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ORIGINAL RESEARCH
PAPER



Elimination of the main damage of the ventilation system of the boiler premise

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ABSTRACT

The article is devoted to solving of urgent problem: creation of staff work safety in the boiler room due to ensure of required conditions by natural ventilation. The aim of the work is to eliminate the main damage of the natural ventilation system of the boiler premise by using of compact air jet due to correction coefficients and updated results. Static and dynamic air pressure, difference of static pressure due to wind, aerodynamic coefficients and air balance for necessary nature ventilation of the boiler premise as well temperature correction coefficient are established. The update calculation dependencies for determining of the air static pressure and its volume flow rate in the boiler room have been obtained. Updated graph, monogram, and analytical equations for natural ventilation calculation of boiler room are presented.

KEYWORDS

boiler room, natural ventilation, flow rate, air velocity, air pressure

1. INTRODUCTION

Premise indoor climate [1–4] directly influences both on the human physiological body in particular and the effectiveness of the personnel works in general. Task of premise ventilation is ensuring of the organization of air exchange [5, 6], air distribution in a room [7, 8] and, as a result, normative indoor air parameters. Thus, demands concerning comfortable air velocity and temperature in the room serviced area [9–11] must be satisfied. Besides this, ensuring of energy saving [12–14] is desirable.

It should be noted that the boiler room must provide a minimum of three times the air exchange per hour. This value applies to natural exhaust ventilation, not mechanical. These measures are aimed at maintaining the maximum safety of the boiler room staff. The air balance of the boiler room should be shifted towards the supply ventilation, as the amount of air flow should compensate for the exhaust ventilation, and the process of gas burning in the boiler requires additional air ΔL [15]. The aerodynamic situation in the boiler room is determined by the supply air jets. Compact air jets are usually used for inflow, which are optimal in terms of aerodynamics and design of air distributors. In this regard, during the commissioning of the boiler room and during commissioning works in the preparatory period, the certification of the boiler room ventilation system is carried out in accordance with the requirements of regulatory documentation.

2. PREVIOUS RESEARCH AND PROBLEM STATEMENT

Free air jets have no obstacles with their flow, and compressed air flows are limited in their development. But the boiler room is a small premise, which is overloaded with technological

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equipment and staff. This creates compressed conditions for development of air jets [16]. The current air velocity is lower than in the case of the free air jets. Therefore, it is required a larger amount of tidal air. In this case, it is more difficult to ensure the normative parameters of the air in the working area [17–19]. In this case, it is more difficult to ensure the normative parameters of the air in the working area; because of air velocity is bigger, than it should be. As a result, it is necessary to use air distributors with the lowest possible attenuation coefficient m . This is achieved by greater turbulence [20–22] of the air flow by increasing aerodynamic local resistance. The most common in boiler rooms are air distributors, which form the compact air jets.

Analysis of previous research has testified that a comfortable state of a person in any premise depends on air temperature [23–25], temperature of the premise surfaces [26], air velocity, dynamic indoor climate, concentration of CO_2 in the premise, noise level, humidity, light, thermal resistance of clothing, etc. The indoor climate also depends on energy saving situation of building [27, 28], heat source [29, 30], internal systems (heating [31] and ventilation), external systems (gas and heat supply), as well renewable energy sources [32, 33]. In particular indoor climate of boiler premises should be according to normalized parameters of internal air of the boiler room. Air distribution in the boiler rooms was considered and analyzed for being most appropriate to be used indoors. It was taking into account first of all the attenuation of tidal air jets [34]. Among the most common air jets (swirl, flat, round, compact, rectangular, etc.), compact ones deserve attention. There are also appropriate mathematical models [35–37] to create an adequate hypothesis regarding the air flow velocity, air pressure and aerodynamic coefficients.

Very often 3-time air exchange in the boiler premises is not satisfied, which means that the ventilation system has main damage. This negative phenomenon is extremely common. This results in not only to excessive concentration of CO_2 in the room, but also to its gassiness. Ensuring comfort and safety conditions in the boiler rooms by using of compact air jets is an extremely important task.

3. THE PURPOSE OF THE ARTICLE

The purpose of this article is elimination the main damage of the natural ventilation system of the boiler premise by using of compact air jet for of staff work safety due to: establishment of updated equations for determination of boiler premise natural ventilation; determination of internal aerodynamic coefficient due to proposed method; establishment of the correction coefficient concerning external and internal air temperature.

