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Energy and Buildings 37 (2005) 311–323
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

# Combined thermal and natural ventilation modeling for long-term energy assessment: validation with experimental measurements

Chris J. Koinakis*

*Laboratory of Building Construction and Physics, Department of Civil Engineering, Aristotle University of Thessaloniki, Thessaloniki GR-54006, Greece*

Received 26 January 2004; received in revised form 10 March 2004; accepted 15 June 2004

**Abstract**

The role of ventilation in the energy balance of buildings is very important, as well as the need to model the use of large openings by occupants in energy simulation. Examples of detailed assessment of natural ventilation in overall building thermal simulation procedures are rather rare, especially for long-term evaluation and different types of ventilation. This study addresses this need focusing on natural ventilation modeling in building energy simulation and introducing coupled thermal and ventilation nodal modeling in 1 h simulation steps. All the related parameters are taken into consideration, from wind pressure data to building envelopes and user behavior. The results are validated by conducting experiments on existing constructions and the thermal behavior is monitored and compared in detail in specific building elements. Coupled thermal and ventilation modeling is then implemented to model and assess ventilation strategies for optimum energy-efficient ventilation in a common apartment. These strategies are compared and analyzed for mild Mediterranean and oceanic climates and optimum design procedures are proposed.


*Keywords:* Ventilation; Large openings; Energy balance; Energy efficiency

## 1. Introduction

Ventilation models were initially based on the regression analysis of measured data for infiltration and driving weather forces [1,16]. The coefficients between similar residences have varied tremendously and ventilation was not simulated, so these models were not appropriate for building energy analysis, since ventilation rates are very important in energy balance, usually reaching 40% and more. During the last 10 years a lot of research has been done on determining infiltration flow rates and air flow through large openings. Various phenomena are included in air flow through large openings, from steady gravitational flow to unsteady flow due to wind turbulence. The flow through a large opening is bidirectional and usually differs at the upper and at the lower part. Two main categories of causes of flow through large openings can be distinguished: causes leading to a steady flow regime due to mean values and causes leading to unsteady flows due to the fluctuating nature of the phenomena. Research in these fields in mentioned in the bibliography [1–3].

All the above-mentioned flows should be included in a multizone infiltration nodal model, which is the most appropriate way to simulate these phenomena for long periods. Additionally, these models have the potential to be combined with a nodal thermal model in order to integrate the closely correlated thermal and ventilation phenomena.

In computational fluid dynamics models (CFD), on the other hand, a higher system resolution can be obtained, but generality is usually lost and therefore these models are more suitable for special case studies and specific components [4,5]. The high computational burden involved in CFD and the demand for very detailed boundary condition data are also prohibitive for long-term and general purpose simulations.

* Tel.: +30 2310 41 8041.
*E-mail address:* chrisko@civil.auth.gr.

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doi:10.1016/j.enbuild.2004.06.022

## 2. Basic principles and equations of air flow and thermal nodal modeling.

### 2.1. Air flow modeling

Air flow through the rooms of a building originates from pressure distribution around and within the building itself. Pressure distribution is due to the combined actions of wind, thermal buoyancy (stack effect) and mechanical ventilation if it exists. Due to the turbulence characteristic of the wind flow in the lower layers of the atmosphere, the pressure field driven by the wind on building surfaces is always unsteady and difficult to predict and simulate. Differential pressure due to the stack effect depends on density field and on the mechanical ventilation [6,7].

