

# Heady mix



## Masterclass

Professor Doug King

In his third masterclass, **Professor Doug King** looks at some of the mechanics of room air movement

**W**hen we are designing ventilation or air conditioning systems, it is important to find an efficient means of delivering fresh or conditioned air to the room, and, ensuring even distribution without causing discomfort due to draughts or temperature fluctuations. There are two principal means of air delivery: mixing ventilation and displacement ventilation.

Mixing ventilation, as its name suggests, aims to achieve a mixed condition so that the air quality and temperature is uniform throughout the room. This is accomplished by introducing the supply air with sufficient momentum to stir up the air in the room. The supply air becomes thoroughly mixed with the room air within a short distance from the supply grille, which means that we can use greater temperature differentials in order to deliver heating or cooling into the space.

Displacement ventilation uses the natural convection generated by heat sources within the room to create the air movement without mixing. The supply air is introduced at close to the desired room condition, directly to the occupied zone, whilst overheated air convects away for extraction at ceiling level.

It is worth understanding the mechanics of room air movement, as this allows us to quickly assess the likely success of ventilation systems without needing to resort to in-depth analysis. Essentially, we need to know whether our air movement is turbulent, creating mixing, or laminar, when simple convection will dominate.

When air is introduced through an orifice from a high-pressure zone into a low-pressure zone, as in any mechanical ventilation system, it forms a characteristic flow pattern, known as a jet (see Figure 1). At the edges of the jet, the moving air interacts with the stationary room air, creating a ring of vortices around the laminar



core of the jet. In this turbulent boundary some of the room air is entrained into the jet and dragged along with it. This causes the jet to expand conically but, as the mass of moving air increases, the velocity decreases in order to conserve momentum. After some distance the turbulence penetrates the core of the jet and the jet velocity decays rapidly with further distance. Empirically it has been determined that the angle of expansion of a jet is constant at  $11.8^\circ$ . Now, due to the conservation of momentum, the mean jet velocity at a distance from the orifice is inversely proportional to the mass of air it contains, which is proportional to its cross-sectional area.

**Turbulent flows dominate most ventilation scenarios. Here a buoyant plume is created when air rising by stack effect expands into a wider space above the balcony rail. The smoke reveals the turbulence at the boundary layer**

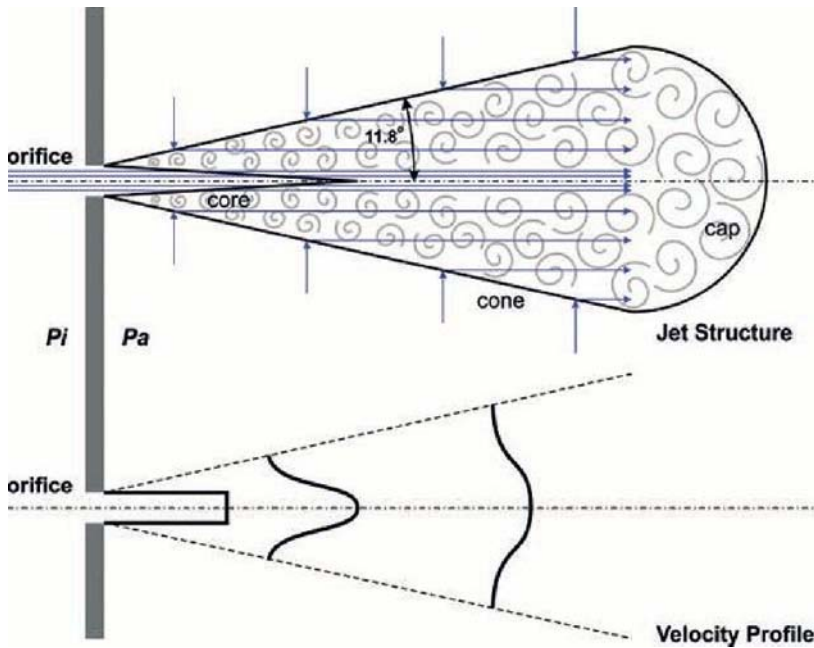


Figure 1: A jet is a stream of air created by a pressure difference across an orifice, as in most supply air situations, even a breeze through an open window. The jet has a turbulent interface with the static air through which it passes, resulting in mixing between the two air masses