This requires: to research static pressure of external and internal air environment and equations for its determination; to develop the theoretical knowledge of natural ventilation of boiler rooms; to research the axisymmetric (compact) air streams and obtain calculation equations; to

perform theoretical and experimental research of the boiler room natural ventilation; to create charts and obtain empirical dependencies for determination of the internal aerodynamic coefficient, volume air flow rate in the boiler room, correction coefficient concerning external and internal air temperature.

4. RESEARCH OF THE BOILER ROOM NATURAL VENTILATION

The article continues air dynamic investigations [7, 16]. The variation of the flow rate was provided. This required to realize experimental investigations and to determine numerically of ventilation system productivity in the boiler premise.

As it is known [8], that compact air flow is popular in air distribution techniques. They are often applied as horizontal flows. A hole for axisymmetric (compact) air streams is round, square or rectangular close to square. The compact air jets have suitable velocities characteristics, velocity attenuation coefficient, and the aerodynamic resistance coefficient. The initial velocity of the air stream and the size of the supply nozzle are decisive in determining the speed of air flow in the boiler premise.

In the article there is proposed unification of all formulas for obtaining the aerodynamic characteristics of the axisymmetric (compact) streams in universal form. For universality all values are presented as dimension-less. Boilers and staff in the boiler premise significantly affects the distribution of air speed [16]. Combustion of gas requires excessive tidal air. Efficiency of the ventilation system can be increased due to use of the round, compact and rectangular tidal air jets and exhaust ones. Thus, optimal air distribution scheme at presence boilers and personnel in a low height boiler premise [16] is air supply to the working area by horizontal round, rectangular or axisymmetric (compact) air streams.

Here the axisymmetric (compact) horizontal air streams in the low height boiler room are investigated. In ventilation technique air tidal is realized through inlets by non-isothermal turbulent compact air streams. Air exchange in the boiler room is due to the static pressure difference between outdoor and indoor air caused by wind [38]. The distribution of pressure and velocity of the outside air on the surface of the windward facade depends on the height. As the altitude increases, the air velocity also increases.

Let us determine the indoor air velocity due to the difference of static pressures Δp :

$$v = \sqrt{\frac{2\Delta p}{\rho}}, \quad (1)$$

where v is the air velocity, m s^{-1} ; Δp is the difference of static air pressures, Pa; ρ is the air density, kg m^{-3} .

It should be external air temperature at air density determination.



To determine the difference in static pressure Δp it is necessary to know the aerodynamic coefficients. They represent the ratio of the corresponding static pressure to the dynamic one. Aerodynamic coefficients on windward façade k_w , zone of aerodynamic shadow k_{as} and internal k_{in} are determined by Eqs (2)–(4), respectively:

$$k_w = \frac{p_w}{p_{dyn}}, \quad (2)$$

$$k_{as} = \frac{p_{as}}{p_{dyn}}, \quad (3)$$

$$k_{in} = \frac{p_{in}}{p_{dyn}}, \quad (4)$$

where p_w , p_{as} and p_{in} are the static air pressure on windward façade, in zone of aerodynamic shadow and internal one respectively, Pa; k_w , k_{as} and k_{in} are the dimensionless aerodynamic coefficients on windward façade, in zone of aerodynamic shadow and internal one respectively; p_{dyn} is the dynamic air pressure, Pa.

It should be noted that the value of k_w is always positive, k_{as} is negative, and k_{in} can be both positive and negative depending on the aerodynamic situation in the boiler room. The inflow is due to the pressure difference $\Delta p_t = p_w - p_{in}$, and it hoods $\Delta p_e = p_{in} - p_{as}$, but the pressure difference is the same: $p_w - p_{in} = p_{in} - p_{as}$. Based on Eqs (2)–(4) the equations: $p_w = k_w p_{dyn}$, $p_{as} = k_{as} p_{dyn}$ and $p_{in} = k_{in} p_{dyn}$ can be obtained. The pressure difference for the tidal (5) and exhaust (6) of air, respectively:

$$\Delta p_t = p_{dyn}(k_w - k_{in}), \quad (5)$$

$$\Delta p_e = p_{dyn}(k_{in} - k_{as}), \quad (6)$$

where Δp_t , Δp_e are the static pressure differences for tidal and exhaust air respectively, Pa.

