11th Canadian Masonry Symposium, Toronto, Ontario, May 31- June 3, 2009

AIR PERMEANCE TESTING OF CONCRETE MASONRY

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ABSTRACT

Air infiltration has been identified as a major contributor to energy loss in buildings. Infiltration is a result of leaks around doors and windows, through cracks and holes, in heating and cooling systems and fireplaces, from vents, and diffusion through walls and roofs. Energy recommendations in the United States and Canada also include the use of air barriers on exterior walls to restrict diffusion.

To assess wall diffusion, ASTM E 2178-01, *Standard Test Method for Air Barrier Materials* [1] was developed. However, it primarily tests air permeance of non-porous materials. Being a porous material, concrete masonry has its own particular challenges to rate its air permeance. In a research project conducted for the National Concrete Masonry Association [2], fifteen wall assemblies were constructed from three different sets of concrete masonry units and tested for resistance to air leakage under defined pressures. The contribution of mortar joints to the air permeance was also evaluated.

This paper will describe a portion of the research, discuss a modified testing program for single-wythe concrete masonry, and present the results obtained to evaluate the air permeance of test walls constructed of concrete masonry units meeting ASTM C 90 and masonry mortar meeting ASTM C 270, Type S.

KEYWORDS: infiltration, air barrier, concrete masonry units, mortar, energy.

INTRODUCTION

The requirement for air barriers on buildings is becoming more prevalent in the United States as various states adopt federal energy recommendations to restrict air infiltration. While unlikely, each state could adopt different acceptance criteria. For example, the current criterion for the allowable air infiltration of new buildings that is allowed by Massachusetts versus Wisconsin varies by a factor of approximately six.

The primary advocate for including air barriers in the United States has been the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Since 2005, Addendum z of ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings* [3] has been in development. The basis for the addendum was to require a continuous air barrier on the exterior walls. The addendum was initially approved for publication as part of the 2007 standard but was withdrawn in September 2008 based upon several appeals. It is currently being reconsidered for the 2010 standard.

The proposal for Addendum z included the following compliance options:

5.4.3.1.2 Compliance Options. *Compliance of the continuous air barrier for the opaque building envelope shall comply with section 5.4.3.1.1 and shall be demonstrated by one of the following:*
(a) Using individual materials that have an air permeance not exceeding 0.004 cfm/ft2 under a pressure differential of 0.3" w.g. (1.57psf) (0.02 L/s.m2 @ 75 Pa) when tested in accordance with ASTM E 2178; or
(b) Using assemblies of materials and components that have an average air leakage not to exceed 0.04 cfm/ft2 under a pressure differential of 0.3" w.g. (1.57psf) (0.2 L/s.m2 @ 75 Pa) when tested in accordance with ASTM E 2357 or ASTM E 1677; or
(c) Testing the completed building and demonstrating that the air leakage rate of the building envelope does not exceed 0.40 cfm/ft2 at a pressure differential of 0.3" w.g. (1.57 psf) (2.0 L/s.m2 @ 75 Pa) in accordance with ASTM E 779 or an equivalent approved method.

As indicated, the proposal allows compliance by selecting an appropriate material, an appropriate assembly, or by testing the completed building. As stated, the allowable air permeance increases ten-fold between materials and assemblies and another ten-fold for the entire building.

Criteria were also proposed for materials and assemblies that were deemed to comply. These included:

E2.1 *The following materials comply with the requirements of 5.4.3.1.2(a).*
1. *Plywood - minimum 3/8" (10 mm)*
2. *Oriented strand board - minimum 3/8" (10 mm)*
3. *Extruded polystyrene insulation board - minimum 3/4" (19 mm)*
4. *Foil-back urethane insulation board - minimum 3/4" (19 mm)*
5. *Exterior or interior gypsum board - minimum 1/2" (12 mm)*
6. *Cement board - minimum 1/2" (12 mm)*
7. *Built up roofing membrane*
8. *Modified bituminous roof membrane*
9. *Fully adhered single-ply roof membrane*
10. *A Portland cement/sand parge or gypsum plaster minimum 5/8" (16 mm) thick*
11. *Cast-in-place and precast concrete.*
12. *Fully grouted concrete block masonry.*
13. *Sheet Steel.*