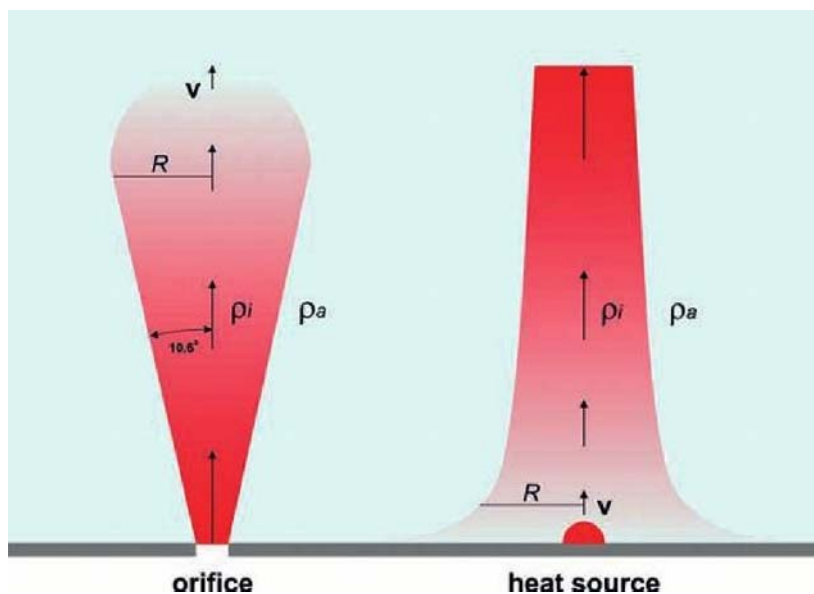


Figure 2: A buoyant plume (left) is similar to a jet, but is created when air passes through an orifice driven by a difference in density. A laminar plume (right) occurs when the change in density is caused by a heat source within the room

> Therefore, knowing the angle for expansion allows us to perform simple calculations on the jet such as the distance travelled before the mean velocity drops to an imperceptible level. Similarly, if the supply air is initially at a different temperature to the room air, the entrainment will also change the temperature of the jet along its length due to mixing, and we can estimate the mixed-jet temperature using the same rule of thumb.

An isothermal jet in free air will travel in a straight line. As air is entrained into the jet there must be momentum perpendicular to the jet axis, as indicated by the inward streamlines in Figure 1. As the entrainment occurs equally from all directions, these momentums balance, satisfying conservation of momentum and creating an all-round pressure that constrains the jet to travel in a straight line. A jet at a different temperature to the room air will still expand at the same rate as an isothermal jet, but its axis will follow a trajectory dictated by the buoyancy of the air in the jet relative to the surrounding air.

A buoyant plume is very similar to a jet in its characteristics, being a stream of air from an orifice whose propagation into the room is driven by a temperature difference rather than pressure (see Figure 2). A buoyant plume has the same turbulent mixing at the boundary layer, although with a slightly reduced angle of expansion of 10.6°. It is rare to find genuine plumes in ventilation systems as the air is almost always introduced to the room with some pressure difference.

Plumes may, however, be encountered in natural ventilation design, for instance where a room has an opening roof-light admitting cool air. Plumes were also sometimes used to introduce mixing ventilation in Victorian theatres, where there was sufficient headroom for cool air to mix with room air before entering the occupied zone.

The aim of air conditioning design, particularly in cooling, is to ensure that the supply air jet has adequately mixed with the room air and its velocity has decayed sufficiently so that it does not give rise to discomfort through cold draughts. One well-established way to increase the distance travelled by a jet or plume is to use the ceiling effect. It has been observed that if a cold supply grill is located close to a ceiling, the resulting jet travels further before succumbing to negative buoyancy (see Figure 3).

