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Thermal Performance of Novel Natural Ventilation Apertures in a High-Performance Single-Family House

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ABSTRACT

Natural ventilation provides opportunities to reduce residential cooling load in summer, but increasing the operability of a façade potentially increases infiltration, which is already a source of significant winter heat load. Solving both of these simultaneously is challenging. The test building for this study was a prototype house containing a novel ventilator detail which allows for porosity for summer ventilation and a tight, insulated seal in winter. We aimed to determine whether the prototype had low enough infiltration and thermal bridging to be worthy of further laboratory testing and subsequent deployment in more buildings. The test home was blower door tested, following the Resnet standard to determine ACH50. While the house was depressurized, diagnostic photographs were taken with a smoke wand at each ventilator to qualitatively document air exchange. The ventilator plan and section details were modeled in THERM v7.6 to look for potential thermal bridging. These tests were conducted in February 2018 on the GRoW Home, a prototype house built for the 2015 Solar Decathlon at the University at Buffalo. The home contains thirteen instances of the ventilation detail in question. ACH50 was found to be 1.16, photographs showed observable infiltration at only five of the thirteen apertures, and only when the operable interior door was open. The thermal flux magnitude analysis did not evidence major thermal bridging. Thus this ventilation approach shows promise for naturally ventilated small buildings in cold climates. Further laboratory study is warranted to characterize and further improve the construction.

KEYWORDS

Natural ventilation, passive, thermal performance, residential, cold climate

INTRODUCTION

Natural ventilation provides opportunities to reduce residential cooling load in summer. Residential air conditioning loads represent 6% percent of total US residential energy consumption, and are responsible for 1.5% percent of residential energy consumption in cold/very cold US climates (EIA 2009). Natural ventilation is a viable option in residential projects to reduce reliance on energy-intensive cooling strategies. Ventilation typically requires increasing the operability of the façade to allow air into occupied spaces, but doing so introduces more opportunity for infiltration in winter as well, thereby increasing heating loads in winter. Typically 6 to 22% (mean 15%) of infiltration occurs at windows and doors in residential buildings (ASHRAE 2001). Winter space conditioning is responsible for 42% percent of total US residential energy consumption, and 54% percent of energy consumption in cold climates (EIA 2009). Infiltration rates can vary by a factor of ten in north America, so the impact on energy consumption is highly variable based on construction typology (ASHRAE 2001). Single family detached homes in the US have ACH50 values from 3 to 40, with a median of about 12 ACH50 (Chan, Joh, and Sherman 2013). Buildings in cold climates with energy recovery ventilation particularly need to control infiltration so as to make best use of the mechanical heat exchange (ASHRAE 2001). However, infiltration is responsible for a third to a half of the space conditioning load of a home (Sherman 2009). Increasing the number of operable apertures would likely further increase winter infiltration. Wall apertures present opportunities for thermal bridging in addition to infiltration because frames are typically more conductive materials spanning the insulation layer. The detail studied in this project is similar to a window or door frame in this regard.

The ventilation apertures in the test home were designed to increase summer ventilation while minimizing winter infiltration and thermal bridging. However, the thermal and air movement performance of these in either field or laboratory conditions is currently unknown. This study seeks to assess whether winter performance in the field suggests viability of this envelope detail approach, and hence whether further lab testing is warranted.

Specific requirements or standards for whole-building ventilation provide an indication of whether a building has infiltration levels within a desired range for energy efficient operations. Significant relevant examples are shown in Table 1.

Requirement	Notes	ACH 50
Energy Star (EPA and DOE 2015)	Under the prescriptive path in climate zone 5.	<4
International Energy Conservation Code (IECC) and NY State Energy Conservation Construction Code (NYSECCC) (International Code Council 2015)	NYSECCC is based on IECC	<3
LEED v4 for Homes: 1 point (US Green Building Council 2013)		<2.75
LEED v4 for Homes: 2 points		<2.0
Passive House Standard (International Passive House Association)		<0.6

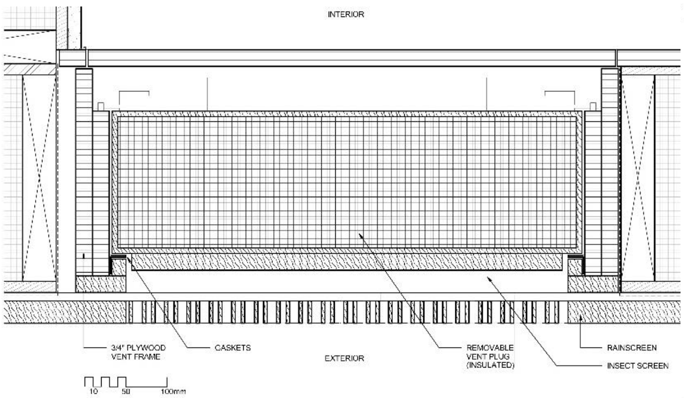
Thermal bridging may be studied using finite element analysis software that maps how heat will flow through all elements of an assembly under ideal specified conditions. Analyzing the magnitude of thermal flux should identify aspects of the test apertures that allow significant heat transfer from inside to outside during winter.