E2.2 *The following assemblies comply with the requirements of 5.4.3.1.2(b).*
1. *Assemblies that include a house wrap continuous air barrier material and comply with ASTM E 2357 or ASTM E 1677 and 5.4.3.1.2(b)*

2. *Concrete masonry walls coated with one application of block filler and two applications of a coating.*

Therefore to comply without testing, concrete masonry walls must either be constructed with a parging, or be fully grouted, or the walls must be coated with block filler and two applications of a coating. Since there has been minimal air permeance research on concrete masonry, the basis for these requirements is questionable especially since there is no specific standard for testing concrete masonry walls.

Previously unpublished testing [4] on concrete masonry walls was performed using a protocol that effectively tests only the face shells of concrete masonry (CMU) walls. The premise of the research in this paper was that the initial testing was too conservative and does not represent actual field-constructed concrete masonry. Thus, there was a need to determine the air permeance of realistic concrete masonry assemblies. A secondary interest was to determine the impact of the mortar joints on the air permeance.

As noted in proposed 5.4.3.1.2 (a), the industry standard for testing for air leakage is ASTM E 2178-01, *Standard Test Method for Air Barrier Materials.* Since this standard was not developed for non-porous materials such as concrete masonry, a challenge was to modify the test procedure.

RESEARCH

Fifteen wall assemblies were constructed using standard construction techniques in accordance with ACI 530.1/ASCE 6/TMS 602 *Specification for Masonry Structures* [5]. The overall nominal dimensions of the finished wall assemblies were 1.63 m (64 inches) in height, 1.42 m (56) inches in length, and 305 mm (12 inches) in thickness.

CMU were classified as Set 1, Set 2, or Set 3 and represent three densities as noted in Table 1. All units complied with the requirements of ASTM C 90, *Standard Specifications for Loadbearing Concrete Masonry Units* [6]. Five assemblies were constructed from each of the three CMU sets. Each wall assembly was constructed with the CMU in running bond using face shell bedding. At the ends of each wall assembly, end webs of the units were mortared. The mortar joints on both faces were struck and tooled concave when the mortar became thumbprint hard. The wall assembly was left ungrouted. However, the cells of the units along the tops, bottoms and sides outside of the test area were fully grouted to isolate the path of airflow through the assemblies. The assemblies were cured under laboratory conditions for 28 days. Figure 1 shows a representative sketch of a typical wall assembly.

The physical properties of each unit type were evaluated in accordance with ASTM C 140 *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units* [7]. Results of the unit tests are summarized in Table 1. Each unit type met the physical, absorption, and compressive strengths requirements of ASTM C 90.

The mortar was batched in accordance to the proportion specification of ASTM C 270, *Standard Specification for Mortar for Unit Masonry* [8] using Type S masonry cement.

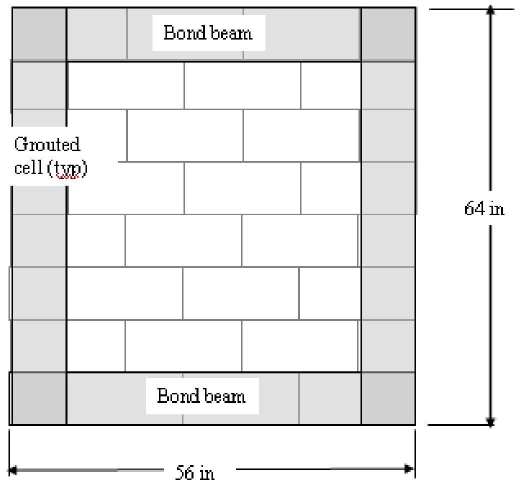

Figure 1: Wall configuration

Table 1: Properties of Concrete Masonry Units

Physical Property (Average of 3 Units)	Set 1	Set 2	Set 3
Width mm (in.)	295.9 (11.65)	295.4 (11.63)	295.7(11.64)
Height mm (in.)	194.6 (7.66)	193.3 (7.61)	194.6 (7.66)
Length mm (in.)	396.2 (15.60)	395.5 (15.57)	395.7 (15.58)
Minimum faceshell thickness mm (in.)	38.4 (1.51)	38.4 (1.51)	38.4(1.51)
Minimum web thickness mm (in.)	33.0 (1.3)	33.0 (1.3)	33.0 (1.3)
Percent solid (%)	42.7	46.8	47.2
Density kg/m^3 (lb/ft^3)	1504 (93.9)	1717 (107.2)	2023 (126.3)
Absorption kg/m^3 (lb/ft^3)	215 (13.4)	191 (11.9)	162 (10.1)
Net compressive strength of unit MPa (psi)	18.9 (2740)	19.1 (2770)	19.4 (2810)

