LABORATORY TESTING OF AIR RETARDERS IN METAL BUILDING PANELS

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ABSTRACT

The authors tested a variety of air retarder configurations for pre-engineered metal buildings. Test panels were devised to simulate a variety of configurations. The panels were tested in an ASTM E 283 apparatus that establishes a difference in air pressure across the test specimen and measures the resulting airflow through the specimen. The specimens were evaluated for their ability to impede airflow due to air pressure differences.

INTRODUCTION

Retarding Air Leakage

Air Leakage Air leakage is a dominant cause of moisture and heat loss problems in pre-engineered metal buildings. Pre-engineered metal buildings present challenges for achieving airtightness. Sealed sandwich insulated panel systems can minimize air leakage effects, but assemblies of sheet metal components and insulation have been less effective in controlling air leakage. Typical pressure differences under calm conditions in low-rise buildings are less than 20 Pa. These pressure differences are more important for defining annual energy consumption. Short-duration pressure differences of up to 1,000 Pa may occur during windy conditions. These pressure differences are more important for defining durability of construction.

Air Retarders The use of modern sheet air retarder materials that come in rolls, such as spun olefin, has become commonplace in air retarders for residential construction. Harkins (1984) proposed one means for applying continuous sheet wind and vapor retarders in pre-engineered metal buildings. However, commonly used specifications or design manuals often have inadequate guidance about air and vapor retarders; for example, that of the Army Corps of Engineers (CEGS 1990) and the American Institute for Steel Construction (AISC 1989). The Canadian Sheet Steel Building Institute (CSSBI 1990) makes reference to a convection barrier as distinct from an air or vapor barrier. It need not have the strength of an air barrier and it must not impede moisture diffusion, like a vapor barrier. This study is part of an effort to explore sheet and other air retarder systems for such metal buildings.

Frame Wall Testing Brown and Poirier (1988) tested air barrier systems for wood-frame walls in pressure ranges of less than 20 Pa (0.08 in. H_2O) that both represented annual air leakage and, in pressure ranges up to 3,000 Pa (12 in. H_2O), represented the structural integrity of the system. They tested 2.55-m × 2.55-m (8.3-ft × 8.3-ft) panels with wooden studs 0.4 m (16 in.) on center and sheathing in the following configurations.

- Spunbonded polyolefin sheet wind retarder on fiberboard sheathing.
- Semirigid fiberglass insulation with a spunbonded polyolefin face, taped at the joints (two each).
- Gypsum wall board (GWB) installed horizontally and taped at the joints (two methods).
- Extruded polystyrene (EPS) boards installed horizontally and taped at the joints (two each).
- Exterior insulation and finish system (EIFS).
- Double-skinned plywood panel.
- Taped fiberboard with and without foam insulation and GWB.

Brown and Poirier found that most of the configurations permitted airflow of less than 25×10^{-3} L/s·m^2 at a pressure difference of 75 Pa. Two configurations—fiberboard with a spunbonded polyolefin sheet air retarder and semirigid insulation board skinned with the same type of sheet air retarder and taped at the joints—permitted an airflow of more than 300×10^{-3} L/s·m^2 at a pressure difference of 75 Pa.

They further found that the two examples of semirigid fiberglass insulation with a spunbonded polyolefin face, taped at the joints, withstood peak pressure differences of 1,000 Pa or less. The sheet wind retarder on fiberboard sheathing and two of the GWB systems withstood peak pressure differences of between 1,500 and 2,000 Pa.

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The remaining systems, including a GWB system with a special tape, the EIFS, and the taped fiberboard, plywood, and EPS board systems, withstood 2,500 Pa.

While testing the airtightness of curtain wall systems is commonplace, the conscious design and testing of air retarder systems in pre-engineered metal buildings is less common.

Objective of Study

The goal was to evaluate the airtightness of a variety of configurations for air retarder systems for pre-engineered buildings with sheet metal (not insulated panel) exteriors.

PROCEDURE

Air Leakage Tests

The laboratory constructed a test panel that was adaptable to several configurations and then followed ASTM E 283-91 (ASTM 1994), with some variations, to perform air leakage tests on the test panel and to report visible degradation of its airtightness or structural integrity. The ASTM test method allows determination of rates of airflow through a test specimen for each difference in air pressure across the specimen to which it is subjected.

