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Research Paper

Characterisation of ventilation rate in naturally-ventilated buildings using heat dissipation from a line source

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To determine air exchange in naturally-ventilated buildings, Eren Özcan, Vranken, and Berckmans (2009) used heat dissipation from a heat source close to an inlet to measure ventilation rate through the opening. Because their method used a bulky heat source, which caused an obstruction to airflow, they were unable to cover the whole of the inlet opening, and therefore, an improved technique was required. This study extended the earlier method to investigate heat dissipation by using a line heat source that covered the whole vertical extent of the inlet. Steady state experiments were performed with a constant heat source, and dynamic experiments, where the heat source was turned off during the ventilation process. A two-dimensional temperature distribution around the ventilation opening was obtained by infrared thermal imaging. Using data-based mechanistic approach, well-mixed temperature zones were used to predict the volumetric concentration of fresh air supply, and to investigate the effect of buoyancy on the heat plume. Results obtained revealed that ventilation rate can be predicted using data-based mechanistic approach with an error of 8%.

1. Introduction

Measurement of the ventilation rate through naturally-ventilated buildings remains a challenge because of the non-uniform airflow through the ventilation openings. This non-uniform flow is greatly influenced by temperature differences and the number and nature of the openings into the buildings (Gan, 2000; Linden, 1999). Rapidly fluctuating pressure differences produced by buoyancy or wind forces further complicate the movement of the air through a naturally-ventilated building. Methods that have since been employed to study natural ventilation include empirical models (Andersen, 2003, 2007), experimental measurements (Chao, Wan, & Law, 2004; Chen & Li, 2002; Dascalaki et al., 1996), computational fluid dynamics simulations (Favarolo & Manz, 2005; Li & Delsante, 2001; Peppes, Santamouris, & Asimakopoulos, 2002), and data-based mechanistic approach (Van Buggenhout et al., 2006).

Until recently, tracer gas and hot-wire anemometry have dominated the measurement of ventilation through naturally-ventilated buildings (ASHRAE, 2005, chap. 26; ASTM

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Nomenclature

Abbreviations

DBM	Data-based mechanistic
IR	Infrared
LS	Least squares
SISO	Single input single output
SRIV	Simplified refined Instrumental variable
TF	Transfer function
WMZ	Well-mixed zone
YIC	Young identification criterion

Symbols

A	Area (m^3)
$A(s)$	Polynomial (–)
$B(s)$	Polynomial (–)
c_p	Heat capacity ($J\ kg^{-1}\ K^{-1}$)
$\xi(t)$	Additive noise (–)
β	Volumetric concentration of fresh air supply (s^{-1})
δ	Advective time delay (s)
γ	Density ($kg\ m^{-3}$)
K_1	Total heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
S_1	Surface area of heat exchange (m^2)
s	Laplace operator (–)
R_t^2	Coefficient of determination (–)
T	Temperature (K)
t	Time (s)
U	Average velocity ($m\ s^{-1}$)
$u(t)$	Model input (–)
V	Ventilation rate ($m^3\ s^{-1}$)
$y(t)$	Measured model output (–)

Standard, 2004, 16 pp.). The tracer gas technique has limitations due to its difficulty to employ continuously in full-scale buildings with varying ventilation rates (Benjamin & Roberts, 2001; Janssens, Van Brecht, Zerihun Desta, Boonen, & Berckmans, 2004). Hot-wire anemometers are expensive to use during day-to-day activities in buildings and can only measure flow parameters at a given point. In general, these methods cannot provide a consistent accuracy greater than 70% (Eren Özcan, Vranken, & Berckmans, 2009). These limitations have motivated studies to develop practical methods to measure ventilation rate based on temperature mapping at air inlets using a heat source located close to the ventilation inlet.

The rate of heat loss from a source has been correlated with the airflow dynamics and empirical relationships (Hasegawa, Kikyuma, Asakura, Kawaguchi, 1997; Wen & Jang, 2002). Based on this foundation, more correlations are being developed between ventilation rate and temperature. Related studies done by Eren Özcan et al. (2009) have applied the basic principle of the introduction of a heat source perpendicular to the direction of the airflow through an opening. Heat dissipation and temperature decay were measured close to the heater by thermal imaging captured on a screen. The results of this work revealed that airflow can be related to the temperature along a virtual ellipse arc drawn after the inlet and heat source. Problems associated with this technique were airflow obstruction and localised heating at the inlet, all caused by the heat source geometry (a rectangular heat source smaller than the inlet opening was used). Flow around obstacles has been found to be greatly affected by thermal buoyancy (Turki, Abbassi, & Nasrallah, 2003), and this has also been observed in the results of Eren Özcan et al. (2009). Kaye and Hunt (2007) discovered that for large cross sectional area inlets, the flow was driven by localised heat sources reaching steady state more rapidly than that driven by more uniformly distributed heat. Since the heat source in Eren Özcan et al. (2009) did not cover the inlet opening, the resulting correlation might not be useful for a bidirectional flow.

For complete characterisation of the ventilation rate in natural ventilation, there are many external and internal influences to cater for. Trying to establish all influencing factors involved can be tedious and impractical. Therefore, approaches and methods that derive interest on desired key parameters need to be employed in determining ventilation rate where natural ventilation is applied. A data-based mechanistic approach for which the influence of unmeasurable parameters is catered for in a transfer function could be a useful tool in overcoming the challenge (Van Buggenhout et al., 2006; Zerihun Desta et al., 2005). Therefore, after identifying the prevailing relationship between the system variables and ventilation rate, an estimation model could be established based on physical behaviour of the system.

The aim of this paper is to further study the heat dissipation from a line heat source placed at the inlet of the air opening. A data-based mechanistic approach to relate ventilation rate with heat dissipation in an opening was employed. Steady state and dynamic state results generated are meant to provide more insight on possible parameters that would contribute to the trend of model parameters obtained in data-based mechanistic model.

2. Materials and methods

2.1. Test room installation

Experiments were conducted at the outlet section (0.5 m × 0.5 m) of a standardised test rig at M3-BIORES. The outlet section is defined as the inlet with respect to the room/opening where the experiments were being performed (Fig. 1a). A detailed description of the installation was reported by Eren Özcan et al. (2009), and NBN 688 NI (1996, 32 pp). A line aluminium heat source (⌀0.001 × 1.005 m) was placed vertically at the outlet of the installation. A connected step transformer was manually adjusted to obtain the desired effective power at the heat source. 100 W was the maximum power applicable to the heat resistors in the line heat source. In order to have well-defined temperature zones against those of the surrounding air in the opening, the heating power was set at 70 W.

A non-reflective blue curtain screen (1.27 × 0.87 m) placed close to the heat source was used as a measurement surface for infrared (IR) imaging. An IR thermal camera (*Agema Thermovision 570*, Advanced Test Equipment Corporation, San Diego, California, USA) was used to receive thermal images and