Industrial Revolution

Every home makes compromises among different and often competing goals: comfort, convenience, durability, energy consumption, maintenance, construction costs, appearance, strength, community acceptance, and resale value. Often consumers and developers making the tradeoffs among these goals do so with incomplete information, increasing the risks and slowing the adoption of innovative products and processes. This slow diffusion negatively affects productivity, quality, performance, and value. This department of Cityscape *presents, in graphic form, a few promising technological improvements to the U.S. housing stock. If you have an idea for a future department feature, please send your diagram or photograph, along with a few well-chosen words, to elizabeth.a.cocke@hud.gov.*

Breathing Wall: Concept and Thermal Performance

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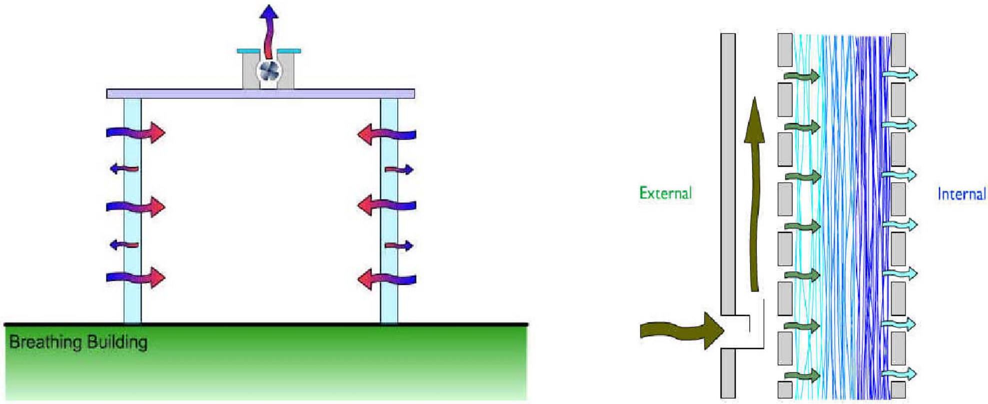
Introduction

As advances in building technology continue to transform building energy performance and promote new and innovative construction techniques, traditional challenges are met, and new issues continually arise. One example is the paradigm of improving energy efficiency but compromising the indoor air quality (IAQ) of buildings. Leaky buildings traditionally perform very poorly in terms of energy consumption, but, in general, their IAQ—as a result of the incoming outside air—is fairly good. For the sake of energy efficiency, the trend has been tighter, more effectively sealed buildings, which in turn has led to more IAQ issues, mold, and sick building syndrome (SBS) problems. As the push for improved energy performance points designers and builders toward tighter construction, the very principle that reduces the building's energy consumption—reduced infiltration—is a net loser for IAQ.

A promising new technology introduces a method for avoiding the efficiency/air quality compromise, yielding better energy efficiency *and* improved IAQ. The technology, referred to as a "breathing wall," draws a steady stream of filtered air through the walls and into the building at all times, providing exceptionally clean ventilation air to the occupants. A schematic breathing wall diagram is presented in exhibit 1. Whereas higher ventilation rates traditionally produce higher energy loads in buildings, the "dynamic insulation" used in breathing walls actually works to reduce that load, effectively creating efficient, superinsulated walls.

Exhibit 1

Breathing Wall Configurations



Source: Reprinted from Imbabi and Peacock (2003)

The projected energy savings and air quality implications associated with breathing wall technology are astounding. Previous studies of the energy and air filtration efficiencies of breathing walls estimated that such technologies can reduce year-round heating and cooling loads between 10 and 40 percent, while providing a steady stream of fresh ventilation air, filtered to HEPA (high-efficiency particulate arresting) standards, 365 days per year (Imbabi and Peacock, 2003). Breathing walls may also be able to clean up polluted cities, because the filtered air exhausted by breathing-wall buildings will effectively contain lower concentrations of pollutants and particulate matter than the outdoor air. The study also suggests that the filter mechanism of the walls will last throughout the lifetime of the building, providing the energy savings and air filtration for 60 or more years, without requiring replacement. Although a few preliminary reports have projected promising energy and IAQ benefits of breathing walls, much research remains to be done. One major issue at hand pertains to understanding the heat transfer mechanism between the breathing-wall media and the incoming air, particularly under varied ambient conditions.