Wind flows produce a velocity and pressure field around buildings. The relationship, for free stream flow, between velocity and related pressure at different locations of the flow field can be obtained from Bernoulli's equation. Assuming constant density along a streamline at a given height Bernoulli's equation can be simplified thus:

$$P_{\text{start}} + \frac{1}{2}\rho v^2 = \text{constant} \tag{1}$$

The wind velocity profile is calculated by a power law expression.

$$\frac{v(z)}{v(Z_{\text{ref}})} = \left\{\frac{Z}{Z_{\text{ref}}}\right\}^{\alpha} \tag{2}$$

The value of the exponent increases with the increasing roughness of the solid boundary. The wind pressure distribution on the building envelope is described by dimensionless pressure coefficients – the ratio of the surface dynamic pressure to the dynamic pressure in the undisturbed flow pattern measured at a reference height. The pressure coefficient $C_p$ at point $k(x, y, z)$, with reference dynamic pressure $P_{\text{dyn}}$ related at height $z_{\text{ref}}$, for a given wind direction $\varphi$ can be described by:

$$C_p(z_{\text{ref}}, j) = \frac{P_k - P_0(z)}{P_{\text{dyn}}(z_{\text{ref}})} \tag{3}$$

where:

$$P_{\text{dyn}}(z_{\text{ref}}) = \frac{1}{2}\rho_0 v^2(z_{\text{ref}}) \tag{4}$$

The pressure coefficients of the under examination building are calculated by implementing a parametrical calculation algorithm taking into account climatic, building and environmental parameters [8]. The results were compared with wind test studies in the bibliography for similar buildings [9].

The effect of thermal buoyancy or the stack effect is the other natural phenomenon driving differential pressure in a building. It is due to density differences between inside and outside air or between two zones of a building. The density is mainly a function of temperature and the moisture content of air. The local pressure difference between two points $Z_i$ and $Z_j$, in the two zones, if $M$ and $N$ are two zones on the opposite sides of a leakage is given by:

$$P_i - P_j = P_m - P_n P_s \tag{5}$$

where $P_{\text{s}}$ takes the stack effect into account:

$$P_{\text{s}} = \rho_m g(Z_m - Z_i) - \rho_n g(Z_n - Z_j) \tag{6}$$

$Z_m$, $P_m$, $T_m$, $\rho_m$, $Z_n$, $P_n$, $T_n$, $\rho_m$ are respectively the height, pressure, air pressure and air density at the reference points.

Natural ventilation phenomena in buildings could be categorized mainly as flow through cracks and flow through large openings. The influence of HVAC systems should also be calculated.

Simulation of the air leakage characteristics of cracks under real conditions, based on the exponential power law, takes the general form of:

$$Q = C_{\text{s}} v^{1-2n} \rho^{-n} (\Delta P)^n \tag{7}$$

Air mass flow $Q$, is described here as a function of pressure difference $\Delta P$. The coefficient $C$ depends on the crack form (duct shape). The flow regime (laminar, transitive or turbulent), the type and geometry of the crack and the temperature of the air in the cracks are also taken into account [1,12,13].

The flow through large openings is simulated to fit easily into the network definition and to model the phenomena that influence the behavior of large openings [10,11]. The main assumptions in the COMIS model are: (a) steady flow, in viscid and incompressible fluid, (b) linear density stratification on both sides of the opening, (c) turbulence effects represented by an equivalent pressure difference profile, and (d) effects of reduction of the effective area of the aperture represented by a single coefficient. Further analysis of the problem may be found in the bibliography [6,7].

Nodal natural ventilation programs like the COMIS model which is implemented in this work establish the infiltration and ventilation rates in a building by solving of a non-linear system of equations that represents a network [1]. An iterative method can be used in which a linear system of equations is solved at each step of the process. The network consists of pressure nodes and links. A mass flow balance must exist at each node, as described by the following flow balance equation:

$$\mathrm{f}(P) = \sum_i \frac{\mathrm{d}m_i}{\mathrm{d}t} = 0 \tag{8}$$

and in vector form for all nodes:

$$\mathbf{f}(\mathbf{P}) = 0 \tag{9}$$

An appropriate function describes the flow rate as a function of pressure difference for each link. Non-linear expressions of the following type are predominant; for a better understanding we here disregard the temperature correction factor $K$. introduced in

$$\dot{m} = C_{\dot{m}}(\Delta P)^n \tag{10}$$