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A METHOD OF ASSESSING ENERGY CONSUMPTION OF BUILDINGS DURING COMMISSIONING

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ABSTRACT

The method for instrumental assessment of specific energy consumption for heating and ventilation of buildings before commissioning has been developed. The paper contains basic principles of assessing energy consumption of a building, equations for engineering calculations of drying and accumulating coefficients for the building envelope, the results of field tests.

Keywords: energy consumption, buildings, specific energy consumption, heating, ventilation, instrumental assessment, building envelope, drying coefficients.

INTRODUCTION

One of the main problems, determining the success of energy saving policy is implementing the instrumental control of actual values for energy consumption of a building before commissioning.

The paper contains the basic principles of the proposed method for instrumental assessment of specific energy consumption for heating and ventilation of a building before the commissioning. The method allows assessing energy consumption of a building not impacted by the subjective behavioral factors of the residents. The actual energy consumption of the utilities is measured by the energy meters of the whole building. The method does not require any specific (or regulatory) conditions of microclimate and air exchange in the building. Energy losses for drying the building envelope and accumulating of thermal energy in the building envelope is calculated. The result of the instrumental assessment of energy consumption of a building before the commissioning is the actual value of annual specific energy consumption for heating and ventilation of the building reduced to standard conditions. Conformity assessment of energy efficiency of a building is performed by comparing the current standard values for annual specific energy consumption of a building to the values obtained according to the proposed method.

There are many papers concerning the impact of the humidity conditions on the thermal parameters of the building envelope (E. Verecken, L. Van Gelder, H. Jassen, S. Roel, 2015, S.P. Casey, M.R. Hall, S.C.E. Tsang, M.A. Khan, 2013). Authors (G.P. Vasilyev, V.A. Lichman, N.V. Peskov, M.M. Brodach, Y.A. Tabunshchikov, M.V. Kolesova, 2015) have created a mathematical model and have carried out a set of calculation experiments simulating non-stationary heat transfer processes in multilayer the building envelopes, used in modern construction. This paper contains simple equations, which can be used for engineering calculation of drying coefficients. This coefficient allow expressing thermal energy consumed for drying the building envelope through energy of transmission losses.

Non-stationary thermal processes, caused by alterations in the ambient air temperature, lead to accumulation of the thermal energy within the walls. This paper contains the equations, obtained for engineering calculations of accumulation coefficients, which allow expressing thermal energy, accumulated within the walls through energy of transmission losses.

Assessing the amount of energy, required for heating and ventilating

Field thermal tests are to be carried out during the heating period while the building is uninhabited. Tests should run for ten days. During the 10 test days thermal energy in the building covers heat losses through the building envelope (transmission heat losses), heating of the supply and/or infiltration air, drying of the building envelope and heat accumulation in walls. There is no domestic heat generation in the building before the commissioning. Part of the thermal energy is gained from the solar radiation. Climatic data and data on solar radiation may be measured or retrieved from the nearest weather station. Further on, we are going to neglect this part of the energy balance to simplify the calculations. Then, the heat balance equation for the test period is:

$$Q_{h,m}=Q_{tr}+Q_{v,m}+Q_{acc}+Q_{dry} \quad (1)$$

where $Q_{\text{h,m}}, \cdot kW \cdot h$ - the amount of energy, consumed for heating of the building; $Q_{tr}, \cdot kW \cdot h$ - the amount of energy, lost by through the building envelope; $Q_{v,m}, \cdot kW \cdot h$ - the amount of energy, used to heat the incoming ventilation and/or infiltration air; $Q_{acc}, \cdot kW \cdot h$ - the amount of energy, accumulated in the building envelope and caused by the ambient air temperature alteration during the test period; $Q_{dry}, \cdot kW \cdot h$ - the amount of energy, used to dry the building envelope.

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We shall derive Q_{acc} and Q_{dry} using energy of transmission losses $Q_{acc}=\beta_{acc}\cdot Q_{tr}$; $Q_{dry}=\beta_{dry}\cdot Q_{tr}$, then:

$$Q_{tr}=\frac{Q_{h,m}-Q_{v,\mathrm{m}}}{(1+\beta_{acc}+\beta_{dry})}, \tag{2}$$

The value of $Q_{\mathrm{h,m}}$ in (2) is determined by the heat meters readings; $Q_{v,m}$ - by the measured volumetric flow rate of the air in the exhaust ventilation system of the building; coefficients of accumulation β_{acc} and drying β_{dry} - are calculated.