Apparatus

ASTM E 283-91 The apparatus for ASTM E 283-91 is a test chamber that accommodates a test panel specimen tightly sealed onto or into an opening on one face. The chamber has an air system that provides positive or negative pressure. It features metering of volumetric airflow in or out of the pressure difference across the specimen.

Specimen Panel Configurations

Test Panel The test panel dimensions were 2.44 × 2.44 m (8 × 8 ft). It incorporated two parts—a metal building panel and an indoor finish panel. A gasket seal made the interface between the indoor finish panel and the metal building panel airtight. The panels fastened together securely in a manner that did not interfere with a tight seal between the panels and the testing apparatus.

Metal Building Panel The metal building panel employed components from a pre-engineered metal building system (Figure 1). These comprised a frame of structural steel sections around the perimeter, a horizontal girt at mid-height, and a preformed sheet metal cladding. The sheet metal cladding panel was readily removed to accommodate a variety of air retarder treatments. The panel was also readily separated from the interior finish panel.

Indoor Finish Panel The indoor finish panel was framed with 2 × 4 metal studs, 406 mm (16 in.) on center, to be the same dimensions as the metal building panel.

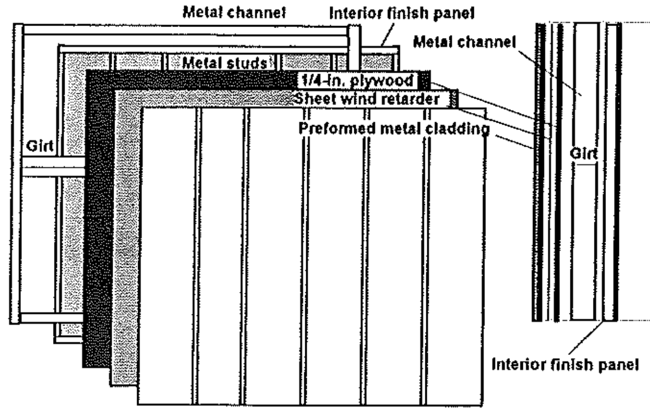

Figure 1 Front and side blown-up elevation of case 5 panel system with sheet wind retarder backed with plywood, tested with interior, insulated panel.

It had fiberglass batt insulation between the studs and a continuous black polyethylene vapor retarder continuously placed over the indoor face of the panel, which was covered with 13-mm (1/2-in.) gypsum wallboard, fastened with sheetrock screws.

In addition, these panels were adapted for use as blanks to establish a baseline leakage around the specimen frames and in the apparatus before each test. The blank for the metal building panel was the metal building panel frame, with a seamless, sealed membrane substituted for its cladding. The blank for the metal building and interior finish panel combination was the blank for the metal building panel with the interior finish panel attached.

Test Treatments The test treatments were in two categories—without and with the indoor finish panel. The configurations included:

Without Indoor Finish:

1. Metal building panel—The baseline panel was an uninsulated metal frame, consisting of channels obtained from a manufacturer of pre-engineered metal buildings, and preformed metal cladding screwed onto the frame in a removable manner, according to the manufacturer's specifications.
2. Metal building panel with wind retarder—A sheet air retarder was placed behind the metal cladding of the baseline panel.
3. Metal building panel with vinyl-backed insulation—Vinyl-backed, 90-mm (3.5-in.) fiberglass insulation was installed on the side opposite the cladding, according to the manufacturer's specifications and sealed around the perimeter of the frame in a manner consistent with those specifications.

With Indoor Finish:

4. Both panels—The metal building panel and interior finish panels together.

5. Both panels with batt insulation—The interior finish panel had 90-mm (3.5-in.) fiberglass batt insulation installed.
6. Both panels with sheet air retarder system—The metal building panel had a sheet wind retarder placed beneath the cladding.
7. Both panels with sheet air retarder system with plywood—Same as 6, except that the sheet wind retarder was sandwiched between the cladding and 6-mm (1/4-in.) plywood. The wind retarder was wrapped around the metal building panel and taped.
8. Both panels with taped plywood—Same as 7, except that the sheet wind retarder was omitted and the 6-mm (1/4-in.) plywood was taped at the seams and edges. The seams coincided with framing on the metal building panel.
9. Both panels with foam board air retarder system—A 51-mm-thick (2-in.-thick) expanded polystyrene (EPS) insulation board was installed vertically in the framing of the metal building panel, such that the outer surface was coplanar with the framing. All joints and edges were taped with contractor's tape. The cladding was installed in the conventional manner.