If a jet is introduced close to a surface, it tends to attach to the surface and expand more slowly, travelling further than a jet in free field. As the jet propagates, it is unable to expand in all directions; it is constrained by the surface on one side, but expands freely in the opposite direction.

As room air is only being entrained into the jet from one direction, this results in unbalanced momentum, creating a pressure that keeps the jet pressed against the surface. This unbalanced momentum probably has as much to do with jet attachment to surfaces as the Coanda Effect, the tendency of a flowing fluid to follow a surface.

Now let's look at laminar flows. When a heat source is introduced into a room, we observe natural convection as air around the source is warmed, becomes buoyant and rises. Air is drawn in from the surroundings to replace the air displaced by convection. This creates a laminar plume which, following the same laws for the conservation of momentum, accelerates as it rises and contracts, but does not involve any turbulent mixing with the room air (Figure 2). This is the source of room air movement in a displacement ventilation system.

However, the method of introducing the supply air is critical to ensure that the displacement effect works correctly. In many instances the grilles chosen for displacement systems are too small, and thus introduce the air with a pressure difference creating a turbulent

### ■ The method of introducing the supply air is critical to ensure that the displacement effect works correctly ■

jet. Similarly, if supply air is too cold in relation to the room air, it is possible to create a buoyant plume, again creating turbulent mixing and upsetting the laminar flows.

The choice between mixing and displacement ventilation and the location of supply air grilles can depend on a large number of variables. So having a brief understanding of the nature of turbulent and laminar flows allows us to quickly assess the likely room conditions from a proposed ventilation solution. This saves us having to know the final grille selections in order to use manufacturer's nomograms; nor do we need to spend time on complex computational fluid dynamics (CFD) analysis in the early stages of a design. ●

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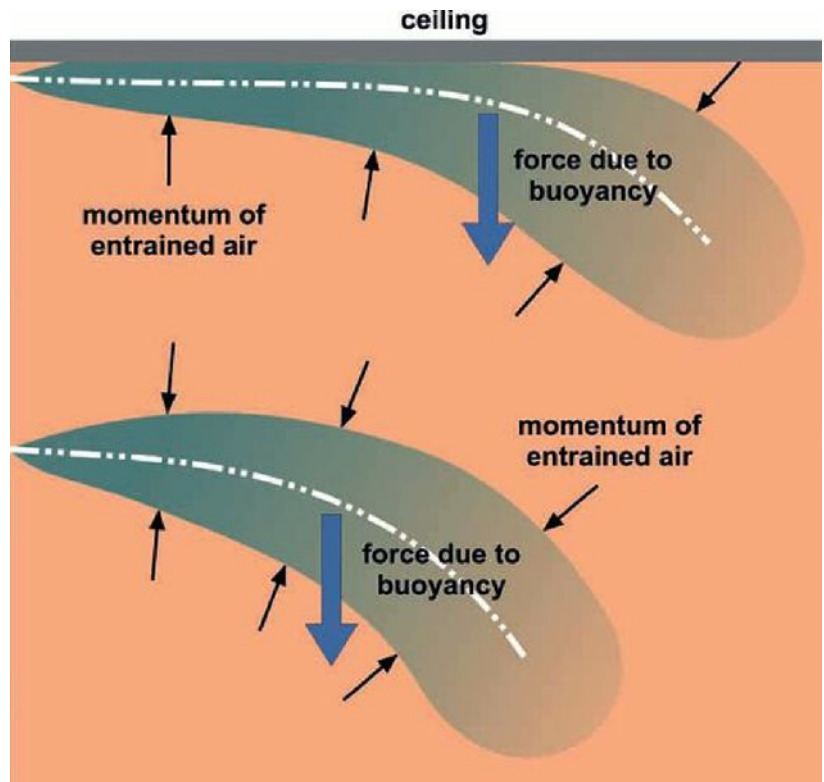


Figure 3: A jet at a different temperature to the room air is subject to gravity: its path is determined by its buoyancy. The ceiling effect is often used to overcome the negative buoyancy of cold supply air

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