The wall assemblies were tested in general accordance with ASTM E 2178. The test method uses a sealed cabinet with a nominal testing surface area of 1.0 m^2 (10.8 ft^2), which is attached to the wall assembly. For this research, a pressure differential is applied to the assembly by means of either a low flow or a high flow air pump, depending upon the air permeance of the assembly. The range of the low flow pump is 0 to 150 standard liters per minute (SLPM) (0 to 5.3 ft^3/min) and the high flow from 0 to 750 SLPM (0 to 26.5 ft^3/min). The negative pressure differential created inside the cabinet is measured via a digital pressure gage in units of Pascal (Pa). Once the specified pressure differential across the wall assembly is achieved, the air flow required to maintain this pressure differential is measured in SLPM. This SLPM measurement is then correlated to the calibration of the cabinet as described in the following paragraph, becoming the air permeance measurement of the assembly. Figure 2 shows the pressure cabinet attached to a wall assembly.

Figure 2: Vacuum cabinet attached to wall assembly

While ASTM E 2178 was developed to measure the air permeance of flexible sheet or rigid panel-type materials, it was not intended to evaluate building assemblies or porous materials. The standard specifies that the air permeance be determined using prescribed pressure differences. Air leakage measurements are taken at pressure differentials of 25, 50, 75, 100, 150, and 300 Pa (0.52, 1.04, 1.57, 2.09, 3.13, and 6.27 lb/ft^2 respectively) and then repeated for 100, 75, and 50 Pa (2.09, 1.57, and 1.04 lb/ft^2 respectively) to determine the accuracy and repeatability of the airflow measurements. These measurements are then corrected to account for air leakage that may have occurred through joints or connections in the testing equipment. The procedure to determine system leakage in the system equipment is to enclose the test specimen in polyethylene film and perform the permeance test.

The overall air permeance rating is taken from the reading at 75 Pa (1.57 lb/ft^2). If the test specimen can not sustain the specified pressure differential, the rating is based upon interpolation. The vacuum of 75 Pa (1.57 lb/ft^2) was used because it is the standard vacuum used to determine if walls meet air permeance requirements. For example, ASTM C 1677, *Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls,* rates air retarders at 0.3 L/s.m^2 (0.06 cfm/ft^2) at 75 Pa (1.57 lb/ft^2). Also, developing building codes are proposing requirements on masonry wall systems of 0.2 L/s.m^2 (0.04 cfm/ft^2) at 75 Pa (1.57 lb/ft^2).

The ASTM procedures were not practical for evaluating the air permeance of concrete masonry units. Whereas sheet and panel-type materials could be fabricated to the desired size to suit the test equipment, that was not possible for individual concrete masonry units. Therefore, it was decided that it would be more appropriate to test wall assemblies and capture the effects of both the units and the mortar joints in one test.

In order to meet the intent of the ASTM test method, the following modifications were introduced in the test set-up. First, the hollow cells around the periphery of the test surface were grouted in an attempt to inhibit unintended flow of air from entering through the sides, top, and bottom of the wall assembly. By comparison, typical CMU walls generally have grouted cells adjacent to control joints and have bond beams at floor and roof levels. The non-incidental areas of the wall assembly were coated with an epoxy paint to reduce extraneous air leakage. Second, using polyethylene over the wall assemblies to calibrate the system air leakage was not appropriate to CMU walls; sealing the perimeter was reliable. Rather than use the CMU, the system air leakage was determined by measuring the air permeance of a 19 mm (3/4 inch) sheet of Plexiglas at the specified pressure differentials stated above. The Plexiglas is considered to be impermeable to air leakage, so any leakage is attributed to cabinet leakage at connections and seals. The calibrations were determined many times during the course of the testing and had some variations. The most recent calibration at the time of testing was used to determine actual permeance values.

