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Methodology to Determine Heat Losses as an Element of a Ventilation Automatic Control Energy-Saving System.

Ivan Pavlovich Yakushkin*.

LLC "Interregional Energy-Saving Company" 124498, Russia, Moscow, Zelenograd, Solnechnaya alleya, 6.

ABSTRACT

One of the primary future trends is automatic microclimate control systems, including those to control exhaust and supply ventilation. For effective operation of automatic system of this kind, a lot of factors shall be taken into account. One of the most important trends is measuring heat energy losses in premises. To control this parameter, simple and accurate monitoring tools shall be applied, one of which is infrared diagnostics. Infrared control methods are applied in construction, medicine, industry and aerospace field. The primary aim of this article is to develop elements for automation systems of buildings that would consider thermal losses through the envelopes of buildings and structures.
Keywords: Non-destructive thermal testing, infrared diagnostics, heat losses, envelope, thermal protection, heating, ventilation, automatic systems.

**Corresponding author*

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INTRODUCTION

The modern society has entered the era of high dependency on power resources. Extraction, transfer and consumption processes have a substantial environmental impact. To reduce the harmful effect, it is necessary to improve technologies, implement state-of-the-art and smart equipment, develop and use precision systems of monitoring and increase the efficiency of energy use at all stages: from extraction to final consumption. One of the primary trends in diagnostics and assessing the energy efficiency parameters in generation, transmission and consumption of heat energy is heat control (HC). In its turn, the most frequently used HC method is infrared (IR) diagnostics, the basic advantages of which lie in non-destructive and prompt monitoring of the condition of envelope heat protection [1-3].

For 2015, the world production of power resources was 13887 Mtoe [4], which is 1.01% higher than in 2014 and 38.5% higher than in 2000. The energy capacity in Russia is the same in 2015 as in 2007 – 0.337 koe/$2005p. For the same period, the global energy capacity decreased from 0.172 to 0.149 koe/$2005p, e.g. by 13.4%. Currently, the Russian Federation is the most attractive country among all large ones to implement energy efficient technologies.

Irrespective of modern software and hardware for infrared diagnostics and the prospects of using non-destructive and operative methods for heat control, there is no methodology in Russia to analyze and precisely calculate the lost and consumed heat energy through building envelopes. Currently, one of the most urgent issues in thermal non-destructive testing is the search and adoption of precise and easy-to-use estimation methods for thermophysical properties of external envelopes and heat energy losses through them. This issue is urgent for being used and newly developed constructions, thermal insulating, coating materials and products.

The building's thermal balance is the most important factor in its temperature behavior [5-7] that eventually defines the success of the process. The unbiased information concerning heat ingress and losses through envelopes and external surfaces of process equipment as the heat balance components is one of the conditions to control and monitor the quality of the in-process environment at various life cycle stages of such premises.

Obtaining this information in operating conditions represents substantial challenges related to multiple simultaneous heat-exchanging processes that can hardly be considered. So the analysis of quantitative indicators of thermal losses through the envelope is done in laboratory conditions by experimental analytical study of the facility in combination with the mathematical description of processes inside the facility and calculation of primary thermophysical parameters based on experimental data.

Although there is a trend towards automation and intellectualization, ventilation is based on natural air movement force in most residential houses, including those that has been recently built. The air supply from outside is ensured by non-tightness of window openings, or during ventilation, and the air is also suctioned from the stairwell. The mechanical supply ventilation must be provided in a residential house in the northernmost areas where the ventilation in winter seasons is almost impossible.

Since the ventilation has been a non-compulsory task in Russia for many years, it has not been paid much attention to. However, in residential premises, sound and regulated ventilation is an essential task, since carbon dioxide and other gases, heat and moisture excesses shall be regularly removed, especially those gases that are emitted during cooking.

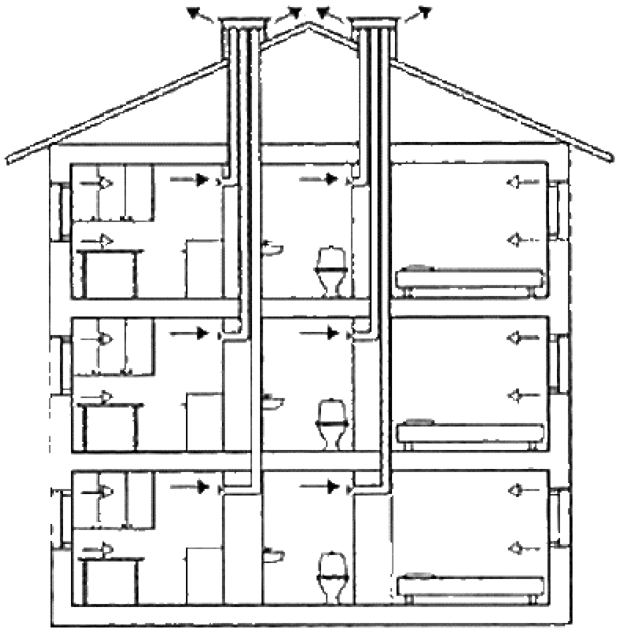

Figure 1. Natural ventilation scheme in a building

Current status

Currently, building's automation systems are developing, in particular, supply and exhaust ventilation automation systems. More than a half of the air removed in such systems is cleaned for further use. In terms of operation, such systems are rather sustainable, since they provide adjustment for both air exchange of individual premises and supply of fresh air depending on the intensity of use of a specific premise. Vertical ducts of exhaust and supply ventilation systems are mounted in special shafts, and integration of automation systems suggests analyzing the existing system, designing a new automation system, its installation in the facility and commissioning. Whereas designing and installation takes comparatively little time thanks to standard solutions employed by designing contractors, the analysis of the existing system and commissioning take rather much time.

