Building and Environment 91 (2015) 51–60

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

A perspective on fifty years of natural ventilation research

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ARTICLE INFO

Article history:
Received 1 December 2014
Received in revised form
22 February 2015
Accepted 24 February 2015
Available online 5 March 2015

Keywords:
Natural ventilation
Buildings
Historical review
Research

ABSTRACT

A brief history is given of research into natural ventilation over the first fifty years of the Journal, from the personal perspective of the author. One of my aims is to give an indication of the contribution that the Journal has made to reporting research on this subject. Another aim is to provide a background for researchers who are starting out in research. There are nine areas of research that I have identified, namely:- steady envelope flow models; flow characteristics of openings; unsteady envelope flow models; internal air motion, zonal models and stratification; contaminant transport; age of air; CFD and its applications; scale modelling; full-scale measurements. For reasons given in the text, some of these topics are only very briefly mentioned. For example, the sections on contaminant transport and CFD are relatively brief, partly because they are the subject of other papers in this issue. (Similarly, the feasibility of natural ventilation relies on the adaptability of the occupants to be comfortable, but thermal comfort is not covered at all here, because it too is the subject of other papers.) The paper concludes with a few personal comments on the design process, since the underlying aim of research is to minimise the risks associated with naturally ventilated buildings.

1. Introduction

At the outset I wish to emphasise that the article is a personal perspective on the history of natural ventilation research. To a large extent therefore it is conditioned by my own experiences. I also wish to make it clear that the article is not a state of the art review; it is a history, and inevitably covers research that nowadays might be considered outdated.

My acquaintance with the journal (and with ventilation) began in the early 1970's when I came across the review paper on tracer gas measurement techniques by Hitchin and Wilson (1967) [1]. This connection has continued in one form or another (reviewer, contributor, Associate Editor, Board Member) to the present day. Incidentally, Barry Wilson was the first editor of *Building Science* (and Roger Hitchin was eventually a colleague of mine). *Building Science* eventually became *Building and Environment*.

My aim is to give a brief history of natural ventilation research over the past fifty years of the Journal, which could be of general interest as a record of developments. It could also be of use to researchers starting out today, since it will give them a background to what has been done in the past, and why. There are several points to note. First, although it is a personal perspective, I do have experience of co-authoring or authoring two reference books [2,3], on ventilation. The latter is purely concerned with natural ventilation, whereas the former also covers mechanical ventilation. This brings me to the second point, namely that natural ventilation is fundamentally different to mechanical ventilation, due to its strong dependence on weather conditions. However, theoretical models and experimental methods developed for mechanical ventilation are often applied to natural ventilation by assuming truly steady flow conditions (i.e. slowly varying conditions). The third point is that I have biassed the choice of references to those from the Journal. This seems reasonable, bearing in mind that the aim is to celebrate the contribution that the journal has made to expanding knowledge in the field. With this in mind, it will be appreciated that the choice of references has no particular significance as far as precedence is concerned.

To keep the paper within a reasonable length, reference is made to sections in the books [2,3] in the following way:- E&S4.2 and E4.2 refer respectively to Section 4.2 in Refs. [2,3]. Readers who wish for further information can refer to my Website [4], which includes corrections to the books.

To conclude this section, I wish to explain what I mean by the term “natural ventilation” and some other terms. A building envelope that is naturally ventilated is one for which the ventilation

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http://dx.doi.org/10.1016/j.buildenv.2015.02.033
0360-1323/

occurs through openings in the envelope, as a result of pressures generated across the openings by the action of wind and buoyancy. There are two basic types of opening – purpose-provided (e.g. air vents) and adventitious. Adventitious openings are simply all openings that are not purpose-provided (cracks in building components such as windows and doors are known as component openings, and other cracks are known as background openings). Ventilation that occurs through adventitious openings has a specific name i.e. infiltration. Rather confusingly, ventilation that occurs specifically through purpose-provided openings is often called natural ventilation. This is not strictly correct, because an envelope that has no adventitious openings probably does not exist, so some infiltration will always be present. The term "passive ventilation" usually refers to natural ventilation, sometimes meaning a system equipped with chimneys and air vents. The terms "hybrid" and "mixed-mode" refer to some form of combined natural and mechanical ventilation system. Such systems are not considered here. The term "leakage" refers to a measure of the size of openings in an envelope (usually with purpose-provided openings sealed). The leakage is the flow generated by a specified pressure difference across the envelope.