Test Procedure

Description of Tests The panels were tested according to ASTM E 283-91 except that each specimen was tested at four differences in pressure, both positive and negative; and a blank, sealed panel was used to establish a baseline or tare leakage between the specimen frames and the apparatus to be subtracted from the test results.

Order of Testing The two blanks were tested prior to each specimen series. The order of testing the panels was random.

Replications of the Test A replicate entailed demounting of the test panel from the apparatus, disassembly for inspection of the test panel, and remounting of the panel. Replicates were not performed for all four series prescribed under "Pressure Levels." Instead, replicate tests were done only to the highest pressure difference that was achieved in the previous test of that treatment, unless it was believed that the cause of failure was an anomaly.

Each blank was tested a minimum of five times to establish the reliability of installing the specimen on the apparatus. In addition, test treatments 2 and 6 were tested a minimum of five times to establish the reliability of installing the sheet air retarder materials. Replicates were not done consecutively, except for the blanks, but were done at intervals determined by the randomization plan.

Position of Panel The panel was mounted on the apparatus so as to obtain a tight, repeatable seal.

Pressure Levels The tests were conducted at the following approximate levels of pressure difference between inside and outside the test apparatus: 25, 50, 75, and 100 Pa (0.1, 0.2, 0.3, and 0.4 in. H_2O), starting at the lowest value. Except for tests on the two blank configurations, the tests were run at both negative and positive pressures at each pressure level before proceeding to the next level. Positive pressure is defined as being in the direction from the outdoor surface of the panel toward the indoor surface.

Data Collection Data were recorded on a spreadsheet computer file for pressure inside and outside the apparatus, air temperature inside and outside the apparatus, flow rate through the specimen at standard conditions, and annotations of failure modes that were photographed.

Panel Reconditioning After each pressure test series, the sheet material in both panels was replaced with fresh pieces, i.e., the polyethylene vapor retarder in the interior finish panel and the air retarder material in the metal building panel.

Calculations

The metered flow for the test panels, Q_m, and the extraneous flow obtained for the blank panels, Q_L, were corrected to standard conditions and recorded for each pressure station. These data were used to calculate the airflow through the specimen, Q, as required in ASTM E 283-91 at 75 Pa (0.3 in. H_2O). Values for Q_L were obtained using the mean flow rate data from testing the blank for the metal building panel for specimens 1, 2, and 3 and the blank for the metal building and finish panel combination for specimens 4 through 9.

RESULTS

Calibration

Calibration of the Apparatus The apparatus was calibrated according to ASTM E 283-84, since ASTM E 283-91 does not contain a specific procedure. The apparatus proved to be within the allowable error of ±5%.

Airflow

Airflow Results Airflow data were collected for each positive and negative pressure difference. The 75-Pa (0.3-in. H_2O) results are summarized in Figure 2, which shows flow normalized per unit of area as $L/s \cdot m^2$. Initially there was no measurable airflow through the sheet metal cladding of the panel. For the test to proceed and represent the action of the layers behind the cladding, four 5.6-mm (7/32-in.) holes were drilled in the cladding.

Replicates Two sets of five replicates were performed for positive and negative pressurizations of the following specimens: the baseline panel with vinyl-backed insulation and the panel with a sheet wind retarder and plywood. The vinyl-backed case had a coefficient of variation of 9% for pressurization and 14% for depressurization. The configuration of a sheet wind