Using Eqs (5) and (6) it is determined the flow rate for tidal L_t and exhaust air L_e :

$$L_t = \mu_t F_t \sqrt{\frac{2\Delta p}{\rho}}, \quad (7)$$

$$L_e = \mu_e F_e \sqrt{\frac{2\Delta p}{\rho}}, \quad (8)$$

$$L_t = \mu_t F_t \sqrt{\frac{2p_{dyn}(k_w - k_{in})}{\rho}}, \quad (9)$$

$$L_e = \mu_e F_e \sqrt{\frac{2p_{dyn}(k_{in} - k_{as})}{\rho}}, \quad (10)$$

where L_t and L_e are the tidal and exhaust air flow rate respectively, $\text{m}^3 \text{s}^{-1}$; μ_t and μ_e are the flow rate dimensionless coefficients of tidal and exhaust air respectively; F_t and F_e are the openings area of tidal and exhaust air respectively; m^2 .

The flow rate dimensionless coefficients of tidal and exhaust air depend on openings form, material, etc., and are usually in limits 0.6–0.7.

To determine the flow of ventilation air L unknown value is only the internal aerodynamic coefficient k_{in} all other values are known. The article offers a graphical and analytical way to solve this problem. The graphical solution is to calculate the ventilation air flow rate L at two values of the internal aerodynamic coefficient k_{in} . To increase the accuracy of the result, it is advisable to choose one value positive and the other negative. In this case, 2 solutions can be obtained: in one the amount of supply air will be greater than $L_t > L_e$, and in the second – the exhaust $L_e > L_t$. The equality of these quantities, i.e., the air balance is represented by the point A of intersection of the graphs in Fig. 1. From this graph the internal aerodynamic coefficient k_{inr} and the amount of ventilation air L_r are determined as a result of problem decision.

It should be noted that the value of the internal coefficient is affected by the phenomenon of door opening/closing. Opening the door results in increase of tidal air flow and an increase in the internal coefficient, and closing it restores the initial situation. Opening the door is a short-term and temporary phenomenon, and the main position of the door is considered “closed”.

The analytical method is to take into account the equality of Eqs (9) and (10). After transformation Eq. (11) the following is obtained:

$$\frac{\mu_t F_t}{\mu_e F_e} = \sqrt{\frac{k_w - k_{in}}{k_{in} - k_{as}}}. \quad (11)$$

Let us present the left part of Eq. (11) by a certain dimensionless constant c_1 and obtain Eq. (12):

$$\frac{\mu_t F_t}{\mu_e F_e} = c_1. \quad (12)$$

Taking into account Eq. (12) it results in:

$$\frac{k_w - k_{in}}{k_{in} - k_{as}} = c_1^2, \quad (13)$$

The final solution is:

$$k_{in} = \frac{k_w + k_{as} c_1^2}{1 + c_1^2}. \quad (14)$$

According to this value, calculated by Eq. (14), it is determined the amount of ventilation air L , based on the air balance in the boiler premise. But it should be noted that this will be the amount of L_e exhaust air. Since it is necessary to take into account the additional amount of tidal air ΔL for

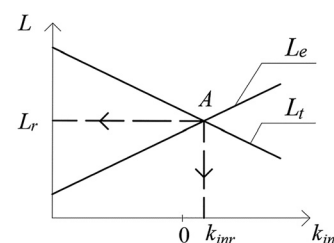


Fig. 1. Graphic way to determine the amount of air

combustion of gas in the boiler, the amount of supply air L_t is determined from Eq. (15):

$$L_t = L_e + \Delta L, \quad (15)$$

It should be noted that the productivity of natural ventilation for public buildings is determined at an outdoor temperature of 5 °C. Calculation of the natural ventilation of heating boiler rooms is carried out at an outdoor temperature 8 °C, which is associated with the beginning of the heating season (Fig. 2). Determination of the productivity of natural ventilation in most cases is carried out at real ambient and exhaust air temperatures that do not coincide with the calculated ones. In this regard, there is a need to recalculate the determined productivity L of natural ventilation at real conditions to the required productivity under the calculated conditions L_c . In general, the performance of the exhaust duct is determined from the Eq. (16):

$$L_e = \mu_e F_e \sqrt{\frac{2gh(\rho_{ext} - \rho_{in})}{\rho_{in}}}, \quad (16)$$

where L_e is the exhaust air flow rate, $\text{m}^3 \text{s}^{-1}$; F is the area of the exhaust duct, m^2 ; g is the acceleration of gravity, m s^{-2} ; ρ_{ext} and ρ_{in} are the air density at external and internal temperature respectively, kg m^{-3} ; h is the height of the exhaust duct, m .

