FORECASTING OF ECOLOGICAL SITUATION IN COURSE OF BUILDINGS' DESIGN

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Abstract

Design of buildings requires the all-round forecast aimed at the provision of ecologically safe environment in buildings while minimizing power consumption. To increase the efficiency of design solutions and indoor air quality "IAQ" the inner environment of a building and its surrounding environment shall be treated as a single dynamic system (SDS). In the process of forecasting of the environment in course of buildings design the integrated approach is used: experimental researches and numerical simulation. The article provides the examples of the creation of ecologically safe environment using CFD method.

Key words: ecological safety, mathematical simulation, buildings design

In recent years, Russia has shown the trend for the implementation of "green construction" approach which conversely requires not only a higher quality of design and construction of buildings, but also reliable methodologies for assessment of the environmental situation in the course of design of buildings, especially in large cities. Applying only regulations on the design stage, unfortunately, do not guarantee ecologically safe and comfortable environment in the buildings. Design technology for residential and industrial buildings based on mathematical simulation simultaneously solving problems of the structural physics, heating, ventilation, energy saving and environmental protection will allow for the determination of the best performance of buildings assigned for different purposes throughout their life cycle with maximum use of ambient energy.

Ecological safety of designed buildings means a set of requirements for a comprehensive assessment of the design solutions which in course of construction and operation of the facility will provide a comfortable living environment with minimum energy consumption and minimal amounts of solid and liquid waste. Environmental safety requirements for residential buildings, their placement in the settlement areas, for building constructions and engineering systems are adopted in accordance with current regulations (STO NOSTROI 2.35.4-2011; RMD 23-16-2012).

To assess the ecological safety of residential buildings a comprehensive indicator of ecological safety (CIES) is suggested; its numerical values (similar to the energy efficiency class) show the ecological safety class of residential buildings. This method (CIES) is based on the rating system using 54 indicators of ecological safety (IES) as initial values; each of these indicators contributes to the CIES assessment (Datciuk et al., 2013). Qualitative and quantitative IES are grouped into six clusters that characterize the various aspects of the living environment. Each cluster has the upper and lower boundaries of the significance range of its IES. This developed methodology uses a prioritization method for assessment of the ecological safety of residential buildings.

Accuracy of the assessment of ecological safety of residential buildings in turn depends on accuracy of the initial values of IES. There is a set of basic IES for assessment of the living environment quality, quantitative values of which shall be strictly determined in the course of objects design. The inner environment of a building and its surrounding environment should be considered as a single dynamic system (SDS), which is characterized by the set of IES. The building envelope where complex processes of heat and mass transfer take place is divided into subsystems: internal and external ones. Features of the processes of heat and mass transfer in the SDS are treated as dynamic communications (Datciuk, 2009).

Set of basic IES includes:

for external subsystem — wind speed, dynamic pressure and the concentrations of harmful substances near the facades of buildings, the temperature and humidity of the outside air, solar radiation flow;

for internal subsystem — temperature, air humidity and mobility, allowable concentration of harmful substances, daylight factor (DF), solar insolation duration, air change rate;

for building envelope — transmission and infiltration heat transfer coefficients, vapor permeability, air permeability and sound insulation of building envelope, features of air supply units.

The quality of the internal environment of buildings during the operation will depend on the quality of investigation of the SDS processes and determination accuracy of the basic IES at the design stage as well as on the peculiarities of their space distribution.

To select effective design options and assess ecologically safe environment for designing buildings Saint Petersburg State University of Architecture and Civil Engineering uses an integrated approach, which includes experimental assessment of thermal characteristics of new insulation materials and building envelope, translucent structures, features of the air supply units, computer simulation of aerodynamic mode of development, air pollution caused by emissions from motor vehicles and other sources within the buildings, heat and mass transfer processes in building envelopes and microclimate of the designed buildings. The developed approach is also effective in the design of industrial enterprises and has been implemented, for example, in the course of design of the Boguchany and Taishet aluminum smelters. Computer simulation is performed using “ANSYS” and “STAR-CD” software products (Grimitlin, 2013). The program is used for the calculation of atmosphere pollution with low emissions (Datciuk, 2000). The following are the examples of the suggested approach.

The first stage is about the analysis of the processes taking place in the external subsystem and identification of the values and features of the distribution of IES in the location of the building zone (dynamic pressure and concentration of harmful substances near the facades of the building). Figure 1 shows a wind stream flow around the building and the formation of the wind shadow area when the wind direction is normal to the longitudinal axis of the building. This is obtained by computer simulation of the external subsystem.