For each wall assembly, the specified pressure differentials were attempted and the flow was measured. However, none of the wall assemblies were able to support the specified maximum pressure differentials. In these cases, the actual maximum pressure differential was determined and then increments of this pressure were measured. Wall assemblies were tested and then retested with the mortar joints sealed with silicon sealant. The sealant was used to eliminate air flow through the joints to isolate the air permeance of the units versus the mortar joints. The sealant was applied using a caulk gun and smoothed into the mortar joint using a gloved finger.

Following the initial testing, the mortar joints were sealed and retested. The surface area of the mortar joints was calculated to be approximately 645 cm^2 (100 in^2), which is approximately 7 percent of the total tested wall area.

RESULTS

Figures 3, 4, and 5 shows the measured air permeance for the Set 1, Set 2, and Set 3 wall assemblies, respectively. The plotted values are the average values obtained from the five test specimens for each wall type. Plotted along with the measurements are linear regression lines that represent a linear best fit to the measurements. All cases show that sealing the mortar joints decreased the air permeance. The solid lines represent the unsealed mortar joints, while the dotted lines represent the sealed mortar joints.

None of the specimens could achieve the maximum 300 Pa (6.27 lb/ft^2) of differential pressure required by ASTM E2178. Set 1 and Set 2 walls did not achieve 75 Pa (1.57 lb/ft^2). The Set 1 units could not exceed 10 Pa (0.21 lb/ft^2). The rated air permeance values for each of the five wall types were determined by interpolation. See Table 2 which also indicates the reduction in air permeance with sealed joints.