For selective determination of small concentrations (below 0.5 TLV) of volatile organic substances that are primary air contaminants in premises, new types of fine sensors and sensor materials shall be created. There are many papers in the scientific literature that refer to various aspects of this issue. However, they are dedicated to individual compounds, the detection of which is based on other physical and chemical principles.

There are multiple sensing devices to analyze the air environment (primarily for a few number of medical applications), but in most cases they are based on gas chromatography or on the conductivity variance principle when volatile organic compounds affect non-organic environments. Fluorescent chemosensoric materials are inexpensive and environmentally-friendly alternative to the above methods, as no expensive components are required to produce them and devices on their basis. Important advantages of devices based on fluorescent analysis methods proposed in this paper include small size, low power consumption and low cost due to no expensive materials used in production. The most intensive work to create fluorescent sensors (acetone, formaldehyde, phenol, naphthalene) has been conducted in China, USA, Japan and Great Britain.

Application of automated heating and ventilation systems and building thermal models of envelopes through which primary heat energy losses occur [8-9] will allow significantly increasing the energy efficiency of buildings and structures. These measures will be urgent for newly commissioned buildings and for the operation of existing buildings.

Study

To maintain the ambient air temperature at the required level with minimal expenses, the envelopes shall have high energy efficiency. An additional factor increasing the heating energy efficiency is the formation and adjustment of heat balances in residential buildings. This is possible by means of monitoring and processing of relevant information concerning the heat energy obtained from heat sources, the number and structure of heat energy consumed and the condition of thermal protection of residential buildings and structures. To apply the results of thermal calculations in the algorithms of the ventilation automatic control system, the errors in applying these models shall be studied.

In most cases, a building envelope can be regarded as a plane-parallel wall. During heat-exchange between the wall and the environment, the heat energy going through the envelope dissipates on the wall's external surface to the environment. The heat energy transfer on the envelope surface is composed of heat flows with radiation and convection. For radiation, the Stefan-Boltzmann law is applied, and for convection, the Newton-Richmann law is applied. In the envelope, the heat energy transfer takes place predominantly by using heat conductivity described by the Fourier law.

According to the Newton-Richmann law [10], at the air/wall boundary, the thermal will q_a be:

$$q_a = \alpha_a (T_{aa} - T_{aw}) = (\alpha_{ra} + \alpha_{ca})(T_{aa} - T_{aw}), \quad (1)$$

where: α_a = heat output coefficient at the air/wall boundary in the premise; T_{aw} = wall temperature in the premise, T_{aa} = air temperature in the premise, K;

According to [11], for vertically oriented surfaces in the premise on the wall surface, the convective heat output coefficient α_{kv} can be assessed under the following formula:

$$\alpha_{ca} = 1.66 (T_{aa} - T_{aw})^{1/3}, \quad (2)$$

The heat output coefficient with radiation α_{ra} in this case can be calculated by using the Stefan-Boltzmann equation [12]:

$$q_{ra} = \varepsilon\sigma(T_{aa}{}^4 - T_{aw}{}^4) = \varepsilon\sigma(T_{aa}^2 + T_{aw}^2)(T_{aa} + T_{aw})(T_{aa} - T_{aw}) = \alpha_{ra}(T_{aa} - T_{aw}),$$

where: ε = reduced radiation coefficient; σ = Stefan-Boltzmann constant $\sigma = 5.67 \cdot 10^{-8}$ W/(m²·K⁴);

Thus, we obtain an expression for α_{ra}:

$$\alpha_{ra} = \varepsilon\sigma(T_{aa}^2 + T_{aw}^2)(T_{aa} + T_{aw}) \quad (3).$$

For building envelopes, the total heat output coefficient on the outside surface is a sum of convection and radiation coefficients [8] and it will equal:

$$\alpha_v = \alpha_{ra} + \alpha_{ca} = 1.66 (T_{aa} - T_{aw})^{1/3} + \varepsilon\sigma(T_{aa}^2 + T_{aw}^2)(T_{aa} + T_{aw}), \quad (4)$$

When substituting the formulas (4) in (1), we get the final expression to calculate the thermal flow q on the wall's internal surface, e.g., in the premise:

$$q_a = \alpha_a (T_{aa} - T_{aw}) = 1.66 (T_{aa} - T_{aw})^{4/3} + \varepsilon\sigma(T_{aa}^4 - T_{aw}^4). \quad (5)$$

The proposed methodology allows assessing the heat flow through envelopes of real objects by using modern temperature measurement methods on the envelope surface. The modern methods allow determining temperatures T_{aa}, T_{aw} with the accuracy of ±0.1 ºC. Now, we wonder how accurate the determination of the heat flow of the envelope under study will be. To get the accuracy estimate, two error calculation methods were used: PC statistic modeling and analytical method.