The value of $H_{\mathrm{tr,f}}=Q_{tr}/D_z$ characterizes the quality of the building envelope. Assuming it constant during the heating period makes it possible to calculate the amount of transmission losses during the heating period:

$$Q_{tr}^{ann}=Q_{tr}\cdot D_h/D_z \tag{3}$$

where Q_{tr} - is derived from the equation (2); $D_z=(t_{\mathrm{int}}^{av}-t_{amb}^{av})\cdot\tau_z$ - degree hours of the test period; $t_{\mathrm{int}}^{av},\cdot{}^0C$ and $t_{amb}^{av},\cdot{}^0C$ - average temperatures of internal and ambient air of the test period; $\tau_z,\cdot h$ - duration of the test period; $D_h=(t_{\mathrm{int}}-t_h^{av})\cdot\tau_h$ - degree-hours of the heating period; $t_{\mathrm{int}},\cdot t_h^{av},\cdot\tau_h$ - congruent parameters of the whole heating period.

Now, using established standard values for other components of the heat balance of the building the value of specific heat consumption of the building for the whole heating period can be calculated.

It should be noticed, that value $H_{\mathrm{tr,f}}=10^{-3}\cdot A_{env}^{tot}\cdot K_t^{tr}$ is in proportion to the transmission heat transfer coefficient $K_t^{tr}, W/m^2\cdot{}^0C$, present in energy passport of the building, which is prepared on the design stage of the project. This fact presents an opportunity to compare calculations, performed during the design stage and the results of the field thermal tests; A_{env}^{tot}, m^2 - total area of the building envelope.

Accumulation coefficient β_{acc} , which considers thermal energy consumption during the period τ_z , and depends on thermal accumulation capacity of the building envelope is determined mostly by thermal properties of envelope's outmost layers:

$$\beta_{acc}=\beta_{amb}\cdot\beta_R, \tag{4}$$

where the dimensionless coefficients are:

$$\beta_{amb}=\frac{\Delta t_{amb}}{3{,}6\cdot D_z}\cdot\sum_{i=1}^{N}c_i\cdot\rho_i\cdot d_i\cdot\left(\frac{1}{\alpha_{\mathrm{int}}}+\sum_{j=1}^{i-1}\frac{d_j}{\lambda_j}+\frac{d_i}{2\lambda_i}\right)\approx$$
$$\approx\frac{\rho_{amb}\cdot d_{amb}\cdot c_{amb}\cdot\Delta t_{amb}}{3{,}6\cdot D_z}\cdot\left(R_W-\frac{d_{amb}}{2\cdot\lambda_{amb}}-\frac{1}{\alpha_n}\right), \tag{5}$$

$$\beta_R=\frac{r\cdot(1-f)\cdot R_F}{[(1-f)\cdot R_F+r\cdot f\cdot R_W]}, \tag{6}$$

Equations (4-6) are shown for quasistationry approximation. Where $\Delta t_{amb}=(t_{\mathrm{amb},z}-t_{\mathrm{amb},1}),\cdot{}^0C$ - difference of average temperatures of the first $t_{\mathrm{amb},1}$ and the last $t_{\mathrm{amb},z}$ days of the test; $c_{amb}, kJ/(kg\cdot K)$; $\rho_н, kg/m^3$; $d_н, m$; $\lambda_{amb}, W/(m\cdot K)$ - specific heat, density, thickness and thermal conductivity coefficient of the first (outmost) layer of the building wall; $f=A_W/(A_W+A_F)$ - glazing coefficient of the building facade; A_F, A_W, m^2 - areas of transparent and opaque (walls) parts of the building; $R_F, m^2\cdot{}^0C/W$ - thermal resistance of the transparent part of the building; r - thermal uniformity coefficient of the wall; $\alpha_{\mathrm{int}},\alpha_{amb}, W/(m^2\cdot{}^0C)$ - heat transfer coefficients of the innermost and outmost layers; N - number of layers; $R_W, m^2\cdot{}^0C/W$ - design thermal resistance of the wall.

$$R_W=\frac{1}{\alpha_{\mathrm{int}}}+\sum_{j=1}^{N}\frac{d_j}{\lambda_j}+\frac{1}{\alpha_{amb}}, \tag{7}$$

Values of coefficients β_{acc} for some of the building envelopes and different values of glazing coefficient f are present in Table-1.

Table-1. Accumulation coefficient β_{acc} for some of the building envelopes and different values of glazing coefficient f .