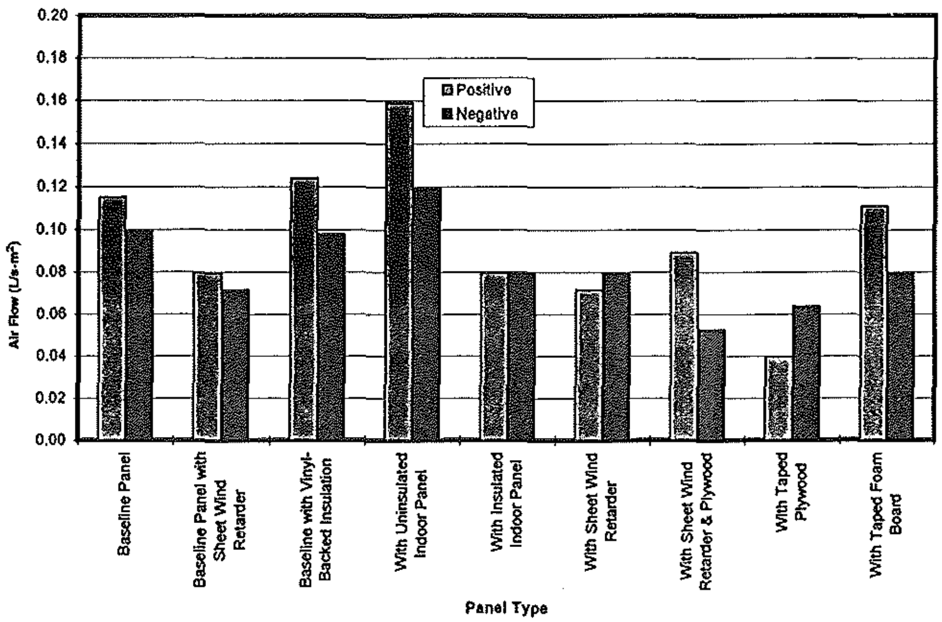

Figure 2 *Average airflow per unit area at 75 Pa for the panel configurations tested.*

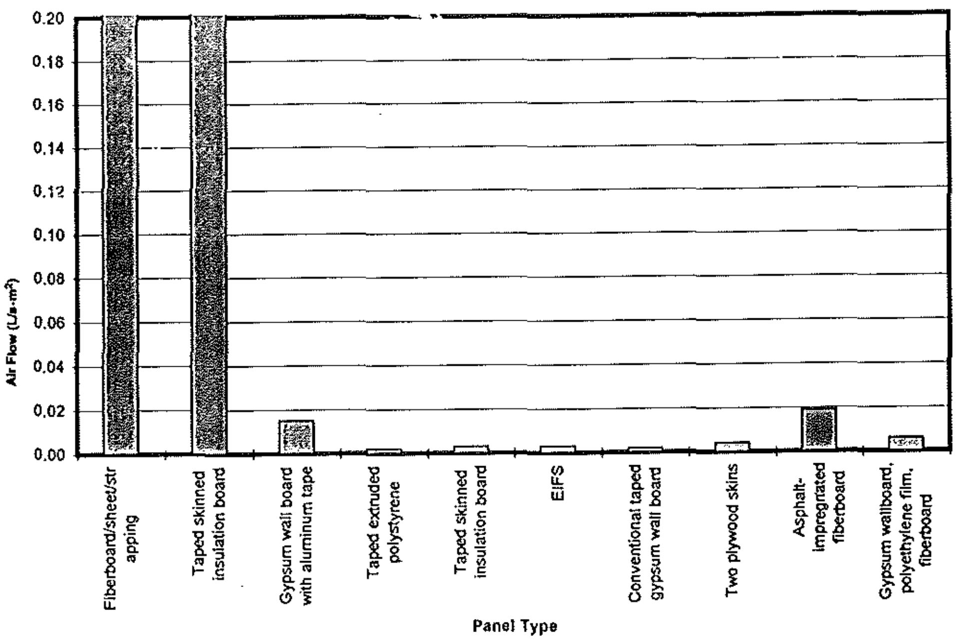

Figure 3 *The reported average airflow per unit area at 75 Pa for the panels tested in Canada (Brown and Poirier (1988)).*

retarder with plywood had a coefficient of variation of 28% for pressurization and 41% for depressurization.

Treatments

Treated vs. Untreated The specimens with a sheet wind retarder or with taped seams were considered to be treated and those without were considered to be untreated. A two-sided t-test was applied to determine whether the treated specimens differed from the untreated. In each case the difference in the means between the two classes of specimen was greater than the value u, estimated for the 95% confidence interval by

$$u = t_{(1-\alpha/2)}\frac{s}{\sqrt{n}} \tag{1}$$

where

$t_{(1-\alpha/2)}$ = value from the t-table for $n-1$ degrees of freedom,

s = estimate of standard deviation for a sample, and

n = number of measurements in the sample.

Damage to Specimens No damage to air retarders was observed for the pressures tested.

