar, STS 2019. 2019. P. 012140. DOI: 10.1088/1742-6596/1382/1/012140. URL: https://iopscience.iop.org/article /10.1088/1742-6596/1382/1/012140/pdf (data obrashcheniya: 07.01.2022)
3. Malyavina, E.G. Rashchet tempa ostyvaniya pomeshcheniya posle otklyucheniya teplosnabzheniya [Calculation of the rate of cooling of a room after turning off the heat supply]. Promyshlennoe i grazhdanskoe stroitel 'stvo [Industrial and Civil Engineering]. 2015. 2. Pp. 55–58. URL: http://pgs1923.ru/ru/index.php?m=4&y=2015&v=02&p=00&r=14 (date of treatment: 07.05.2020 (rus)
4. Doroshenko, A.V. Imitacionnaya termodinamicheskaya model' zdaniya [Simulation thermodynamic model of the building]. BST: Byulleten' stroitel'noy tekhniki [Bulletin of construction equipment]. 2017. 12. Pp. 42–43. URL: https://elibrary.ru/item.asp?id=30598682 (date of treatment: 07.05.2020 (rus)
5. De Rosa, M., Bianco, V., Scarpa, F., Tagliafico, L.A. Modelling of energy consumption in buildings: an assessment of static and dynamic models. Russian Journal of Construction Science and Technology. 2016. V. 2. 1. Pp. 12–24. DOI: 10.15826/rjcst.2016.1.002
6. Liu, C.-S. An integral equation method to recover non-additive and non-separable heat source without initial temperature. International Journal of Heat and Mass Transfer. 2016. Vol. 97. Pp. 943–953. DOI: 10.1016/j.ijheatmasstransfer.2016.03.003
7. Horikiri, K., Yao, Y., Yao, J. Modelling conjugate flow and heat transfer in a ventilated room for indoor thermal comfort assessment. Building and Environment. 2014. 77. Pp. 135–147. DOI: 10.1016/j.buildenv.2014.03.027
8. Bouhacina, B., Saim, R., Oztop, H.F. Numerical investigation of a novel tube design for the geothermal borehole heat exchanger, Applied Thermal Engineering. 2015. 79. Pp. 153–162. DOI: 10.1016/j.applthermaleng.2015.01.027
9. Mansurov, R.Sh., Rafalskaya, T.A., Efimov, D.I. Mathematical modeling of thermal technical characteristics of external protections with air layers. E3S Web of Conferences. 22nd International Sci-entific Conference on Construction the Formation of Living Environment, FORM 2019. 2019. P. 06007. DOI: 10.1051/e3sconf/20199706007. URL: https://www.e3s-conferences.org/articles/e3sconf/pdf/2019/23/e3sconf_form2018_06007.pdf (data obrashcheniya: 07.01.2022)
10. Zemitis, J., Borodinecs, A., Lauberts, A. Ventilation impact on VOC concentration caused by building materials. .Magazine of Civil Engineering. 2018. 8 (84). Pp. 130–139. DOI:10.18720/MCE.84.13
11. Sáez Blázquez, C., Farfán Martín, A., Martín Nieto, I., González–Aguilera, D. Measuring of thermal conductivities of soils and rocks to be used in the calculation of a geothermal installation. Energies. 2017. 10 (6). Pp. 795. DOI: 10.3390/en10060795
12. Ozturk, A. Overall heat transfer coefficient of functionally graded hollow cylinder. Solid State Phenomena. 2017. 267 SSP. Pp. 177–181. DOI: 10.4028/www.scientific.net/SSP.267.177

13. Li, N., Chen, Q. Experimental study on heat transfer characteristics of interior walls under partial-space heating mode in hot summer and cold winter zone in China. Applied Thermal Engineering. 2019. Vol. 162. Pp. 114264. DOI: 10.1016/j.applthermaleng.2019.114264
14. Marino, B.M., Muñoz, N., Thomas, L.P. Estimation of the surface thermal resistances and heat loss by conduction using thermography. Applied Thermal Engineering. 2017. Vol. 114. Pp. 1213–1221. DOI: 10.1016/j.applthermaleng.2016.12.033
