On Modelling of Influence of Air Condition of Building on Gas-Consuming Equipment with an Open Combustion Chamber Functioning

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Abstract. Nominal operation of gas consuming equipment with an open combustion chamber installed in the various purposes buildings’ premises depends on the receipt of the required amount of air to ensure the complete combustion process. The supply of primary air in an amount of 40-60% of the theoretically required volume allows a stable process of gas combustion. In this case, flame separation is prevented. Requirements for safe operation of the gas consumption system are satisfied. For reliable operation of the gas distribution system, it is necessary to provide installation of the automation devices that respond to any deviations in gas burners. In the process of gas fuel burning, two cones are formed. The internal cone in which the gas burnt is provided by the primary air. In the outer cone of the flame gas is burnt due to air coming from the room. In the lower part of the burner, conditions are created under which the velocity of the gas-air flow and the normal velocity of flame propagation are ensured. This ensures the creation of an incendiary belt, which constantly ignites the air-gas mixture, and provides a stable and constant combustion of gas. The inflow of air into the room where the gas consuming equipment is located is through the filling of light holes during infiltration. Increasing the resistance to air permeation of filling the light apertures is performed to improve the energy efficiency of the building by means of reducing infiltration heat loss. Reduction of natural inflow through constructive non-densities in the fillings of the light apertures leads to a decrease in the infiltration process, and, consequently, to the violation of the process of the nominal functioning of the gas consuming equipment. The possibility of creating an air regulation mechanism for individual rooms and the building is considered, ensuring the influx of the required amount of air, depending on the parameters of the outside air, the air permeability of the fillings of the light apertures, and also the height of their location. Analytical dependencies that consider the effect of the air condition of buildings for various purposes on the joint operation of natural ventilation systems with an unorganized inflow in the required volume, excluding the formation of the effect of reverse thrust in the combustion products removal system are presented.

1. Introduction
As a source of heat for residential buildings, as well as for water heating in the hot water supply system, automatic heat generators, a device designed to generate thermal energy by burning gas, are used. Gas heat generators with an open combustion chamber are connected to an individual chimney, and the combustion air is taken directly from the room. It is allowed to use automated gas heat
generators with an open combustion chamber in residential apartment buildings up to 15 meters high. The location of heat generators, the chimney utilities and facilities, as well as the air ducts should ensure the safety of their operation, ease of maintenance and repair. The supply air ducts must enable the inflow of the necessary volume of air for the combustion of gas, and the chimneys - the complete removal of the combustion products into the atmosphere. The design and the location of the chimneys and air ducts are determined in accordance with the architectural and planning decisions of the room [1-8].

The systems of the air supply and removal of the combustion products of heat generators, taking into account local climatic conditions, are designed according to the following schemes: with a combined air supply and removal of combustion products; different air supply and removal of the combustion products by built-in or attached collective air ducts and chimneys; an individual air duct providing the air intake through the wall and its supply individually to each heat generator, and removal of flue gases by a collective chimney.

A united technological system for supplying the required volume of air in the building's premises considers a set of air, thermal and gas modes for a normal operation of the gas-consuming equipment with an open combustion chamber [9-14].

The principle of operation of ventilation and smoke channels is based on the thrust arising from the difference in the air pressure inside and outside the channels. Since the density of the air decreases with the increasing temperature, as a result, the temperature difference between the internal and external air leads to the pressure difference, contributing to the process of the outdoor air penetration through the leaks in the enclosing structures and periodically opened windows and transoms into the room (infiltration). Provided is an uncontrolled flow of the fresh air. Thus, the main condition, which enables a sufficient traction in normal temperature conditions is the provision and maintenance of a constant air inflow for the air exchange in the different purpose rooms, as well as the full operation condition of ventilation and smoke channels.

2. Problem formulation

In the mass housing construction the following scheme of ventilation is used in the apartments: the exhaust air is removed directly from the area of its greatest pollution, i.e., from the kitchen and sanitary facilities, through natural exhaust duct ventilation. Its replacement is due to the outside air coming through the leaky external enclosing structures (mainly, the window filling) into all rooms of the apartment and heated by the heating system. Thus, the air exchange is provided in its whole volume. The modern housing construction is focused on the family apartments, where the apartment doors, as a rule, are open or have a trimming of the door leaf, reducing their aerodynamic resistance in the closed position.

In the living rooms and the kitchen, the air flow is provided through adjustable window flaps, transoms, vents, valves or other facilities.

Natural ventilation of residential rooms should be carried out by the air flow through the windows, transoms, or through special holes in the window sashes and ventilation channels.

