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A review of ventilation opening area terminology

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ABSTRACT

The design of a natural ventilation strategy requires the establishment of the location and size of a series of purpose provided ventilation openings (PPOs). The success of the design is dependent on knowledge of the aerodynamic performance of the PPOs often described by their geometry (normally an area) and resistance to airflow. The incorrect interpretation of this information can lead inappropriate ventilation strategies and buildings that overheat and have an excessive energy demand.

Many definitions of PPO area are used by standards, guidelines, text books, and software tools. Each can be assigned multiple terms and a single term can be assigned to different definitions. There is evidence that this leads to errors in practice. An *effective* area of a PPO, defined as the product of its discharge coefficient and its *free* area, is proposed as a standard description because it is unambiguous and its measurement is governed by recognised standards. It is hoped that PPO manufacturers will provide an *effective* area as standard and that its use will be recognised as best practice. It is intended that these steps will reduce design errors and lead to successful natural ventilation strategies and better buildings.

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1. Introduction

Openings located in the thermal envelope of a building comprise those that are intentional, known as purpose-provided openings (PPOs), and those that are unintentional, known as adventitious openings [24]. It is desirable to minimize adventitious openings to minimize a building's energy demand and to ensure the satisfactory operation of a system of PPOs [37]. When designing a ventilation strategy that comprises a system of PPOs, a fundamental objective is to establish their location and size. Both factors depend on the airflow rates required through each PPO for a given pressure

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drop in order to maintain adequate indoor air quality (IAQ) and to dissipate heat gains under limiting conditions [12]. Accordingly, a description of the geometry of each PPO and its resistance to airflow are required in order to enable a designer to establish the performance of a system using envelope flow models [12–24]. The same information can also be used when working with more complex simulation tools to ensure that a building meets relevant energy and indoor environment quality (IEQ) criteria, such as indoor air quality (IAQ), thermal comfort, overheating, and noise levels. The geometrical information and resistance to airflow of a specific PPO can also be used to compare the relative aerodynamic performance of other PPOs.

The information about a PPO should comprise an indication of opening geometry, normally an area, a coefficient of discharge and an indication of its dependence on Reynolds number.[1] These factors are related and cannot be considered in isolation. An incorrect interpretation of the resistance to flow through an opening can have serious consequences, such as inadequate airflow through a space with consequent overheating and/or air quality issues, or PPOs that are oversized and hence too expensive.

This paper reviews existing terminology used to describe the geometry and aerodynamic performance of PPOs. A brief overview of relevant theory and terms is given in Section 2 and these are then used in Section 3 in order to review the terminology used by regulatory and guideline documents and software tools. Here, examples of similarities, differences, and even contradictions, are given. Section 4 briefly considers an emerging body of anecdotal evidence of confusion in the industry about the terminology used to describe the geometry and aerodynamic performance of PPOs. It also provides an example of the consequences of term conflation. In Section 5 we state preferred definitions of terms and recommend those that should be used by standards and guidelines, both in the UK and elsewhere.

2. Theory

2.1. Single opening

A circular *sharp-edged orifice* (see Fig. 1) can be defined as an opening of circular geometry with unsmoothed edges, and a length, L (m), that is significantly shorter than its hydraulic diameter, d_h (m),[2] so that $L/d_h < 2$ [24].

The turbulent uni-directional airflow rate, Q (m^3/s), through any sharp-edged opening is proportional to its cross-sectional (measurable, geometric) area, often known as a *free area*, A_f (m^2). It is also a function of the pressure drop across the opening ΔP (Pa), the density of the air ρ (kg/m^3), and the shape of the opening so that

$$Q = C_d A_f \sqrt{\frac{2\Delta P}{\rho}} \tag{1}$$

Here, C_d is a dimensionless discharge coefficient used to account for the constriction of streamlines after flow passes through the orifice. The cross-sectional area of the flow downstream of the orifice is smaller than that of the orifice itself and so C_d is a positive number less than 1. Fig. 2 shows a series of *streamlines* through an orifice that are tangential to the direction of airflow at every point so that airflow does not occur across a streamline. Fig. 2 also shows that as air passes through the orifice it accelerates and contracts