Performance Test

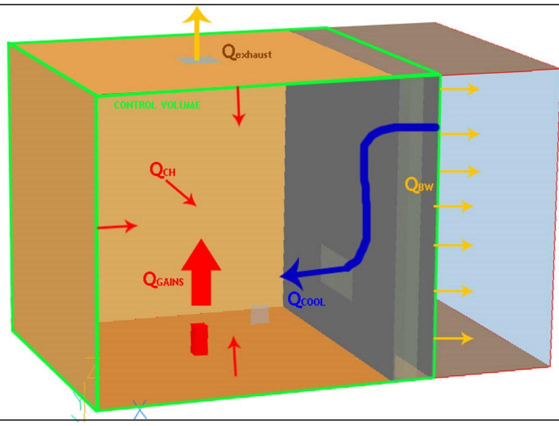
Both experimental and computational approaches were employed to test the thermal performance of the breathing wall, as illustrated in exhibit 2, under a wide variety of exterior and interior environmental conditions. The tested breathing wall was constructed with outside dimensions of 1.1176 by 1.1176 meters and features interior and exterior cladding made of plywood 6.35 millimeters thick. The exterior façade features an inlet grille located in the center of the wall, 0.767 meters up from the bottom. The interior façade features a similar exhaust grille located 0.2 meters from the bottom. An air gap is created between the cladding element and the porous breathing-wall material, so that air is allowed to freely flow away from the inlet vent and penetrate the porous material in a relatively even fashion. The prototype breathing wall was constructed using commercially available unfaced fiberglass batt insulation, which was spread out across a fiberglass window screen and secured within the wood plane of the wall. The efficiency of the wall, referred to as η_3, is defined as in equation (1) (Zhai and Slowinski, 2013).

$$\eta_3 = 1 - \frac{U_{dynamic}}{U_{static}}, \quad (1)$$

where U_{static} and $U_{dynamic}$ are the wall U values, respectively, without and with airflow. Exhibit 3 shows the η_3 contour for varying indoor and outdoor air temperature differences and different airflow rates. The results show a clear, positive correlation between airflow rate and efficiency and also a clear, negative correlation between temperature differential and efficiency. Efficiencies range from -10 to +30 percent. The testing results were verified by both analytical and computational results.

Exhibit 2

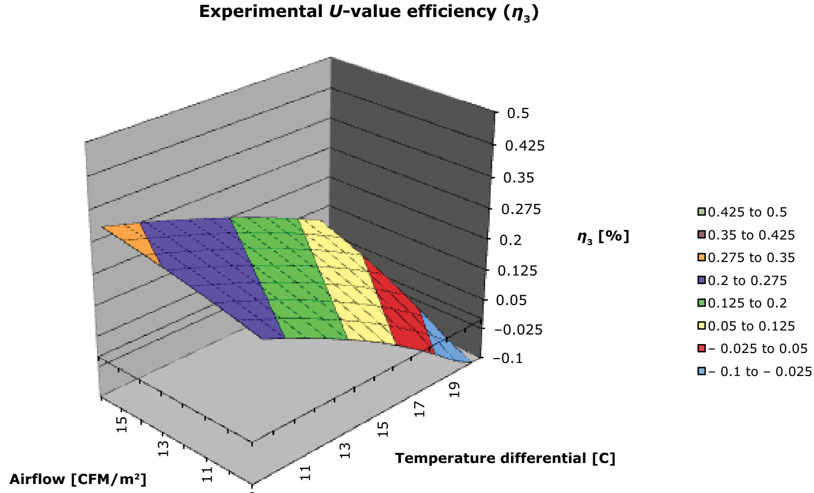
Test Chambers and Breathing Wall in Between



Q = heat flow rate in watts.

Exhibit 3

Experimental Efficiency (η_3) for Varying Temperature Gradients and Airflow Rates