$f=A_F/(A_W+A_F)$	0,15	0,20	0,25	0,30	0,50
Wall structure (layer thickness), beginning with the outermost:					
Concrete (0.1) - Styrofoam (0.15) - concrete (0.15)	0,20	0,17	0,15	0,13	0,07
Concrete (0.1) - mineral wool (0.15) - concrete (0.15)	0,18	0,16	0,14	0,12	0,07
Mineral wool (0.2) - concrete (0.2)	0,023	0,020	0,017	0,015	0,008
Mineral wool (0.2) - aerocrete (0.3)	0,033	0,027	0,023	0,020	0,010
Brick (0.12) - styrofoam (0.1) - aerocrete (0.2)	0,18	0,15	0,13	0,11	0,06

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Values of coefficient β_{acc}, shown in Table-1, were obtained for temperature difference $(t_{amb,z} - t_{amb,1}) = 10 \cdot {}^0C$, where $(t_{\text{int}}^{av} - t_{amb}^{av}) = 20-(-3{,}1) = 23{,}1 \cdot {}^0C$. It should be mentioned, that if ambient air temperature decreases during the period, coefficient β_{acc} becomes negative, because $(t_{\text{amb},z} - t_{\text{amb},1}) < 0$.

Coefficient β_{dry}, considering thermal energy consumption during the period τ_z for drying the building envelope is determined mostly by the properties of the innermost layers:

$$\beta_{dry} = \beta_{\text{int}} \cdot \beta_R, \quad (8)$$

Where coefficient

$$\beta_{\text{int}} = \frac{\rho_{\text{int}} \cdot d_{\text{int}} \cdot \Delta\omega_{\text{int}} \cdot \Delta E_L}{D_z} \cdot R_W, \quad (9)$$

where $\Delta\omega_{\text{int}} = \omega_{\text{int,ini}} - \omega_{\text{int,fin}}$ - difference between values of mass humidity of the inner layers of the building envelope measured at the beginning $\omega_{\text{int,ini}}, \%$ and at the end $\omega_{\text{int,fin}}, \%$ of the test period; $\rho_{\text{int}}, kg/m^3$; d_{int}, m - density and thickness of the innermost layer of the building envelope; $\Delta E_L = 686 \cdot W \cdot h / kg$ - specific energy of the water to vapor phase transition.

Values of drying coefficients β_{dry} for some of the building envelopes and different values of glazing coefficient are shown in Table-2.

Table-2. Drying coefficient β_{dry} for some of the building envelopes and different values of glazing coefficient f

$f=A_F/(A_W+A_F)$	0,15	0,20	0,25	0,30	0,50
Wall structure (layer thickness), beginning with the outermost:					
Concrete (0.1) - styrofoam (0.15) - concrete (0.15)	0,084	0,072	0,062	0,054	0,030
Concrete (0.1) - mineral wool (0.15) - concrete (0.15)	0,084	0,072	0,062	0,054	0,030
Mineral wool (0.2) - concrete (0.2)	0,12	0,10	0,085	0,073	0,040
Mineral wool (0.2) - aerocrete (0.3)	0,041	0,034	0,029	0,024	0,013
Brick (0.12) - styrofoam (0.1) - aerocrete (0.2)	0,022	0,019	0,016	0,014	0,008

Values of drying coefficient β_{dry}, shown in table 2, were obtained for values $\Delta\omega_{\text{int}} = \omega_{\text{int,ini}} - \omega_{\text{int,fin}} = 0{,}1\%$; $r = 0{,}75$; $\tau_z = 240h$; $\alpha_{\text{int}} = 8{,}7 \cdot W/(m^2 \cdot K)$; $\cdot\alpha_{amb} = 23 \cdot W/(m^2 \cdot K)$; thermal properties of the materials, used in the calculations are shown in table-3.

Table-3. Thermal properties of the materials.

Material	$c, kJ/(kg \cdot K)$	$\rho, kg/m^3$	$\lambda, W/(m \cdot K)$
Concrete	0,84	2500	2,04
Styrofoam	1,34	20	0,04
Mineral wool	0,84	100	0,045
Aerocrete	0,84	500	0,2
Brick	0,84	1800	0,7

A series of tests of multilayer building envelopes in the climatic chamber of JSC "NIIMosstroy", as well as field tests of buildings before commissioning have been carried out to study drying and energy accumulating processes in walls and to test the obtained equations.

RESULTS OF FIELD TESTS, ASSESSING SPECIFIC ENERGY, CONSUMED FOR HEATING AND VENTILATION OF THE BUILDING

Field thermal tests implementing the proposed method have been carried out in a 17-storey 5-section apartment building of standard line P44K/17 before commissioning. Consider the test results, obtained during two test periods from 07.03 to 16.03 and from 16.03 to 25.03 in the year of 2013.

External walls are made of three layer reinforced concrete panels, with Styrofoam insulation 140 mm thick. Main parameters of the building in question are obtained from the project: total apartment area $A_h = 15560 \cdot m^2$; living area $A_r = 9025 \cdot m^2$; design number of inhabitants is 700; total area of the building envelope $A_{env}^{tot} = 17427 \cdot m^2$; external wall area $A_W = 11950 \cdot m^2$; area of the transparent part of the building envelope $A_F = 3105 \cdot m^2$; glazing coefficient $f = A_F/(A_W + A_F) = 0{,}21 \cdot m^2$. Design value of the wall thermal resistance $R_W = 3{,}75 \cdot m^2 \cdot {}^0C/\text{W}$. Thermal uniformity coefficient $r = 0{,}7$. Windows: double glass panes, with thermal resistance according to the specification $R_F = 0{,}8 \cdot m^2 \cdot {}^0C/\text{W}$.