To implement the PC statistic modeling method [8], MS Excel software was used. When determining the temperature of structural elements, an error occurs that is distributed according to the normal law. So, the temperatures measured will be random values showing normal distribution with the mathematical expectation equaling to the nominal value and the mean square deviation approximately equaling to 1/6 of the error limit.

For calculations, let us assume that the ambient air temperature and the wall temperature in the premise equal to $T_{aa} = 300$ K , $T_{aw} = 295$ K , respectively. As described above, the temperature measurement accuracy equals to $\Delta T_{aa} = \Delta T_{aw} = \pm 0.1K$, whereas the mean square deviation equals $\sigma_t = 0.033$.

MS Excel allows generating random values of measured temperatures by using the NORMINV function (rand,(), Tav, σt). For the selected number of temperatures, the total coefficient of heat output is calculated by the formula (4), and the heat flow through the structural element is calculated by the formula (5). If we repeat these actions N times, we can get the statistics for a heat flow through the envelope, for which we can determine the average value of qcp parameters and its average square deviation σq.

Table 1 gives cropped modeling MS Excel sheets for both options. 50 calculations were made for the selected values.

Table 1. Input data and modeling results

Tap	Twp	alpha	q		
300.016	294.989	8.816	44.319	qav	44.048
299.988	294.966	8.814	44.260	σ	0.401018
299.997	295.037	8.804	43.677	δ	0.009104
299.983	294.974	8.811	44.139	Δq	0.054625
299.988	294.975	8.812	44.177		
300.021	295.013	8.813	44.135		
299.980	294.993	8.807	43.920		
299.966	295.013	8.801	43.593		
300.011	294.990	8.815	44.258		
300.065	295.028	8.821	44.426		
299.945	295.026	8.794	43.253		
300.059	294.991	8.825	44.728		
299.987	295.062	8.798	43.321		
300.034	295.039	8.812	44.016		
300.047	294.993	8.822	44.586		
299.949	294.938	8.809	44.144		
300.021	294.961	8.822	44.636		
300.024	295.011	8.814	44.178		
300.031	295.011	8.816	44.248		
300.043	295.020	8.817	44.283		

As a result of modeling, the value of average heat flow qcp and mean square deviation σR were obtained. The variation coefficient of the calculated heat flow value is $\delta_q = \sigma_q / q_{av} = 0.009$, respectively, and the relative error of heat flow determination is $\Delta q = 6\sigma_q / q_{av} = 0.055$ (5.5% of the measured value). The modeling results show that the proposed methodology for assesing the heat flow though envelopes of buildings allows assesing these parameters with engineering accuracy.

To assess the heat flow measurement error, the analytical method was applied.

The analytical methods consists in the fact that if $q = f(T_{aa}, T_{aw})$, e.g., it is not q that is measured, but T_{aa} and T_{aw}, then the measurements are indirect.

Then:

$$\Delta q = \sqrt{(\frac{\partial q}{\partial T_{aa}} \Delta T_{aa})^2 + (\frac{\partial q}{\partial T_{aw}} \Delta T_{aw})^2} \qquad (6)$$

By substituting the formula (5) to the formula (6), we obtain:

$$\Delta q = \sqrt{((2.21(T_{aa} - T_{aw})^{1/3} + 4\sigma T_{aa}^3)\Delta T_{aa})^2 + ((-2.21(T_{aa} - T_{aw})^{1/3} + 4\sigma T_{aw}^3)\Delta T_{aw})^2}$$

Calculation results based on initially selected values are given in Table 2.

Table 2. Input data and error assessment results for heat flow

Input data		Results		
Tap	Twp	q	Δq	%
300	295	44.05	2.76	6.27

The obtained results show that the error is 6.3%, which is rather accurate measurement.

It has been shown that when reaching certain accuracy of measurement, the assessment error of a heat flow through building envelopes can be defined with engineering accuracy with certain precision of metering instruments.

CONCLUSION

The primary advantage of the obtained calculation method is the rate with which the measurement object is monitored. This allows obtaining real values of heat energy losses by envelopes. This methodology can also be applied to other objects of monitoring, such as heating appliances, boilers, furnaces or heating pipes and systems.

One of the advantages of this approach is its universal nature and applicability in various external conditions. In this case, the additional error in measurements can be contributed by weather conditions, but if they are reliably considered, they have no significant effect on measurements and errors.

Using automatic adjustment systems in apartment building will allow increasing the energy efficiency of thermal and electrical power used by population, which enables substantially reducing overhead costs in generation of this power. Energy-saving is also possible when using smart adjustment systems in production. All these measures will finally result in reduced energy capacity in Russia and will allow it taking the leading position in effective use of energy resources.

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