Given that for exhaust channel F_e , μ_e , g , h are constant values, Eq. (16) becomes (17):

$$L_e = c_2 \sqrt{\frac{\rho_{ext} - \rho_{in}}{\rho_{in}}}, \quad (17)$$

where the dimensionless constant, c_2 is determined from Eq. (18):

$$c_2 = \mu F \sqrt{2gh}. \quad (18)$$

On the basis of Eq. (17) the ratio $k = L_c/L$ of exhaust ventilation productivities L_c and L at calculated temperature and the real one are proposed, respectively,

$$\frac{L_c}{L} = \sqrt{\frac{t_{inc} - t_{extc}}{t_{in} - t_{ext}}}, \quad (19)$$

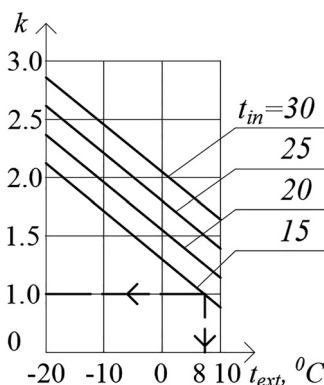


Fig. 2. Nomogram of recalculation of productivity of natural exhaust ventilation

where t_{inc} , t_{extc} are the calculation temperatures of exhaust and external air respectively, °C; t_{in} , t_{ext} are the real temperatures of exhaust and external air respectively, °C.

On the basis of Eqs (16) and (18) (barometric pressure of 745 mm of mercury) the nomogram (Fig. 2) is made. It allows recalculating the value of exhaust ventilation at various temperature conditions. The calculated productivity L_c for which $k_c = 1$, is reduced to the conditions of $t_{ext} = 8$ °C and $t_{in} = 15$ °C. The estimated air exchange L_c is determined from Eq. (20) due to pre-determined ratio $k = L_c/L$,

$$L_c = Lk. \quad (20)$$

If the value of L_c determined from Eq. (20) and nomogram is greater than the normative air exchange, it is necessary to reduce the productivity of exhaust ventilation, and if less – to increase it by installing additional natural extraction by increasing the area F of the exhaust hole. To perform analytical calculations, the nomogram (Fig. 2) has been approximated by Eq. (21):

$$k = 0.68 + 0.045t_{in} - 0.056t_{ext} + 6t_{in}t_{ext}10^{-4}. \quad (21)$$

The experimental investigations of the air distribution have been carried out in the boiler premise under following conditions and simplifications: all air jets were slightly non-isothermal; air volume flow rate was approximately within: $L = 400\text{--}500 \text{ m}^3 \text{h}^{-1}$ ($0.11\text{--}0.14 \text{ m}^3 \text{s}^{-1}$); the initial velocity of air in nozzles for supply was in the range of: $v_0 = 2\text{--}6 \text{ m s}^{-1}$; the cross section area of openings $F_0 = 0.02 \text{ m}^2$. Air velocity has been measured by thermal anemometer Testo-405 using a coordinate system with a grid of points $5 \times 5 \text{ cm}$. Due to measured initial average air velocity $v_a \text{ m s}^{-1}$, it has been determined hourly air volume flow rate $L, \text{ m}^3 \text{h}^{-1}$, from Eq. (22):

$$L = 3600v_a F, \quad (22)$$

where v_a is the initial average air velocity, m s^{-1} ; F is the air outlet space area, m^2 .

So as not to cause the main damage in the natural ventilation system it is required hourly air volume flow rate $L, \text{ m}^3 \text{h}^{-1}$ of air stream to determine according to Eq. (22). After that it is necessary to make a temperature correction according to nomogram (Fig. 2) and Eq. (20). To obtain satisfactory experimental results of measurements of air velocity in the boiler room it should take into account both external and internal air temperature. Obtained data testify a satisfactory convergence of results. The obtained results allow calculating with higher accuracy the air volume flow rate needed for the ventilation of the boiler premise according with normative documents. This developed method allows more accurately determine the needed air volume flow rate for the boiler premise natural ventilation to eliminate the main damage to the ventilation system of the boiler room and ensure safety work for staff.

5. CONCLUSIONS

Graphical and analytical dependencies for determination of air flow rate for compact air streams in the boiler room have been received, that testify experimentally.



The updated calculation dependencies and nomogram for determination of needed air volume flow rate in a boiler room are obtained, taken into account internal aerodynamic coefficient and both external and internal air temperatures.

Proposed method allows more accurately determine the needed air volume flow rate for the boiler premise natural ventilation eliminates major damage to the ventilation system of the boiler room and ensures both health and the safety of personnel.

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