The following values have been obtained by measurement: total amount of energy, consumed for heating during the test period

$Q_{h,m} = 108,17 \cdot (MW \cdot h)$; average ambient air temperature of the test period $t^{av}_{amb} = -5,9 \cdot {}^oC$; average ambient air relative humidity $\varphi^{av}_{amb} = 68\%$; average internal air temperature $t^{av}_{\text{int}} = +23 \cdot {}^oC$; average internal air relative humidity $\varphi^{av}_{\text{int}} = 27\%$. Values t^{av}_{int} and $\varphi^{av}_{\text{int}}$, have been calculated as weighted mean temperature $t_{i,k}, \cdot {}^0C$ and humidity $\varphi_{i,k}, \cdot \%$ of internal air based on hourly values, measured at the mouth of each exhaust ventilation shaft, using weights of corresponding exhaust air volumes. The abovementioned parameters have been measured for four ventilation shafts (one section of the building). Mean exhaust shaft section area is $A_i = 0,37m^2$; average velocity of the exhaust air for all four shafts during all the measurement is $v_i = 0,67m/s$.

Measured volume of supply air, heated by the building's heating system and removed through the exhaust ventilation shafts is $V^h_{vent} = 5,14 \cdot 10^6 \cdot m^3$; volumetric air flowrate is $L_z = V^h_{vent} / \tau_z = 5,14 \cdot 10^6 / 240 = 2,14 \cdot 10^4 \cdot, \cdot m^3/h$. The calculated amount of energy, consumed by the building during the test period, divided by the degree hours: $Q_{v,m}/D_z = c_a \cdot \rho_a \cdot L_z / 3600 = 7,09 \cdot, kW/{}^oC$;

$Q_{h,\text{m}}/D_z = 108170/6933 = 15,60 \cdot kW/{}^oC$

Coefficients $\beta_{acc} = 0,03$ and $\beta_{dry} = 0,003$ have been calculated. The amount of energy, calculated from equation (2), which covers transmission losses of the building, divided by the degree-hours, is:

$$H_{tr,f} = (15,60 - 7,09)/1,03 = 8,26 \cdot kW/{}^oC$$

Reduced transmission heat transfer coefficient of the building: $K^{tr}_t = H_{tr,f} / 10^{-3} \cdot A^{tot}_{env} = 0,47 \cdot W/m^2K$.

The obtained results were reduced to standard conditions. Specific energy consumption, covering transmission losses (SP23-101-2004):

$$q^{ann}_{tr} = H_{tr,f} \cdot D_h / A_h = 63 \cdot kW \cdot h/m^2$$

Specific heat consumption for heating supply and infiltration air:

$$q^{ann}_v = Q_{v,\text{m}} \cdot D_h \cdot \eta_0 / (D_z \cdot A_h) = 53 \cdot kW \cdot h/m^2$$

where

$\eta_0 = L_v / L_z = 0,98$, $L_v = 30 \cdot м^3/(h \cdot pers) \cdot 700 \cdot pers = 2,1 \cdot 10^4 \cdot m^3/h$

Design value of specific heat gains from solar radiation during a heating period:

$q^{ann}_{rad} = \tau_F \cdot k_F \cdot A_F \cdot I^{av}_S / A_h = 14 \cdot kW \cdot h/m^2$. Design value of specific domestic heat generation in the building during the heating period: $q^{ann}_{dom} = q_{\text{int}} \cdot A_r \cdot \tau_h \cdot 10^{-3} / A_h = 36 \cdot kW \cdot h/m^2$.

Specific annual energy consumption for heating and ventilation (SP23-101-2004):

$$q^{ann}_h = [q^{ann}_{tr} + q^{ann}_v - (q^{ann}_{dom} + q^{ann}_{rad}) \cdot \nu \cdot \zeta] \cdot \beta_h = 93 \cdot kW \cdot h/m^2$$

CONCLUSION

The method for instrumental assessment of specific energy consumption for heating and ventilation of buildings before commissioning has been developed. According to the method, the amount of specific energy consumed for heating and ventilation of a building during the heating period is $93 \cdot kW \cdot h/\text{m}^2$. Assessment of the relative error in the determination of this amount is $\delta q_h = \Delta q_h / q_h = 15 \cdot \%$. This error mostly comes from measuring the volumetric air flow rate using anemometers. This error may be mitigated by using narrowing devices for the measurements of air flows.

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