1.1. Overall developments in natural ventilation

As a starting point, I believe it is useful to consider the overall changes that have taken place over the past fifty years in the UK. Similar changes in other countries will be recognised, and in some respects the UK has followed developments elsewhere, particularly in Northern European countries and countries with similar climates.

In the residential sector, the UK has a tradition of naturally ventilated single-family dwellings, which of course goes back much more than fifty years. In the winter, ventilation was provided by purpose-provided air vents and by adventitious openings. In the summer, openable windows could be used as desired. In the non-residential sector, the situation was more mixed, often with smaller buildings naturally ventilated and larger buildings mechanically ventilated. One characteristic that UK buildings had in common was that their envelopes tended to have high adventitious leakage. In the 1970s there was a perceived shortage of fossil fuels and one way of alleviating this problem was to reduce the energy consumption (primarily heating) associated with infiltration (the ventilation occurring through adventitious openings). Such was the international importance of this, it led to the setting up of the Air Infiltration Centre in 1979, which held its first conference in 1980 [5]. Important areas of research were the calculation and measurement of infiltration and leakage, construction techniques for reducing leakage (countries with severe climates, such as the Scandinavian and North American countries, led the way in this area). This represented a big change in the UK and can be summarised by the mantra "build tight, ventilate right", which reflects the fact that building tight is not enough; it is necessary to ensure that purpose-provided ventilation is adequate for air quality, comfort and safety. This led to much research in these areas throughout the world, and which continues to this day.

In the 90s, the stimulus for natural ventilation changed to concerns about environmental pollution arising from fossil fuels and more recently, of course, climate change (global warming) has become the dominant driving force. This has led to research into improving natural ventilation as a cooling system, either on its own or as part of a passive cooling system (a passive cooling system is one that uses no, or relatively little, artificial energy e.g. increased thermal mass with night ventilation). In the UK, this has led to the increased use of natural ventilation in non-residential buildings (sometimes as part of a mixed-mode system).

Another recent development in the UK (following developments in Europe and Scandinavia) has been the desire in some quarters for extremely tight envelopes in residential buildings, allied to purpose-provided air vents or balanced mechanical systems with energy recovery. The fact that envelopes with zero leakage are seriously being considered shows how far construction techniques have developed. However, in my opinion it is questionable whether such envelopes are desirable from the health and safety viewpoint (air vents can be blocked; mechanical systems can deteriorate or fail). Furthermore, the tradition in the UK is for the occupants to have direct control over ventilation, and this tradition may be difficult to overcome.

In the non-residential sector, modern concerns are with intelligent buildings and with control of natural ventilation, as well as the continuing desire to improve design procedures. Intelligent buildings adapt themselves to such things as the weather conditions or occupancy e.g. by changing the properties of glazing. Design procedures can be improved by developing standard routines (where feasible) and by enhanced data specification (e.g. wind pressures). Both approaches offer to reduce the risk associated with naturally ventilated buildings.

2. Basic physical processes

In my opinion, natural ventilation of a building can be considered as two parts, namely envelope flows (how the air gets in and out) and internal air motion (what it does when it is in there). The basic physical processes of natural ventilation have certainly been known much longer than fifty years. Envelope flows arise from pressure differences across the envelope, generated by wind and internal/external temperature differences, which lead to flows through openings. Internal air motion arises from buoyancy forces generated by internal temperature differences and by momentum and forces at the inlet and outlet openings.

Both of these processes are described by one form or another of the Navier–Stokes equations. However, with envelope flows, integrated forms of the equations are applied, since it is bulk flow rates that are of interest. Envelope flows are much more amenable to calculation, by means of envelope flow models, and it is this area where developments first took place (Section 3). Room air motion was the subject of more empirical methods (Section 6), until CFD became feasible.

3. Steady envelope flow models

A conventional envelope flow model is taken to be one where the flow rates through openings, with known flow characteristics and positions, are calculated, with the assumption of truly steady flow conditions, for given wind conditions and internal temperature distributions (uniform, or with specified vertical variation). The governing principle is mass conservation of the air. The openings are small enough that they do not affect the wind pressure distribution. The fact that the flow characteristics are specified means that such models are best described as *semi-empirical*. The models have generally been used to calculate flow rates for given openings (the so-called *implicit* method of solution). In recent years (from the 90s), the methods have also been used to determine the openings (size and position) required to give the design flow rates and directions under specified conditions. This is the *explicit* method of solution (Section 12). In the design context, the implicit method is used for off-design conditions.

Nowadays, conventional envelope flow models are common, but this was not the case fifty years ago. Models tended to be simple single-cell models. Some models did not specifically use mass conservation. Indeed, some models were *purely* empirical in that