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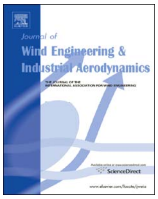

Influence of wind on natural smoke and heat exhaust system performance in fire conditions

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ABSTRACT

This paper presents the results of a numerical study that examines the influence of wind on the performance of natural smoke and heat exhaust systems employing natural smoke ventilators, natural smoke ventilators equipped with deflectors, wall-mounted ventilators on the back façades of buildings and wall-mounted ventilators on the front façades of buildings. The authors present design methodologies along with traditional methods for estimation of the influence of wind on system performance. In the numerical study, three interchangeable natural smoke ventilation systems are presented and evaluated under different wind conditions. For the worst-case scenario, compared to no-wind conditions, the difference in the resulting flow for roof ventilators is 23,6% lower, while the performance of wall-mounted ventilators is reduced by 37% for tests designed with the same assumptions. This study also shows that laboratory estimates of the flow coefficient cannot be simply extended into an efficiency estimate for a complete system. A case with a commonly made mistake is also presented that shows flow into the building instead of out of it, which means that the system is not working at all. Conclusions regarding currently used design methodologies are given.

1. Introduction

Natural smoke and heat ventilation systems (NSHEVs) are a group of technical solutions used in buildings to ensure a required level of fire safety in the buildings, as required by the European Union's Construction Products Regulation (CPR) (UE, Regulation (EU), 2011). As a crucial part of ensuring this safety, the elements of the system should pass additional tests and requirements, as stated in detail in EC Mandate 109 M/109 Mandate to CEN and CENELEC (1996) and hEN standard 12101-2 CEN (2003).

NSHEVs can be considered the simplest and cheapest effective tools for the removal of smoke and hot combustion products out of protected buildings. Their principle of operation involves the natural difference in density between the surrounding air and the hot smoke and gases produced in the fire that causes buoyant forces to act, pushing the smoke out of the protected volume. NSHEV systems can have a strong influence on the safety of buildings by

- increasing the time available for people to evacuate from the building, the so-called available safe evacuation time (ASET), by reducing the threat posed by hot and toxic gases produced in the fire;
- slowing down fire growth by limiting the temperature of the smoke and thus reducing the radiation returned to combustible materials in the building;
- improving the safety of rescue operations in the building by reducing both the amount and the temperature of the smoke inside of the building.

There are some challenges in the design process of NSHEVs that are mainly connected with how the mass flow through the ventilators is determined under fire conditions. A problem that causes most of the issues with this approach is that the industry focuses on determining and improving the flow parameters of individual smoke ventilators, while the designer is responsible for evaluating the flow through the complete system in a building. As this study shows, a common simplification involving the summarization of areas by their coefficients falls short of actual system performance.

2. Natural smoke and heat system design

In Poland, the most commonly used reference design standard is Polish standard PN-B-02877 (PN-B-02877, 2001), which is based on the similar German standard DIN 18232 Teil 2 (DIN, 2007). The design methodology described in these documents is based on evaluation of the fire risk in buildings, as evaluated through risk factors and

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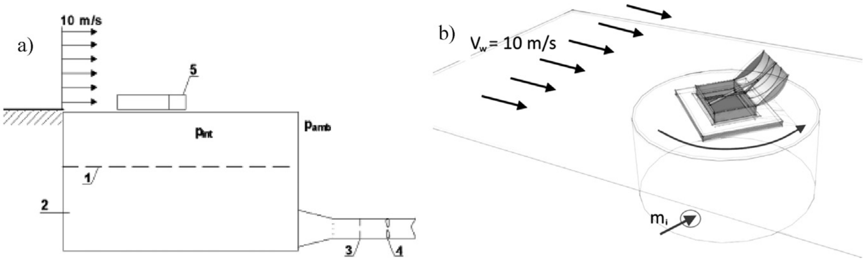

Fig. 1. Schematic drawing of the test chamber (1a) and a 3d visualization (1b) of the setup used in discharge coefficient assessment (CEN, 2003). Key: 1 – screen, 2 – settling chamber, 3 –volume flow measurement, 4 – fan 5 – smoke vent.

tables. The designer assigns the building an appropriate risk class and then determines the percentage of the roof area of the analysed fire zone that must be equipped with natural smoke ventilators. This method has little to do with evaluating optimal system performance and, as expected, fails to provide it in most real-life applications. Other approaches that involve modern design methodologies (VDI, 2006; BSI, 2003; NFPA, 2015) determine the required number of smoke ventilators based on the size of the design fire and air supply. These methodologies originate in the work of Thomas et al. (1963) and others (McCaffrey, 1979; Hansell, 1993), who applied Bernoulli's law to the flow of hot smoke and combustion products from burning compartments to their surroundings. As complex as they are, the methods shown below in Eq. (1) (BSI, 2003) and (2) and (3) (VDI, 2006), require considerable knowledge on the part of the designer about the fire itself. Variables that are boundary conditions for the analysis include the depth of the smoke layer, the temperature of the smoke, and mass flows within the compartment. Even with this detailed information, the result of the calculation is just a general overview of the approximate total area of ventilators required to protect the compartment, but without any information on the individual features of these ventilators (e.g., aerodynamic free area, opening angle).