We predicted that infiltration levels would be lower than the published guidelines without major thermal bridging occurring, and we tested this hypothesis with a blower door test and analysis in THERM.

METHODS

Ventilator / House prototype

The ventilation apertures studied were a set of thirteen 0.121 m^2 operable through-wall openings, shown in Figures 1, 2. These openings cut through a 260mm SIP wall finished with 16mm gypsum board on the interior and 19mm larch rainscreen on the exterior. On the interior face, the units had an operable plywood door so the user could regulate ventilation in the summer, as shown in Figure 3. These had wing up hold open fittings to maintain ventilation when open, and magnetic touch latches to keep them closed. The exterior rainscreen was perforated with 50% openings where the ventilators occurred, as shown in Figure 4. Behind the perforated openings was an insect screen. Each ventilator had a wood-wrapped insulation plug that is inserted in winter. These plugs had an EPDM gasket and were fixed in place with a casement fastener.



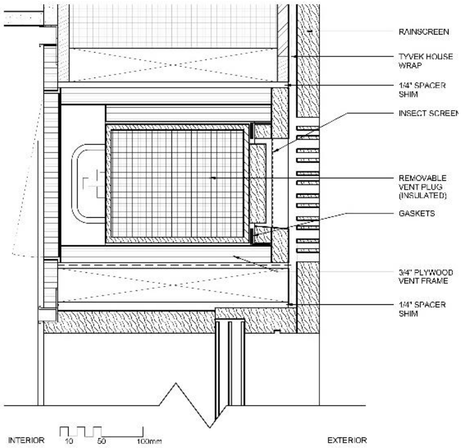


Figure 1: Ventilator construction, plan (left).
Figure 2: Ventilator construction, section (right).

The ventilators were located in a 71.5 m^2 prototype high-performance house located in Buffalo. Windows in the house, with the exception of an egress window in the bedroom, were fixed, triple-paned, and argon-filled. The ventilators are typically located above the windows from 2197mm to 2374mm. The house is equipped with a Greenheck Minicore-5-VG energy recovery ventilator equipped with a CO2 sensor to cycle air when the house is occupied.

Figure 3: Ventilator as seen from inside test house (left).
Figure 4: Ventilator as seen from outside test house (right).

Blower Door Test + Smoke Analysis

The ACH50 was measured by following chapter 8 of the RESNET standards, which specifies procedures for conducting a one-point building enclosure airtightness test[1] (RESNET 2013). We used a Minneapolis Blower door with a single fan. Tests were performed in February and March of 2018, when temperature conditions were between -1 and 4˚C and conditions were not windy. While the house was depressurized to -50 Pascals relative to outside conditions, we performed a qualitative assessment of air infiltration at the ventilators. Using a smoke wand, we examined each of the thirteen ventilators with doors open and doors closed to look for evidence of infiltration, and documented each condition photographically. Ventilation plugs remained inserted for this test.

Therm analysis

The plan and the section detail for the ventilators were examined in THERM 7.6 using a temperature difference of 20.7 ˚C from inside to outside (with external temperature equal to

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[1] Chapter 8 standards were replaced with ANSI/RESNET/ICC 380-2016 and addendum A-2017 as of January 1, 2018.

0.4 ˚C). Table 2 shows the material properties assigned to each of the component materials of the assembly. Emissivity was set to 0.90 for each material.

		Thickness (mm)	**Thermal conductivity (W/m-K)**
Wall assembly	External larch cladding	19	0.11
	Oriented strand board	13	0.13
	Expanded polystyrene (EPS)	235	0.03
	Oriented strand board	13	0.13
	Gypsum wall board	16	0.25
Insulation plug	Plywood	6	0.12
	Extruded polystyrene (XPS)	190	0.034
	Plywood	6	0.12
	EPDM Gasket (D-shaped)	16	0.2