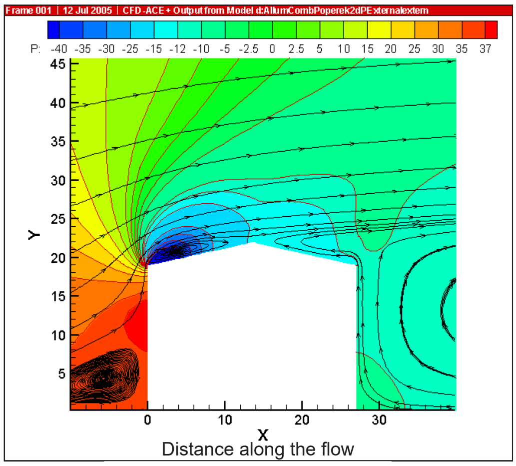

Figure 1. Pressure field and streamlines of the wind flow around the building

We need to know the distribution of pressure near the building facades and ventilation shafts locations for the reliable operation of the natural ventilation system. If the ventilation shaft for the prevailing wind direction is located in a zone of high dynamic pressure, the ventilation “tipping” is very possible.

It is well known that one of the major air pollutants in the cities is urban transport. Heavy traffic, underground garages, car parking stations located in residential buildings or near them as well as emissions from industrial enterprises lead to air pollution. The nature of urban pollution due to low sources is related to the complex structure of air streams and the location of the city roads (Rusakova, 2015). In the wind shadow areas (circulation areas) located near buildings the concentration of pollutants from vehicle emissions often exceeds allowable values. Presence of polluted air in residential buildings leads to the development of chronic diseases of the breathing passages such as asthma, bronchitis as well as to the diseases of the nervous system. For example, in the course of analysis of the air environment of the libraries there have been found the substances which could have been carried into the building only from outside (Kobyakova, Uspenskaya, 1998).

The second stage deals with the analysis of heat and mass transfer processes in building envelopes and the quantitative values of IES which are determined and further used for determination of the energy efficiency class of buildings. Incorrect assessment of the transmission and infiltration coefficients of the heat transfer of the building leads to underestimates of the specific energy consumption. It is a common situation when a building project is referred to the class “A”, however, at the commissioning of the facility (according to the results of field measurements) the energy consumption corresponds to the class “C” only. Unfortunately, it occurs not only due to the construction quality, but also to the inaccurate calculation.

To meet the requirements of energy saving the building envelopes of the modern buildings use different types of insulation materials and structural components. Accurate value of the transmission coefficient of heat transfer of

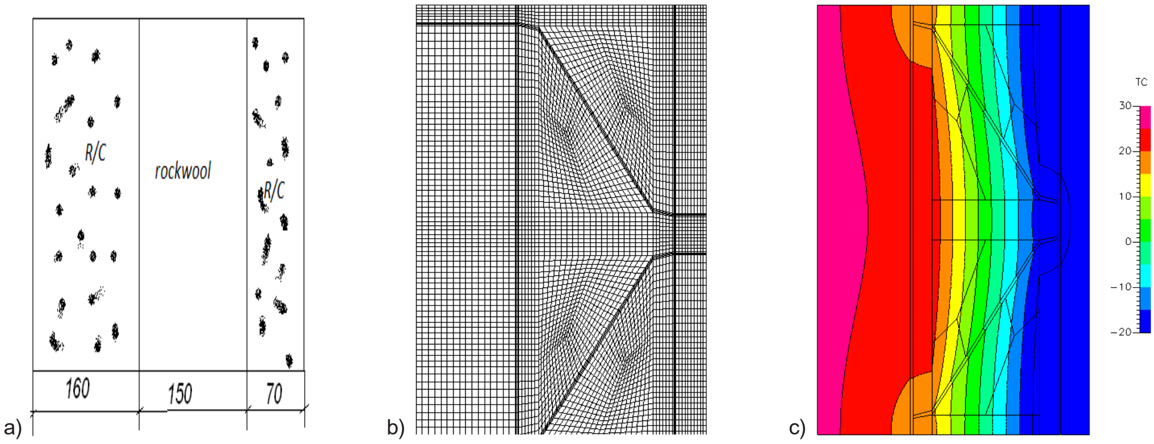

Figure 2 Examples of calculation of the temperature field of the slab piece: a) Slab piece; b) Computational grid; c) Temperature field of the specific slab piece

exterior walls and ceilings depends on the coefficient of heat engineering homogeneity for determination of which it is necessary to conduct tests on specific fragments of structures in a climate chamber and make computer calculation of temperature fields. The values of the reduced resistances to heat transfer calculated on the basis of engineering techniques, unfortunately, are not proven by laboratory experiments.

For example, the results of the tests of the reinforced concrete slab with thermal insulation and flexible communications made by "Peikko" and obtained during the complex studies including testing in a climate chamber and computer simulation of the temperature distribution in the slab are shown in Fig. 2. The experimental value of heat engineering homogeneity coefficient of the slab is 0.82 and the reduced value of resistance to the heat transfer of the body of the slab R = 3.1 m2 C/W. In areas of communications arrangement the deformation of the temperature field is observed (Fig. 2c).

When tested in a climate chamber the slab piece with thermal profile widely used in construction practice showed the dependence of the thermal resistance of the structure on the time of the test. Within 3 days thermal resistance fell by 10%. The coefficient of heat engineering homogeneity according to the test results is 0.65.

