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Modeling convective drying of ventilated wall chambers in building enclosures

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Abstract

In North America, residential enclosure walls are often built with provision for natural convection and, therefore, provide potential for ventilation drying within the wall. At present, our knowledge of the drying process in the wall systems is limited. The drying process is driven by very low airflow rates with complex flow patterns through the narrow and irregular wall cavities, resulting mostly in unstable ventilation driven by natural convection. Different venting strategies coupled with the stochastic nature of driving forces for ventilation contribute to the complexity of the drying process. Both the physical and the mathematical modeling of wall cavity convective drying are challenging. However, it is difficult to accurately predict the convective drying rates in wall cavities at any time during the year. Nevertheless, the convective drying process is probably one of the key mechanisms for mold suppression in residential walls in the US, and therefore, needs to be fully understood and quantified.

An equation is developed to estimate the convective moisture transport in screened and ventilated wall systems. The intent was to develop a simple equation for practical design applications. The equation represents a solution of the two-dimensional moisture transport equation, solved for steady state conditions assuming laminar flow with a uniform velocity field in the wall cavity.

The results derived from the simple equation were compared to measured data obtained in the Building Enclosure Test Laboratory (BeTL) at the Pennsylvania State University (PSU). The comparison showed that the simple equation can accurately predict the convective drying rates. The results are highly sensitive to the environmental conditions in the immediate vicinity of the wet wall surfaces. This equation could be used in engineering practice to provide an estimate of convective drying rates in the ventilated chamber of rain-screened and ventilated wall systems. Future validation with on-site experiments is necessary.

Keywords: Ventilated chamber; Enclosure wall; Natural convection; Ventilation; Convective drying rate; Parametric correction function; Effective wetting surface area coefficient

1. Introduction

The deterioration of materials and human health in buildings due to the presence of moisture in building walls has been the focus of many studies. Although many characteristics of moisture transport have already been defined, there is still a need to understand the nature of convective transport and the control of moisture within and across building enclosures. Therefore, a study of the potential for convective moisture removal from building enclosures is of great importance for many engineers, architects, building owners and manufacturers involved in the design, construction and operation of buildings, particularly low-rise residential buildings. A screened and ventilated wall system, commonly used in North America, is presented in Fig. 1.

Ventilated enclosure wall systems have three basic components:

(1) a screen (brick, masonry or vinyl siding);

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Nomenclature

A	$= W\delta$ ventilated chamber cross sectional area	m^2
C	$\approx \frac{0.622}{p_{atm}}$ constant	Pa^{-1}
D	diffusion coefficient	$m^2 \cdot s^{-1}$
H	height of the ventilated chamber	m
$\dot{m}_{AIR}$	mass flow rate of the air	$kg \cdot s^{-1}$
p	air pressure	Pa
p_{atm}	atmospheric pressure	Pa
p_v	partial water vapor pressure in the air	Pa
$p_{v,s}$	partial water vapor pressure of saturation	Pa
$\dot{Q}$	volumetric flow rate of air	$l \cdot s^{-1}$
$\dot{S}_M$	bulk mass source	$kg \cdot s^{-1}$
T	air temperature	K
u	horizontal velocity component	$m \cdot s^{-1}$
V	$= \frac{\dot{m}_{AIR}}{\rho A}$ uniform inlet velocity ($V = \text{const}$)	$m \cdot s^{-1}$
v	vertical velocity component	$m \cdot s^{-1}$
W	width of the ventilated chamber	m
w	humidity ratio	$kg \cdot kg_{dry,air}^{-1}$

Greek symbols

δ	wall cavity depth	m
μ	water vapor permeability in the air ($\mu = 1.7 \times 10^{-10}$ s)	s
ρ	moist air (bulk) density	$kg \cdot m^{-3}$
ρ_k	density of kth component	$kg \cdot m^{-3}$
λ_n	$= \frac{(2n+1)}{2\delta} \cdot \pi$ characteristic value, $n = 0, 1, 2, \ldots$	

Superscripts and subscripts

AIR	air
atm	atmospheric
k	kth component
M	mass
n	index
v	vapor
s	saturation
wall	wall surface

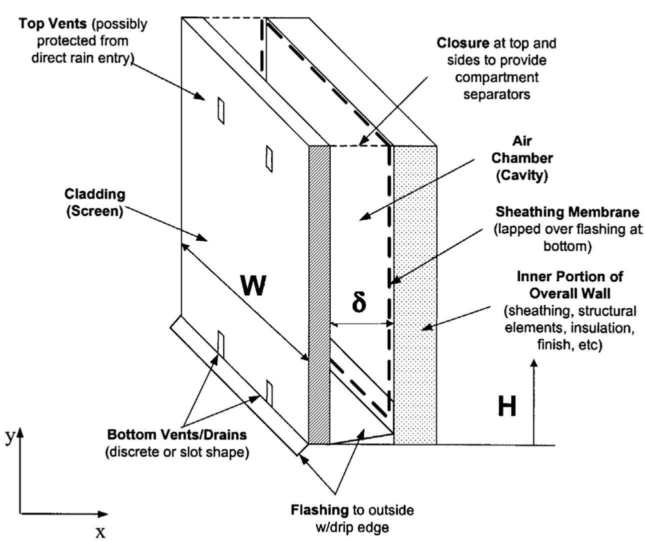

Fig. 1. Representative rain-screened and ventilated wall system.

(2) an air chamber sealed from the building interior;
(3) vent openings, connecting the ventilated wall chamber with the exterior environment (through the screen).

Among the various processes of moisture transfer and moisture storage within and across the building enclosure, convective water vapor transfer, i.e., moisture removal by airflow through the ventilated wall system, is of particular interest. This mechanism is one of the least studied, but its contribution to the overall wall-drying process is significant [1]. An accurate estimate of the convective drying rate is needed to avoid moisture-related problems such as mold growth or corrosion. Moisture within the building enclosure can also cause structural problems, and moreover, it may have serious effects on the health of occupants. Therefore, an estimate of the potential for convective drying in ventilated wall systems is important.

A comprehensive study of moisture transport within a building enclosure should consider the following [1]:

- the nature and availability of moisture sources,
- the mechanisms of moisture storage,
- the transport processes for moisture removal, and
- the materials used in multi-layer wall assembly and their hydrothermal properties.

The focus of this study is the convective transport process for moisture removal assuming the other factors to be known. The basic equations for the moisture-transport mechanisms in liquid and vapor phases through porous media, for the sorption processes with phase changes at the surface layers, and for convective transport at the surface are available in Refs. [2–4]. However, the complexity of the governing equations that describe these processes requires the use of numerical methods to solve the mathematical model [5]. Thus, an accurate prediction of convective moisture removal from a ventilated wall system requires knowledge of the hydrothermal properties of building materials, an adequate model of the transport processes, and efficient numerical solution techniques. One objective in this study is to establish a simpler approach for the prediction of ventilation drying.