Energy and Buildings 107 (2015) 345–354

Contents lists available at ScienceDirect

Energy and Buildings

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

Assessment of different airflow modeling approaches on a naturally ventilated Mediterranean building

Ghjuvan Antone Faggianelli [a,b,*], Adrien Brun [a], Etienne Wurtz [a], Marc Muselli [b]

[a] CEA, LITEN, Laboratoire Energétique du Bâtiment à l'INES, Le Bourget du Lac, France
[b] Université de Corse, UMR CNRS 6134 SPE, Ajaccio, France

ARTICLE INFO

Article history:
Received 28 November 2014
Received in revised form 24 March 2015
Accepted 20 August 2015
Available online 22 August 2015

Keywords:
Natural cross ventilation
Full-scale experiment
Airflow rate measurement
Airflow modeling
Artificial neural networks

ABSTRACT

This paper focuses on a full-scale experiment to assess and model the airflow rate in a naturally ventilated room using different approaches. The building studied is located in a coastal area of Corsica and mostly affected by thermal breezes phenomena which lead to high airflow rate during day (between 8 and 30 *ACH*) and lower during night (between 2 and 8 *ACH*). The first aim of this work is to set up a method in order to measure continuously the airflow rate in cross ventilation configuration using a minimal number of sensors. Our methodology involves direct measurements of velocity on a mesh and use of statistical methods. The second objective is to develop and evaluate different airflow modeling approach in cross natural ventilation configuration. Various levels of complexity are tested and compared: empirical modeling, model calibration and behavioral modeling based on artificial neural networks. In terms of error, the artificial neural network appears to be the best compromise to model the airflow rate and allow to reach a *MAE* of 1.75 *ACH* with a one minute time step.

Suggested model in this paper can be coupled with a thermal model and is suitable for model based natural ventilation control.

1. Introduction

The need to reduce energy consumption and CO_2 emissions in buildings leads to the development of passive strategies to ensure thermal comfort. To meet this objective, it is necessary to exploit the resources of the environment such as solar energy, wind and temperature variation [1].

Among these strategies, natural ventilation in buildings can improve indoor air quality, thermal comfort in summer and limit the use of air conditioning when used wisely [2]. However, its efficiency is highly dependent on local weather conditions and can vary greatly from one site and building to another. Despite the simplicity of this type of system, its operation can also be complex if the user does not have sufficient information and is not always present in the building. Its performance will thus depend on control whether it is manual or automatic. This shows the interest of developing appropriate tools for the study of natural ventilation and implementing simplified control in buildings. Different studies focus on the improvement of summer comfort by natural ventilation with the help of simplified models [3–5]. They show the potential of this type of approach to control the window opening appropriately according to the variations of building temperature and weather conditions.

The aim of this paper is to develop an airflow model suited for a residential building located in Corsica and mainly occupied during summer. For this purpose, the knowledge of the airflow rate is essential to get a reliable model. Computational fluid dynamics methods are generally unsuitable for this type of application due to lack of knowledge for the consideration of local environment and the high variability of boundary conditions. Continuous measurements of airflow rate might not be feasible either as they require intrusive and complex instrumentation. The method studied here is thus to couple velocity measurements with the use of mathematical models such as empirical and statistical models.

2. Airflow modeling in buildings

There are different ways to study the airflow in buildings. Krauss et al. [8] propose a classification of numerical models depending on the type of approach. This leads to two main categories:

- *Phenomenological modeling*, based on a physical description of the phenomenon.

* Corresponding author at: CEA, LITEN, Laboratoire Energétique du Bâtiment à l'INES, Le Bourget du Lac, France.
E-mail address: anto.faggianelli@gmail.com (G.A. Faggianelli).

http://dx.doi.org/10.1016/j.enbuild.2015.08.038
0378-7788/

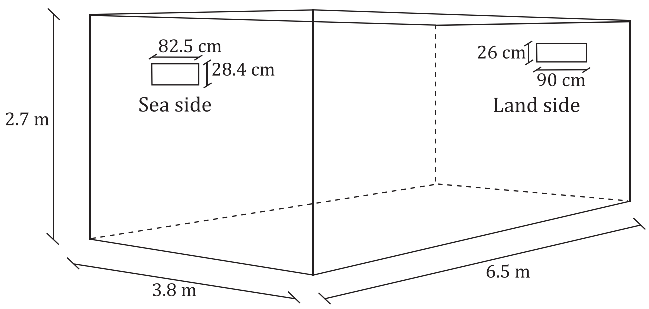

Fig. 1. Case study geometry.

- *Behavioral modeling*, based on a mathematical modeling with the use of tools such as statistics and artificial neural networks.

In each category, there are a large number of possibilities with various degrees of complexity. In this study, the limitation is the need of developing a *simple* model which could be easily coupled with a thermal model allowing to get the airflow rate with a sufficient time step and a minimal set of inputs. As the time step criterion is dependent on the application (dynamic simulation, predictive and real-time control, etc.) we focus here on generic models, suitable for the different cases.