For the normal operation of the gas-consuming equipment in the design mode, it is necessary to provide a constant supply of the required amount of air. The schematic diagram of the organization of the process of entering the air into the room where the gas-consuming equipment is installed is shown in figure 1. The conditions are provided as follows:

\[
\max \{ R_{\text{exhaust ventilation}} = f(G_{\text{exhaust ventilation}}) \} \leq R_{\text{light opening}} = f(G_{\text{light opening}}) \leq R_{\text{vent duct}} = f(G_{\text{vent duct}}). \tag{1}
\]
3. Theoretical part

The state of the air environment of the premises during the operation of gas-consuming equipments affects the safe life of the resident.

If the gas is burning with the excess of air (normal combustion conditions without clogging the ventilation and smoke ducts), the operation of the gas devices, which have been installed in the room, results in formation of the combustion products consisting of carbon dioxide, water vapor, nitrogen and oxygen. In addition to the components (CO2, H2O, N2 and O2) the combustion products may contain incomplete combustion residues of the gas – carbon monoxide (CO), formaldehyde (CH3O) and other compounds.

The components formed in the process of gas combustion have a negative impact on the human body, so they must be timely and sufficiently removed from the room.

The presence of significant amounts of combustion products in the air under the open combustion of gas reduces the concentration of O2 in the air, which also adversely affects human health. The gas contamination of premises by gas combustion products without their removal can reach large values, given that the combustion of 1 m$^3$ of natural gas consumes about 2 m$^3$ of oxygen and produces 1 m$^3$ of carbon dioxide, 2 m$^3$ of water vapor and 7.5 m$^3$ of nitrogen.

The presented Analytical study of the gas pollution of a typical room by combustion products is performed on the example of a typical room with the specified parameters.

The study investigates a room with a volume $A$ in m$^3$, in which a gas device is installed that releases the combustion products $C$ in m$^3$/h directly into the room. The initial gas content of the room is denoted by $X_1$, and the gas content of the room air after the operation of the gas device during the time $\tau$, expressed in hours, is denoted by $X$. Thus, the gas content of the room air during the operation of the gas device will change from the value $AX_1$ to $AX$. Let’s consider the change in the magnitude of the air gas content of the room in time.

At the time moment $\tau + dt$, the gas content of the room volume will be $AX + AdX$. Taking into account that the changes in the temperature and the pressure of the infiltrated air through the translucent external enclosing structures will be insignificant, it can be assumed that the amount of the outdoor air, which is injected into the room $G$ $dt$ with the gas contamination $X_{0}$, will be withdrawn from the room by diffusion through the leaks in the walls and other internal room enclosures in the same amount $G$ $dt$, but with gas contamination $X$. Under the similar conditions (in the presence of the outdoor air infiltration and the indoor air diffusion), the gas content of the room $AX$ (for a period of time $\tau$) at the time moment $\tau + dt$ will be expressed by the equation

$$AX + AdX = AX + (c \, dt + GX_{0} \, dt - GX \, dt)$$  \hspace{1cm} (2)
This equality is the main differential equation of the process of the air infiltration through the exterior enclosing structures and the diffusion through the inner enclosures of the room. The left part of the equation expresses the increase in gas content during $\tau + d\tau$ time, and the right part expresses the gas content during the same time taking into account the release of the gas combustion products by gas-consuming equipments and their removal from the diffusing air. It follows from the equation (1):

$$AdX = (c + GX_0 - GX)d\tau$$  \hspace{1cm} (3)

After transformations:

$$\frac{dX}{c + X_0 - X} = \frac{G}{A}d\tau$$  \hspace{1cm} (4)

For the constants $G$, $X_0$ and $C$, this equation transforms into a first-order differential equation with separating variables. Integrating the left part of the equation within $X_1 - X$, and the right part within the time range $0-\tau$, we get:

$$x = x_1 \cdot e^{\frac{G}{A} \tau} + (x_0 + \frac{c}{G}) \cdot (1 - e^{\frac{G}{A} \tau}).$$  \hspace{1cm} (5)

The resulting equation takes into account the products of combustion (fumes) contained in the infiltration air, through the translucent exterior enclosing structures $X_0$, $X_1$ – the products of combustion contained in the air prior to the beginning of operation of the gas appliance, and $c$ – the products of combustion emitted from the gas appliance into the room.

Considering the effect of the gas device on the change in the gas content of the room air by the combustion products and assuming that $x_1 \neq x_3$, the expression (4) takes the form:

$$\Delta x = x - x_0 = \frac{c}{G} \left(1 - e^{\frac{G}{A} \tau}\right).$$  \hspace{1cm} (6)

The increase of gas content occurs in time according to the exponential law, but the value of the gas content measurement cannot be higher,

$$\Delta x = \frac{c}{G},$$  \hspace{1cm} (7)

which has been got at $\tau \to \infty$.