$$A_{vtot} C_v = \frac{M_l T_l}{\left[2\rho_{amb}^2 g d_l \theta_l T_{amb} - \frac{M_l^2 T_l T_{amb}}{(A_i C_i)^2}\right]^{\frac{1}{2}}} \tag{1}$$

where: A_{vtot} – total required area of smoke ventilators [m^2], C_V – discharge coefficient of smoke ventilators, M_l – mass flow of smoke [kg/s], T_l – average temperature of smoke [K], ρ – ambient air density [kg/m^3], g – gravity [N/kg], Θ – increment of smoke temperature [K], T_{amb} – ambient temperature [K], A_i – total area of inlets [m^2], C_i – discharge coefficient of inlets [dimensionless].

$$A_{vtot} = \frac{\dot{V}}{\bar{c}_v}\sqrt{\frac{T_{amb}}{2g\Theta d - \frac{1}{\bar{c}_i^2} w_i^2 T_l}} \tag{2}$$

$$A_i = \frac{1}{w_i}\left(\frac{\dot{m}_l}{\rho_{amb}} - \dot{V}\right) \tag{3}$$

where: A_{vtot} – total required area of smoke ventilators [m^2], C_v – discharge coefficient of smoke ventilators, C_i – discharge coefficient of air inlets, T_{amb} – ambient temperature [K], T_l – average temperature of smoke [K], g – gravity [N/kg], w_{zu} – flow velocity referred to the geometrical surface area of inlets [m/s], Θ – increment of smoke temperature [K], A_i – total area of inlets [m^2], m_l – mass flow of smoke in fire plume [kg/s], ρ_{amb} – ambient air density [kg/m^3], V – volume flow of air supplied by mechanical means [m^3/h].

Despite the complexity of the calculation procedure, it still does not account for the influence of wind on system performance, besides the introduction of a discharge coefficient for the ventilator.

3. The discharge coefficient of natural smoke and heat ventilators

As NSHEV performance is dependent on wind, its negative influence is traditionally stated in the form of a discharge coefficient (C_v), which varies in value between 0,20 and 0,80. The NSHEV area multiplied by the discharge coefficient is referred to as the aerodynamic free area and is considered to be the effective area of an NSHEV system through which the flow of hot smoke occurs under wind conditions. As it is the only parameter describing the "performance" of the device, the manufacturers of natural smoke ventilators often improve their discharge coefficient values by mounting additional elements, such as fairings or directing jets, on ventilators or by increasing the opening angles of the devices. In addition to the increases in their C_v values, the global efficiency of such solutions in buildings remains unknown. In accordance with harmonized standard EN 12101-2 (CEN, 2003), the discharge coefficient of a ventilator is evaluated with (C_{vw}) and without (C_{v0}) the side wind, Fig. 1.

During the EN 12101-2 test (CEN, 2003), the ventilator is mounted on the top of the settling chamber, which is located beneath the wind tunnel floor in such a way that its roof is level with the wind tunnel floor. The air velocity in the tunnel should be 10 m/s (± 0,5 m/s) and the turbulence intensity should not exceed 20% (10% at a certain height). The uncertainty of the measurement is not limited by the standard, but it must be sufficient to measure the relevant limiting values. The wind attack angles are altered by the rotation of the settling chamber, together with the ventilator mounted on it. According to EN 12101-2, the value of the discharge coefficient for a single pressure point at the most severe wind attack angle is determined with Eq. (4), below. Next, through the use of mathematical regression, the value of the inferred coefficient can be determined for similar devices made by the same producer, depending on their opening angle, the height of the ventilator and the deflector and the aspect ratio of the ventilator throat area.

$$C_V = \frac{\dot{m}_{in}}{A_v\sqrt{2\rho_{amb}\Delta p_{in}}} \tag{4}$$

where: m_{in} - mass flow into the settling chamber [kg/s], A_v – total area of the tested ventilator [m^2], ρ_{amb} – ambient air density [kg/m^3], Δp_{in} – pressure difference between the settling chamber and the wind tunnel [Pa].

It is important to note that, in many applications, the discharge coefficient is independent of the wind effects, as it is usually included as a form of pressure difference. In the estimation of the C_v value in the standardized procedure, this approach is reversed. That is, for a constant wind velocity (10 m/s) and pressure (constant value between 3 and 12 Pa), the mass flow rate through the ventilator is found. This treatment of wind effect is inefficient; it can be only used as a tool for comparison of two different devices under the exact same conditions, but it cannot be expected to determine the performance of a ventilator under a wide range of external conditions, as implied by its inclusion in Eqs. 1–3. In the opinion of the authors, the C_v value and the performance of the ventilator both depend on the local wind velocity