DISCUSSION

Realism of Test

Metal Buildings vs. Test Panels Metal buildings with sheet metal cladding can have significant problems with air leakage. Clearly this does not occur in the middle of a given panel, but at joints. The exterior panel for the test frame was formed of 1000 × 2440-mm (39.5 × 96-in.) panels whose lap joints were fastened with screws and tape, but whose head and sill were siliconed to a preformed neoprene closure conforming to the shape of the panel. This represents more care at the joints than that typical of metal building construction. Hence, the four holes were drilled to induce air leakage through the cladding.

Comparison with Literature

Mid-Range The tests performed on panels in Canada by Brown and Poirier (1988) gave 75-Pa (0.3-in. H_2O) results that ranged between 0.49 L/s·m^2 (0.1 cfm/ft^2) and 0.002 L/s·m^2 (0.0004 cfm/ft^2). The fiberboard sheathing with sheet wind retarder had the highest value and the taped extruded polystyrene board and gypsum wallboard specimens had the lowest values in the Canadian tests, depicted at the same scale in Figure 3 as the authors' results in Figure 2.

In the authors' tests (Figure 2), the values for treated specimens were 6 times better than the worst Canadian specimens, but 40 times worse than the best Canadian specimens. In the Canadian tests, the samples relying on a widely used brand of sheet wind retarder performed much worse than did barrier systems relying on solid materials. In the authors' tests, another brand of sheet wind retarder used with the steel panel performed nearly as well as the solid materials, which as a group did not perform nearly as well as the Canadian solid-material wind barriers.

Variability Between Tests

Within-Specimen Variability Whereas the error for the apparatus was within 5%, the coefficients of variation for tests of the same specimens were at best 9% (for positive pressure on the vinyl-backed specimen) and at worst 41% (for negative pressure on the sheet retarder and plywood specimen).

Between-Specimen Variability The baseline panel was less leaky than the specimen that incorporated the uninsulated indoor panel and slightly less leaky than the same panel with vinyl-backed insulation added. These results run counter to intuition.

Tare Variability Each test was preceded by a test of the panel in a sealed configuration to establish the value of the flows between the specimen frame and the test apparatus. The tare value to be subtracted out was often between one-fourth and three-fourths of the total. These values had an overall coefficient of variation of between 70% and 80%. The coefficients of variation for tare tests prior to testing the replicated specimens were between 15% and 21% (for the vinyl-backed specimen) and at 140% and 129% for the sheet retarder and plywood specimen.

Positive vs. Negative

Bias of Test? The coefficients of variation for all replicates were smaller under positive pressure than under negative. Six out of nine specimens gave higher flows under positive pressure with the higher pressure on the outside surface of the specimen. However, 12 of 17 tare values at 75 Pa (0.3 in. H_2O) resulted in a higher flow under negative pressure than under positive pressure. A two-sided *t*-test determined that, at the 95% confidence level, there was no reason to believe that the average negative tare flow value differed from the average positive tare flow value at 75 Pa. There was no obvious reason to suggest a bias in the test, based on sense of flow.

CONCLUSIONS

High Positive Flows The 75-Pa (0.3-in. H_2O) flows for specimens with sheet wind retarders or vinyl-backed insulation were consistently higher in the positive, flow inward direction. This bias appears to be an unexplained product of the specimens, not a bias of the test method. In the case where the sheet wind retarder was backed up with plywood, the positive flow was also higher than the negative. This suggests that mechanical support of the sheet wind retarder is not a significant factor in determining 75-Pa (0.3-in. H_2O) flow.

Moderate Effectiveness The wind retarder treatments tested were not markedly different from the configurations intended to represent an untreated specimen. The 75-Pa (0.3-in. H_2O) flows were substantially lower than those that represented sheet wind retarders in Canadian tests, but were significantly higher than other treatments that the Canadians tested. It appears that the metal building skin was the dominant air retarder in all of the specimens tested.

Test Refinement Required In these tests, the tare value was a major portion of the sought-after 75-Pa (0.3-in. H_2O) flow. If the tare values had been uniform instead of having a coefficient of variation of between 70% and 80%, then we could have more confidence in the 75-Pa (0.3-in. H_2O) flow results. As it stands, we can only say that our results fell in the midrange of those obtained by the Canadians. We cannot conclude that one treatment is substantially more effective than another. A more consistent approach to establishing tare values is needed in order to derive further meaning from such tests.

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