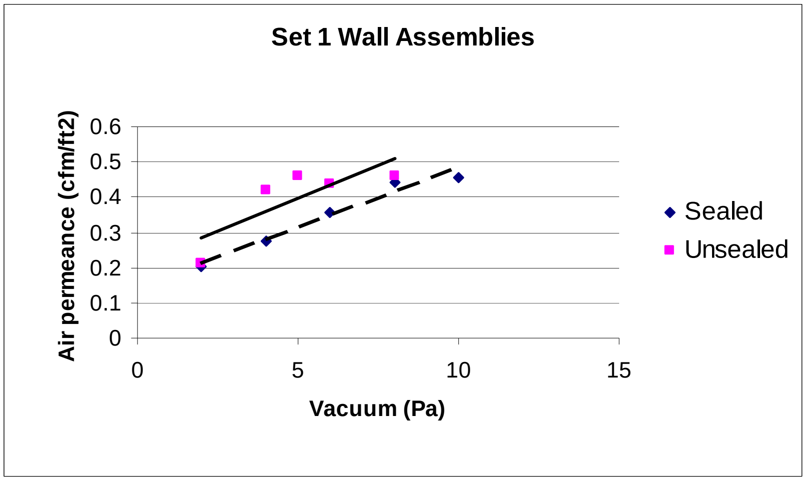

Figure 3: Air permeance of Set 1 wall assemblies

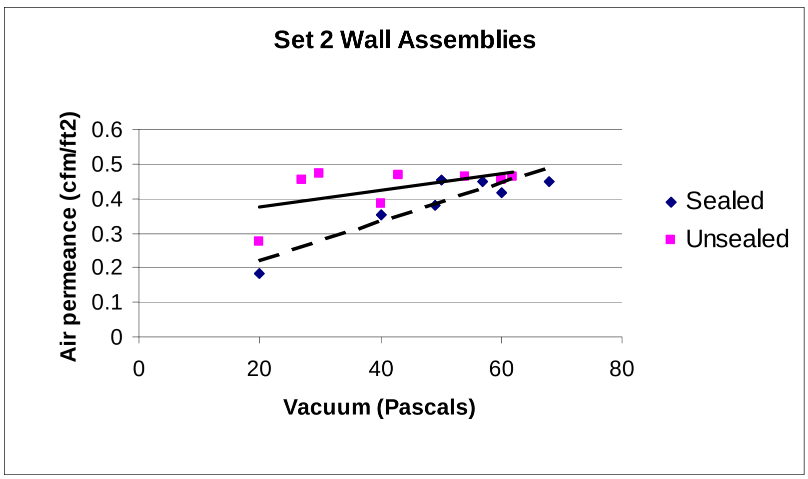

Figure 4: Air permeance of Set 2 wall assemblies

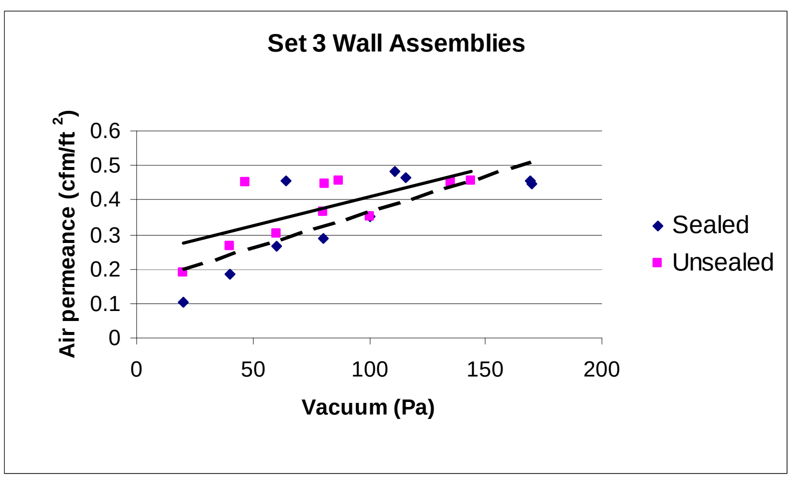

Figure 5: Air permeance of Set 3 wall assemblies

Table 2: Wall assembly comparison

Wall type	Mortar joints	Air permeance, L/s.m^2 (cfm/ft^2) @ 75 Pa (1.57 lb/ft^2)	Percent change
Set 1	Unsealed	15.5 (3.044)	
	Sealed	13.6 (2.672)	-13.9%
Set 2	Unsealed	2.6 (0.508)	
	Sealed	2.7 (0.529)	4.0%
Set 3	Unsealed	1.9 (0.369)	
	Sealed	1.6 (0.313)	-17.7%

Set 2 indicates an increase in permeance. However from Figure 4, the values are derived by interpolation because the 75 Pa (1.57 lb/ft^2) pressure could not be achieved. Thus, the scatter of the results produced an unexpected result.

CONCLUSIONS

None of the assemblies were able to support the 300 Pa (6.27 lb/ft^2) maximum pressure differential required by ASTM E 2178 without sealing the mortar joints. A re-evaluation of the required pressure at which to take leakage readings may be necessary for masonry wall assemblies.

Reduced air flow was measured when mortar joints were sealed. The sealed joints represent approximately 7% of the tested surface area. Based upon Table 2, the air permeance of the Set 1 and Set 3 walls was affected more than 7 % by sealing the joints. Sealing the joints on the Set 2 walls did not reduce the air flow by at least 7%.

As pressure differentials increased, the reduction in permeance decreased. This suggests that there is a reduced benefit to mortar joint sealing as the pressure differential gets larger. This would also indicate that at larger pressure differentials, sealing only a portion of the surface has diminishing returns.

None of the walls could achieve an air permeance rating of 0.2 to 0.3 L/s.m^2 (0.04 to 0.06 cfm/ft^2) at 75 Pa (1.57 lb/ft^2) that is being promoted by ASHRAE. Surface porosity and density were major contributors to the high flow of air through the units. Therefore, it will be necessary to coat, parge, or grout fill the walls. A follow up to this research indicated latex paint could be an alternative to more expensive block filler and coatings.

Subsequent to this research, ASTM International released a standard ASTM E 2357, *Standard Test Method for Determining Air Leakage of Air Barrier Assemblies* [9]. The standard closely matches the ASHRAE proposal for testing.

ACKNOWLEDGEMENTS

The authors acknowledge the encouragement and financial support of the NCMA Research and Education Foundation, the NCMA Air Barrier Testing Task Group, David Dimmick of the task group, and NCMA staff.

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