The required resistance to the air permeability of the window is defined as:

$$R_{need} = \frac{1}{G_N} \left(\frac{\Delta P}{\Delta P_0}\right)^{\frac{3}{2}}, m^2 \cdot h / Pa / kg,$$  \hspace{1cm} (8)

$G_N$ – normative air permeability, kg / m$^2$ h;

$\Delta P_0$ – the difference in air pressure on the outer and inner surface of the window, at which the resistance to the air permeability is determined (10 PA);

$\Delta P$ – the difference in air pressure on the outer and inner surface of the window, Pa;

$$\Delta P = 5,4 \cdot H_1 (\rho_{out} - \rho_{int}) + 0,29 \cdot \rho_{int} \cdot v_{air}^2,$$  \hspace{1cm} (9)

$H_1$ – height from the middle of the first floor window to the top of the ventilation shaft, m;

$v_{air}$ – air flow velocity, m / sec;

$\rho_{out}; \rho_{int}$ – the density of the air, respectively, at the temperature $t_{out}$ and $t_{int}$ for an ordinary living room, kg/m$^3$ is determined according to the formula:

$$\rho = 353 / (273 + t), \hspace{0.5cm} \kappa \rho / m^3.$$  \hspace{1cm}

4. Application results
The given example of calculation refers to the joint work of ventilation and smoke removal systems in the building, where the ducts of the smoke removal from the gas-consuming equipment and ventilation
ducts ceased to function for emergency reasons in the apartment 1. The scheme shows the gas-air mode of that part of a two-storey building, where the apartment 1 is located on the first floor and ventilation and smoke channels are closed for emergency reasons.

The outdoor air is subject to infiltration through translucent exterior enclosing structures and penetrates into the apartment 1 of a residential house. When the ventilation channels and a chimney duct are closed, the pressure in the apartment under investigation increases, the combustion products enter the premise of the combined bathroom and flow into the adjacent rooms of the apartment. The concentration of products of the incomplete combustion of the natural gas reaches its maximum permissible values within 5 minutes.

Due to the increase in pressure, through leaks and cracks in the internal enclosing structures, the products of the incomplete combustion of the natural gas are diffused into the neighboring apartments 2 and 4, which have the common structures and where the indoor pressure is much lower due to the work of natural ventilation in the apartment 4 and a smoke exhaust duct in the apartment 2, than in the apartment with the source of pollution (apartment 1). Thus, the concentration of the harmful combustion products increases in the apartments № 2 and 4, having common structures (walls and ceilings) and threatens the safe life of the occupants.

The outdoor air temperature - 100°C, and the speed of the outdoor air was 3 m/sec. The apartment 1 has been subject to operation of a gas heater without removing the exhaust air, which prevented the inflow of the outside air and thus the air exchange. As a result, a vacuum is created inside the room, which worsens the combustion mode and provokes the rollover of the draught. These conditions contribute to the release of the carbon monoxide in the environment due to the insufficient oxygen concentration in the room of the apartment in question, that is, there was a burning of a poor gas-air mixture. The gas water heater has been of a lower efficiency and heat emissions, which led to an increased release of the carbon monoxide (CO). The carbon monoxide emissions have not been released into the atmosphere, and almost fully have penetrated in the area of the apartment 1, as well as the adjacent apartments 2 and 4.

Thus, there was no air exchange in the living area of the apartment 1 of the residential building in which the gas appliances were installed, i.e. it was not sufficient for the draught in the flue and ventilation ducts in normal temperature conditions.

The air exchange in the premises of the apartments № 2 and 4 of the residential house, in which the gas appliances were installed, was less normative, but sufficient to remove the combustion products from the gas-consuming equipment, that is, the presence of traction.

![Figure 2](image-url)  
Figure 2. The scheme of the air-gas mode of the part of the building, where on the first floor there is an apartment with closed ventilation and smoke duct.
5. Conclusions
The chimneys must be provided with thermal insulation of non-combustible materials. The thickness of the thermal insulation layer should be calculated to ensure the maximum temperature on the surface is not higher than 45 °C and the temperature of the flue wall in the operating mode higher than the dew point temperature of the flue gases at the lowest design temperature of the outdoor air.

The height of the flues from the heat generators in the buildings and the trace of the chimneys and the air supply systems ensuring the operation safety and reliability should be taken according to the results of the aerodynamic calculation and verification by the conditions of the harmful substance dispersion in the atmosphere.

For residential buildings with a height of more than 15 meters, when using apartment heat supply systems, the air supply and exhaust ventilation should be provided with the mechanical drive.

The maintenance of gas pipelines, gas equipment, chimneys and flues should be carried out in accordance with the temporary order of the gas equipment maintenance procedure in residential houses and public buildings.

Being clogged, the ventilation ducts disturb the air exchange of the room and low the oxygen concentration in the premise, which leads to a decrease in the efficiency and the heat transfer of the gas water heater and the combustion of the poor gas-air mixture, that is, the release of the combustion product-CO (carbon monoxide).

The reason for the flow of the carbon monoxide (carbon dioxide) into the premise with installed gas-consuming equipments, can be: installation of sealed fillings of the light openings; insufficient capacity of the ventilation duct; hermetically sealed doors and windows of the apartment.

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