Our case study will be presented in details in next section. As a first step, we only focus on its geometry (Fig. 1) to guide the choice of the models studied in this section. Here, we concentrate on natural cross ventilation with two openings of same dimension in opposite sides. For a very small vertical spacing between the two openings, it is not necessary to take into account the thermal buoyancy, known as stack effect. This assumption can be justified by British Standards method [9] which allows to determine what phenomenon should be taken into account for airflow rate calculation. In this configuration, we can thus focus on wind driven ventilation which appears to be the main phenomenon [2].

2.1. Phenomenological modeling

Phenomenological models can be divided into two classes: micro and macro models. The first class is the most detailed approach, based on Navier–Stokes equations which lead to complex models with significant calculation times. The second class groups zonal, nodal and empirical models which present important simplifications. Among these models, zonal method is still too complex as it requires lots of information such as detailed boundary conditions and distribution of heat sources [10,11]. Nodal models are mainly used in airflow simulation software (COMIS [12], CONTAM [13]) and are based on strong assumptions assuming well-mixed zones and uniform temperature and pressure distribution. In simple mono-zone models, the problem is to correlate the airflow rate with a set of inputs. These inputs are usually more accessible and consist of information on wind profile, temperature and building geometry (different indicators on room and openings).

A very simple method is provided by ASHRAE [14], based on LBNL model [15], but the main problem is the absence of the wind direction which has a great impact on the airflow [17,18].

More advanced models are proposed by Etheridge [19] or Aynsley [20]. For natural cross ventilation, they give the same results as the models of British Standards Institution (BSI). BSI models allow to take into account stack or wind effects for different configurations including up to four openings [9]. In the case of two openings on opposite sides and at the same height (Fig. 2), the airflow rate obtained by wind effect is given by:

$$Q_w = C_d A_w V \sqrt{\Delta C_p} \tag{1}$$

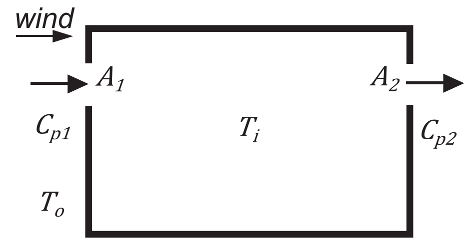

Fig. 2. Cross ventilation for British Standards method.

For openings of same size A and at the same height we have:

$$A_w = \frac{A}{\sqrt{2}} \tag{2}$$

This model adds two important coefficients in airflow modeling: the pressure coefficient C_p and the discharge coefficient C_d. Their determination is the main difficulty to establish a reliable model with this approach.

2.1.1. Pressure coefficient

The pressure coefficient usually expresses the wind pressure on the building envelope. Various studies focus on determining this coefficient [21–23]. However, most of the correlations are established in wind tunnels with regular geometries and wind conditions which can be far from the actual characteristics. Among the main methods, Walton [21] proposes a simple approach to correlate this coefficient with the wind incidence angle φ. Swami and Chandra [22] have developed a more detailed model to determine the normalized pressure coefficient NC_p:

$$\begin{aligned} NC_p = \; & \ln\Big(1.248 - 0.703\sin\frac{\varphi}{2} - 1.175\sin^2\varphi + 0.131\sin^3(2\varphi\ln(A_s)) \\ & +0.769\cos\frac{\varphi}{2} + 0.07\ln(A_s)^2\sin^2\frac{\varphi}{2} + 0.717\cos^2\frac{\varphi}{2}\Big) \end{aligned} \tag{3}$$

They also introduce information on building geometry with the term A_s which represents the ratio between the adjacent walls (width/length).

The actual C_p is then obtained by the following relation:

$$C_p = NC_p \times C_{p,0} \tag{4}$$

where $C_{p,0}$ is the pressure coefficient for a wind incidence angle of 0°, usually estimated to 0.6.

At last, Sharag-Eldin [23] proposes an improvement of Swami and Chandra coefficients, by taking into account a higher number of building configurations:

$$\begin{aligned} NC_p = \; & \ln\Big(2.295 - 1.768\sin\frac{\varphi}{2} - 0.935\sin^2\varphi + 0.147\sin^3(2\varphi\ln(A_s)) \\ & +0.483\cos\frac{\varphi}{2} - 0.034\ln(A_s)^2\sin^2\frac{\varphi}{2} - 0.006\cos^2\frac{\varphi}{2}\Big) \end{aligned} \tag{5}$$

More complex formulations aim to take into account obstacles near the building. However, they are limited to very simple geometries and are not suited for vegetation which can also have an important impact on airflow rate.

2.1.2. Discharge coefficient

The discharge coefficient characterizes the local contraction of the flow due to the presence of an opening. It depends on the characteristics of the fluid but also on the shape of the opening and its dimensions. Its determination is also complex and different models are available [24,25].

Without accurate information, it is common to take a reference value of 0.6 corresponding to a sharp-edged opening [26]. However, this value is only applicable for specific openings and its use is still questionable [27].