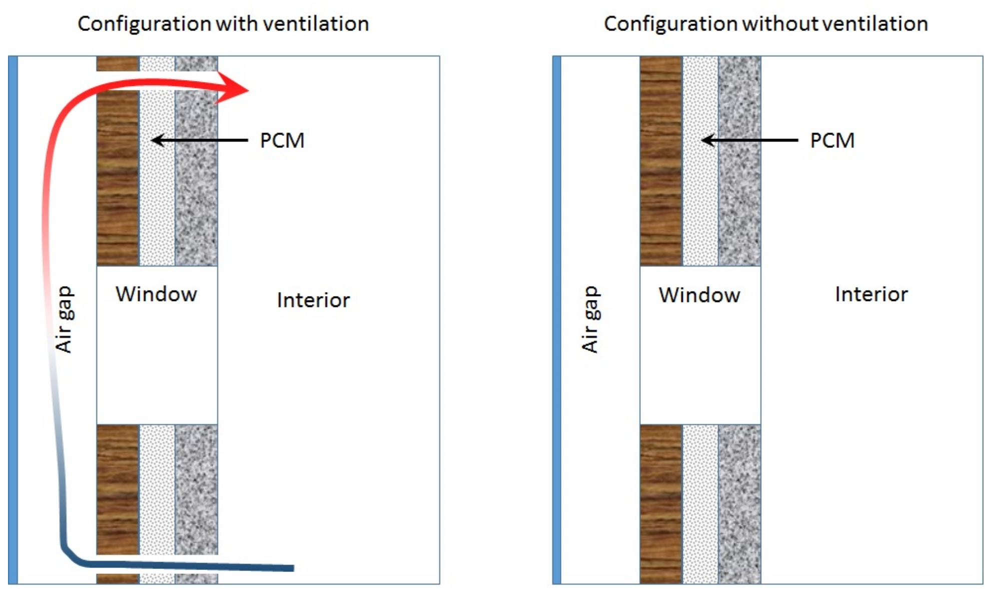
C = Celsius. CFM = cubic feet per minute. η_3 = efficiency of the wall.

The performance of the developed breathing wall was further numerically explored when integrated into a whole building simulation program (El Mankibi et al., 2006), which considers heat transfer through the walls, air infiltration and ventilation, internal heat gains, solar radiations, and auxiliary heating or cooling. The tested building was an 80-square-meter single-family house in a rectangular shape (10 meters long, 8 meters wide, and 3 meters high), with windows in each façade, except the north façade. All the walls had the standard properties, except the south wall, which was replaced with the proposed breathing wall as illustrated in exhibit 4. The tested breathing wall was composed of three layers: (1) external glazing, (2) an air gap, and (3) an internal wall that was made of an outside sensible storage layer, an intermediate latent heat storage layer—phase change materials (PCM), and an inside sensible storage layer. A nondominated sorting generic algorithm has been used to investigate and optimize the thickness, density, and conductivity of the wall layers and the properties (that is, melting temperature range and latent heat) of the PCM layer (El Mankibi et al., 2015).

The results show that the performance of the multilayer living wall system improves the performance of the base case by 28 percent (building with less inertia configuration—light construction) and up to 38 percent (building with high inertia configuration—heavy construction) in energy consumption. It is found that the PCM layer thickness varies between 1 and 4 centimeters, depending on the whole building inertia. The outside and inside wall layers have to be conductive with high thermal inertia. The thickness depends on the ventilation configuration and the whole building inertia. The cavity wall without ventilation is thermally more efficient but induces high risk of thermal discomfort. Control strategies of shading and outdoor air circulation should be provided to avoid this risk.

Exhibit 4

The South Multilayer Breathing Wall Coupled to a Full-Scale Building



PCM = phase change materials.

The results reveal that the ventilated cavity design enhances the wall thermal performance. The cavity improves the performance of interior PCM from 3 percent with no cavity to 30 percent for south-facing and 20 percent for east- and west-facing walls. The cavity on the north-facing wall does not improve the performance of PCM. The full-scale building model results show that an optimized wall system can allow 27 to 38 percent of reduced heating energy consumption while avoiding thermal discomfort.

Conclusions

Breathing-wall technology has the potential to save energy under varying environmental conditions if properly designed and applied. Both experimental and simulation studies prove that breathing walls can save energy above a certain airflow rate, and their efficiency tends to increase with airflow rates. In addition, in most of the studied cases, efficiencies tend to show a slight negative correlation with temperature differential, indicating that convection might play a greater role in breathing walls with cavities when the temperature differential is greater. The η_3 can be used to provide a quick estimate of potential savings to expect from a breathing-wall installation. It is also most easily integrated into an existing piece of building energy simulation software. The η_3 has been shown to range between -10 and +30 percent, depending on the airflow rate and temperature differential.

Multilayer wall systems will improve the building energy and thermal performance when designed properly. Optimal design requires many factors, such as environmental conditions and control strategies. The optimization results show that it is important to pay attention to the whole building thermal inertia (light versus heavy structure) and the glazing ratio when a multilayer wall system is designed and integrated into a building. It is explicit that the optimal configurations are more energetically efficient compared with the reference cases, but, if the designer does not pay good attention to the selection process, he or she may not be able to produce such optimization and the resulting multilayer wall could be less efficient than the conventional wall.

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