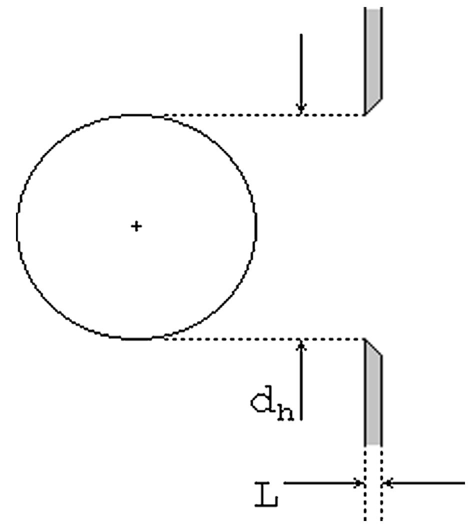

Fig. 1. Circular sharp-edged orifice where $d_h \gg L$.

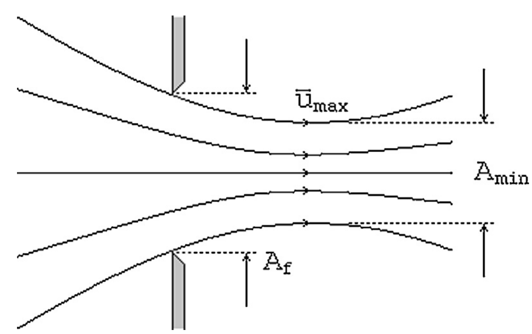

Fig. 2. A *vena contracta* located downstream of a sharp-edged orifice where $A_f > A_{min}$.

to form a *vena contracta*, the point at which streamline velocity is highest, $u_{\max}$ (m/s), the streamlines are parallel, and the flow area is smallest, $A_{\min}$ (m). The phenomenon occurs because the streamlines cannot readily change direction as they pass through the orifice. The air in contact with the edge of the opening is stationary because of the *no-slip*[3] boundary condition at that point. For a given *free area* $\left(A_f\right)$ of an opening, the resistance to the flow provided by the stationary fluid in contact with the edge increases with the length of the perimeter of the opening. Therefore, the discharge coefficient is a function of the shape of the opening; the greatest ratio of cross-sectional area to perimeter length occurs with a circular opening, and hence as opening shapes become less circular the discharge coefficient decreases.

If the airflow is not fully turbulent then caution is required and measurements should be taken to establish an appropriate relationship between Q and ΔP. In practice, this issue may arise if a single PPO is comprised of a number of small openings in parallel, such as an insect mesh.

An orifice is an ideal tool for measuring the rate of flow of a fluid, such as air, because the location of streamlines is fixed so that C_d is independent of the mean velocity of air, $\bar{u}$ (m/s), when $Re > 100$ [24]. A C_d is measured under still-air conditions with uniform density so that the airflow through the opening is exclusively generated by a fan. The discharge coefficient of a standard circular sharp-edged orifice, C_{d_o}, is frequently given as $C_{d_o} = 0.61$ [2,12,24].

[1] A Reynolds number (Re) is the non-dimensional ratio of the inertial and viscous forces in a fluid, in this case air. Therefore, Re is a function of the mean velocity of air, $\bar{u}$ (m/s), that passes through a PPO. It follows that a discharge coefficient that is dependent on Re is therefore also dependent on $\bar{u}$.

[2] An hydraulic diameter (d_h) is a characteristic length used to describe openings of non-circular geometry [26]. For a circular opening d_h is equal to its diameter.

[3] The condition states that at a solid boundary a viscous fluid has zero velocity relative to that boundary.