It is much more difficult to determine the infiltration heat transfer coefficient of the building accurately. Infiltration air flows mostly through the leaks of translucent structures. Generalization of the results of tests on breathability of window units executed in the EC of Saint Petersburg State University of Architecture and Civil Engineering on the results of 10 years has shown that window units which are mostly used in the construction of standardized at 10 Pa let to come less than 5 kg/(h m2) of external air that corresponds to the regulatory requirements for air permeability of the windows made of PVC window profile, however, it is not sufficient to ensure regulatory air change rate. Installation of special air supply units and their choice should be based on the results of complex certification tests.

Ventilation devices: wall and window flaps, or special hardware (for example, "ActivPilot" system by "Winkhaus" with the function of parallel shift of the PAD, PADK, PADM sash) should meet the following requirements:

— amount of the incoming air has to provide the required air exchange rate;

— sound insulation of the translucent structure with a flap is to provide valid values of sound pressure level in residential buildings, especially at night;

— the valve surface temperature is to be above the dew point to avoid condensation;

— distribution of cool air in the room when the air supply unit is opened has to ensure a sufficient degree of mixing eliminating abrupt change in temperature gradient.

The third stage deals with the analysis of the quality of indoor air based on the space interconnection of dynamic processes occurring inside the premises and in the surrounding atmosphere of the building (Datciuk at al., 2014). The amount of air and pollutants coming into the premises is assessed. The simulation of heat and humidity mode was performed in one- and two-room apartments using "STAR-CCM+" hydrodynamic suit. It was a non-stationary problem: temperature field in the outer walls was formed on the basis of the calculations. The calculations took into account wind pressure, ambient air temperature, thermal performance of building envelopes. Resistance to the heat transfer of the outer wall R1 = 3.1 m2 oK/W and of a window unit R2 = 0.56 oK/W was determined in accordance with the regulatory requirements for St. Petersburg.

The simulation was performed for the winter conditions. Outdoor temperature was minus 26°C, the internal air temperature was plus 20°C. Heating device, a convector, was simulated as a rectangular block on the top of which calculated heat flow to compensate heat loss and heat the inlet air was set. The amount of air taken out of the apartment was 110 m3/h: 50 m3/h of the sanitary unit and 60 m3/h of the kitchen. The cross sections of air supply units have been chosen the way that there was single air exchange in the room.

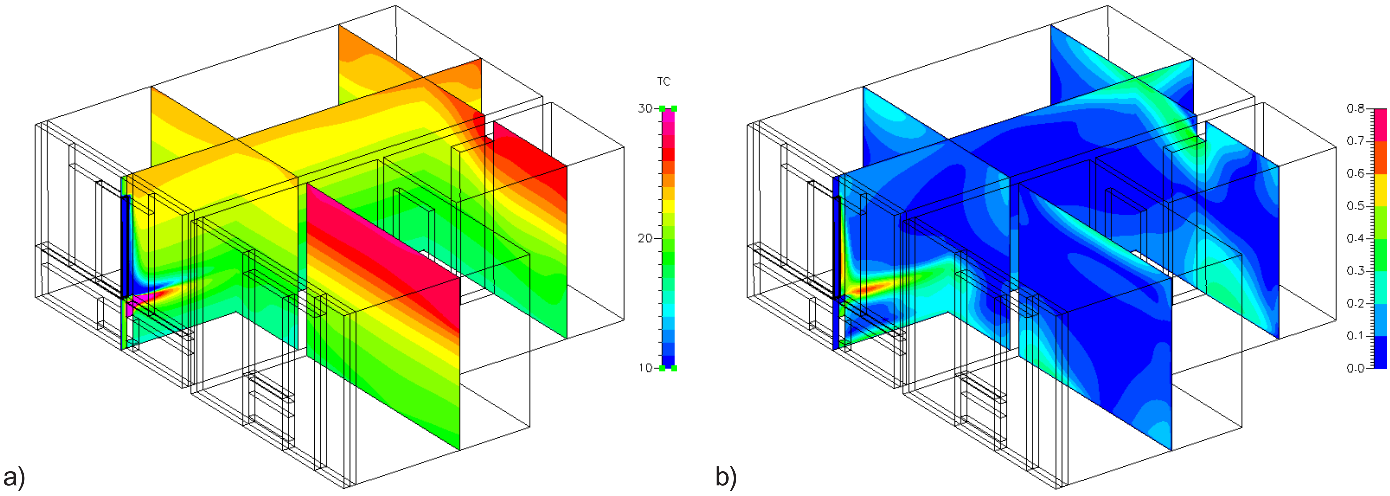

Figure 3. Results of computer simulation of IES distribution (air temperature and velocity) in the one-room apartment: a) The temperature field in the apartment; b) Velocity field in the apartment

As an example, Figure 3 shows the velocity and temperature fields while airing of the one-room apartment through a window unit with “ActivPilot” system accessories with a feature of parallel shift of the sash located in the room. Analysis of the IES distribution showed that areas of increased temperature are located in the locations of suction holes. After installation of the convectors cool air coming through the leaks is heated quickly. Stagnant zone is located at the top of the corridor.

To conclude it should be noticed that the suggested integral approach to the assessment of the quantitative values of the basic IES allows for forecasting of the ecological situation in course of buildings design.

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