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Detailed multi-zone air flow analysis in the early building design phase

Nyuk Hien Wong[a, *], Ardeshir Mahdavi[b], Jayada Boonyakiat[b], Khee Poh Lam[a]

[a] *Department of Building, School of Design and Environment, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore*
[b] *School of Architecture, Carnegie Mellon University, Pittsburgh, USA*

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Abstract

We present BACH, a computational tool for the simulation of air flow in and around buildings in the early stages of the design process. This tool is part of an integrated simulation environment towards comprehensive performance-based building design evaluation. We describe the rational behind the development of this tool, its architecture, and its predictive performance. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

1.1. Motivation

The importance of natural ventilation for indoor air quality, energy conservation, and occupancy satisfaction in buildings is well established. However, there is a lack of effective tools to support the proper design of buildings for natural ventilation. The absence of such tools is particularly evident in the early stages of building design where many important features of design are decided upon, including those features with implications for natural ventilation (e.g. building massing and orientation, size and location of openable apertures in the building envelope).

Most existing tools are either too simplistic or too complicated to provide effective design support. The simplistic ones are often too limiting, in that they apply only to highly generic assumptions regarding building geometry and operation [1,2]. The sophisticated ones [3,4] typically demand too much information, time, and expertise to be helpful to the primary building designers (usually architects) in the early stages of building design.

1.2. Background

The computational tool presented in this paper, Building Air Change (BACH), relies on a modeling approach similar to that adopted by multi-zone methods (see Section 2 for more details). However, it may be distinguished from those in two ways.

(i) From the spatial point of view, BACH allows for the description of the simulation domain with an arbitrary level of resolution in terms of grid of nodes representing the final control volumes within the rooms of the buildings. Air flow within and amongst rooms in a building can be thus modeled at a higher level of detail. The flexible grid structure also allows for the coupled simulation of air flow in and around building as well as the consideration of the effects of the size and position of individual openings in the building's enclosure.

(ii) BACH is embedded within the integrated building simulation environment SEMPPER [5–7]. As such, it can collaborate with other applications towards coupled (and dynamic) energy and mass transfer simulation in buildings. Moreover, BACH's internal representation of the building (i.e., its domain object model (DOM)) can be automatically derived from a high-level building design representation (i.e., the shared object model (SOM)) in the SEMPER environment [8,9]. Once the basic geometric and semantic information of a building is imported in BACH, the DOM required for air flow analysis (including the grid structure of the finite control volumes) is automatically generated. Since other applications in SEMPER (e.g. those for energy, light, and sound analysis) also derive their internal DOMs from SEMPER's SOM, the primary designer can conduct parametric simulation studies on building designs without repeatedly entering the building model in various applications.

* Corresponding author. Tel.: +65-874-3423; fax: +65-775-5502.
E-mail address: bdgwnh@nus.edu.sg (N.H. Wong).

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2. The air flow model (BACH)

2.1. Overview

The air flow model BACH allows transient three-dimensional analysis of air flow and contaminant dispersal. Given the building geometry information (spaces, enclosure, and openings), BACH uses wind speed and temperature difference information to compute the air change rate for each space. A small database, which captures the infiltration characteristics of openings (window and door) is incorporated to account for the effects of infiltration. Using the local weather file, hourly simulation can be performed taking into consideration the effects of the opening schedule. The tool also incorporates a simple gaseous contaminant dispersal model which provides steady, transient, and cyclical contaminant dispersal analysis. In conjunction with other applications in SEMPER, BACH also facilitates the computation of predicted building energy use, indoor air contaminant concentration, thermal comfort indices, and heating, ventilating, air-conditioning (HVAC) systems performance [10,11].

2.2. Generation of nodal network

Fig. 1 shows BACH's internal network structure for a building of orthogonal geometry. This network can be automatically generated for both orthogonal and non-orthogonal buildings upon importing the primary building design information (see Fig. 8 for an example of the network structure for a non-orthogonal design). The simulation domain can be discretized into a network consisting of nodes that represent regions of differing pressures interconnected

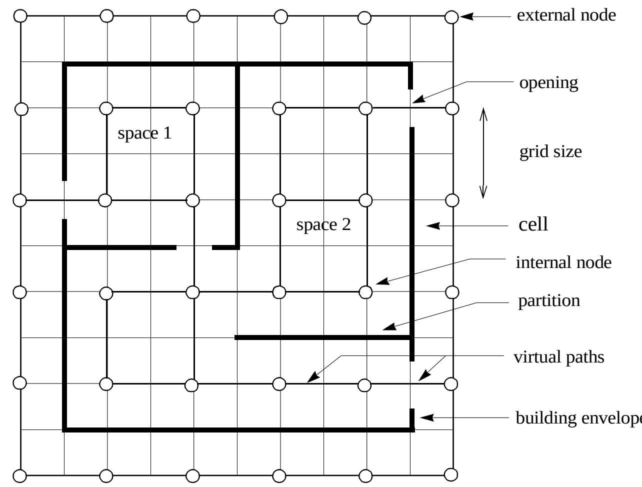

Fig. 1. General schema for grid, network structure and space layout for BACH.

Table 1
Equations used in the model

	Description	Equation	Terms	
1	Flow rate in a linkage path	$\dot{V} = K(\Delta P)^n$	$\dot{V}$	air flow rate ($m^3\ s^{-1}$)
			ΔP	pressure difference across the pipe (Pa)
			K	flow coefficient ($m^3\ s^{-1}\ Pa^{-1}$)
			n	flow exponent
2	Pressure difference due to thermal buoyancy	$P_s = \rho_0 g 273 \left[\frac{1}{T_2} - \frac{1}{T_1}\right][h]$	P_s	stack induced pressure at level h_2 with respect to an opening at level h_1 (Pa)
			g	acceleration due to gravity ($m\ s^{-2}$)
			ρ_0	density of air at 273 K ($kg\ m^{-3}$)
			T_2	temperature at node 2 (K)
			T_1	temperature at node 1 (K)
			h	grid size
3	Time–mean wind speed profile	$v = v_r c H^a$	v	mean wind speed at height H above the ground ($m\ s^{-1}$)
			v_r	mean wind speed measured at a weather station at a height 10 m above ground ($m\ s^{-1}$)
			c, a	terrain factors
4	Concentration of pollutant at node i at steady state	$C_{\alpha,i} = \frac{\lfloor G_{\alpha,i} + \sum_j (w_{j,i} C_{\alpha,j}) \rfloor}{\sum_i w_{i,j}}$	m_i	mass of air in node i (kg)
			$C_{\alpha,i}$	concentration mass fraction of α ($kg_\alpha\ kg_{air}^{-1}$)
			$w_{i,j}$	rate of air flow from node i to node j ($kg\ s^{-1}$)
			$G_{\alpha,i}$	contaminant generation rate ($kg_\alpha\ s^{-1}$)
			$w_{j,i}$	rate of air flow from node j to node i ($kg\ s^{-1}$)