Table 2: Material properties for THERM model

RESULTS

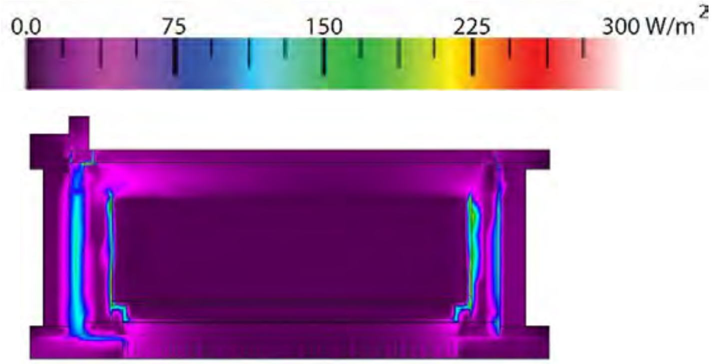
We have earlier postulated that the inclusion of the ventilators do not prevent the test home from meeting published air infiltration guidelines and at the same time introduce more natural ventilation possibilities. Our blower door test result (ACH50) of 1.16, indicate that the air infiltration levels of the whole house are well within the guidelines for Energy Star certification, IECC, NYECCC, LEED v4 for Homes, but do not meet the more stringent requirements for the Passive House standard, as shown in Table 1.

The smoke wand photographs taken while the house was depressurized help to identify qualitatively where infiltration is occurring in the house. Figures 6 is typical of the ventilators in the closed position, showing that there is no discernable air leakage. Figure 7 indicates some air leakage with the ventilator door is open. This occurred in five of the thirteen ventilators when the doors were open.

Figure 6: Photograph of smoke test with ventilator in closed position. No air leakage is evident in this condition at any ventilator (left).
Figure 7: Photograph of smoke test with ventilator in open position. Five of thirteen ventilators showed some discernable air leakage in this position, as shown here (right).

Smoke tests at other envelope locations in the home while it was depressurized show evidence of air infiltration at the base of the folding glass doors, the stove hood, the bathroom fan, and several of the HVAC diffusers suggesting that these are contributing measurably to the whole house air leakage.

Further, we have suggested that these apertures do not introduce substantial new thermal bridges into the building envelope. Our THERM analysis, shown in Figures 11 and 12, suggest that thermal bridging at this detail is not a primary concern but that a less conductive frame material may yield thermal improvements.



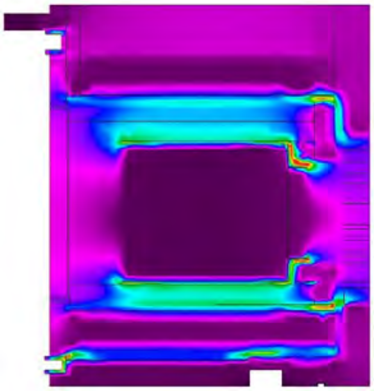


Figure 11: Results of THERM heat flux analysis, plan view (left).
Figure 12: Results of THERM heat flux analysis, section view (right).

We conclude from the results of the blower door testing and the THERM analysis that this ventilation approach is a viable one in cold climates, and may be applicable to other buildings beyond the test home. Thus further laboratory testing is warranted.

DISCUSSION

This study performed initial analysis and in-situ research into a novel natural ventilation aperture which indicates that it is a promising detail for cold climate residential construction. That is, whole house infiltration, including that from the thirteen ventilators, is within several energy efficiency guidelines for infiltration. Further, 2D heat flow analysis suggests that thermal bridging is not problematic. Further laboratory study is warranted to quantitatively characterize heat flow and infiltration. Laboratory studies should focus on heat flux measurements through the assembly, including a hot box test.

While the house meets most of the infiltration guidelines examined, it notably does not meet the PassiveHouse standard. Given that much attention was paid to air infiltration during design and construction, this is a surprise. For example, walls, ceilings, and floors are of SIP construction, where panels are tightly connected with a spline and adhesive. All windows are fixed, with spray foam insulation around the frame; all wall and roof penetrations are caulked. However, the photographic evidence points to air leakage under the folding glass panel doors, as well as at several mechanical system connections. It is recommended that these leaky areas be addressed in order to reduce air infiltration to meet the Passive House standard.

CONCLUSIONS

Design for high-performance residential buildings often includes novel applications of sophisticated active technologies, but may also benefit from novel applications of passive technologies. This paper reports on an investigation into the wintertime performance of novel natural ventilation apertures in a prototype high-performance single-family home in Buffalo, NY. This study assess whether the design approach of decoupling natural ventilation apertures from daylight/view windows can improve wintertime thermal performance of the home. In the test home, natural ventilation occurs through a set of thirteen 0.121 m^2 wood framed, screened openings located in the upper part of the SIP-constructed walls, typically above fixed view windows. Ventilation in summer is controlled with a manual wooden door.

In winter, a gasketed plug of insulation weatherizes the opening and minimizes conductive heat transfer and infiltration.

This design approach is new for cold climates. The operable, dedicated ventilation panels found in temperate locales is modified here to include seasonal insulation. The investigation methods included analysis of whole-building infiltration using blower door testing, diagnostic photography, and modeling in THERM. Results indicate that this approach is viable in cold climates, and should be further studied for implementation to maximum effect in future projects.

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