15. Bilous, I.Yu., Deshko, V.I., Sukhodub, I.O. Building energy modeling using hourly infiltration rate. Magazine of Civil Engineering. 2020. 4 (96). Pp. 27–41. DOI: 10.18720/MCE.96.3
16. Faouzi, D., Bibi-Triki, N., Draoui, B., Abène, A. Modeling a fuzzy logic controller to simulate and optimize the greenhouse microclimate management using Mathlab Simulink. International Journal of Mathematical Sciences and Computing. 2017. Vol. 3. 3. Pp. 12–27. DOI: 10.5815/ijmsc.2017.03.02
17. Latif, M., Nasir, A. Decentralized stochastic control for building energy and comfort management. Journal of Building Engineering. 2019. Vol. 24. Pp. 100739. DOI: 10.1016/j.jobe.2019.100739
18. Ryzhov, A., Ouerdane, H., Gryazina, E., Bischi, A., Turitsyn, K. Model predictive control of indoor microclimate: existing building stock comfort improvement. Energy Conversion and Management. 2019. Vol. 179. Pp. 219–228. DOI: 10.1016/j.enconman.2018.10.046
19. Serale, G., Capozzoli, A., Fiorentini, M., Bernardini, D., Bemporad, A. Model predictive control (MPC) for enhancing building and HVAC system energy efficiency: problem formulation, applications and opportunities. Energies. 2018. Vol. 11. 3. Pp. 631. DOI: 10.3390/en11030631
20. Belussi, L., Barozzi, B., Bellazzi, A., Danza, L., Devitofrancesco, A., Ghellere, M., Guazzi, G., Meroni, I., Salamone, F., Scamoni, F., Scrosati, C., Fanciulli, C. A review of performance of zero energy buildings and energy efficiency solutions. Journal of Building Engineering. 2019. Vol. 25. Pp. 100772. DOI: 10.1016/j.jobe.2019.100772
21. Sha, H., Xu, P., Yang, Z., Chen, Y., Tang J. Overview of computational intelligence for building energy system design. Renewable and Sustainable Energy Reviews. 2019. Vol. 108. Pp. 76–90. DOI: 10.1016/j.rser.2019.03.018
22. Kharchenko, V., Boyarchuk, A., Brezhnev, E., Andrashov, A., Ponochovnyi, Y. Monte-Carlo simulation and availability assessment of the smart building automation systems considering component failures and attacks on vulnerabilities. Advances in Intelligent Systems and Computing. 2019. Vol. 761. Pp. 270–280. DOI: 10.1007/978-3-319-91446-6_26
23. Samarin, O.D. Raschet ostyvaniya pomeshcheniy zdaniya v avariynykh rezhimakh dlya obespecheniya nadezhnosti ikh teplosnabzheniya [The calculation of cooling of building in emergency conditions to ensure reliability of their heating]. Vestnik MGSU [Papers of MSUCE]. 2019. Vol. 14. 4 (127). Pp. 496–501. DOI: 10.22227/1997-0935.2019.4.496-501. URL: http://vestnikmgsu.ru/ru/ (date of treatment: 07.05.2020) (rus)
24. Samarin, O.D. Thermal mode of a room with integrated regulation of cooling systems. Magazine of Civil Engineering. 2021. 103 (3). Article No. 10312. DOI: 10.34910/MCE.103.12
25. Odineca, T., Borodinecs, A., Korjakins, A., Zajecs, D. The impacts of the exterior glazed structures and orientation on the energy consumption of the building. IOP Conference Series: Earth and Environmental Science. 2019. Vol. 290 (1). P. 012105. DOI:10.1088/1755-1315/290/1/012105. URL: https://iopscience.iop.org/issue/1755-1315/290/1 (data obrashcheniya: 07.01.2022)
26. Lysak, O. Analysis of the temperature distribution in a space heated by a dynamic (fan) storage heater. Eastern-European Journal of Enterprise Technologies. 2017. Vol. 3. 8 (87). Pp. 17–25. DOI: 10.15587/1729-4061.2017.103778

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