Simple, Fast, Cost Effective Methods of Foam Board Joint Sealing for Air Barrier Assemblies in Commercial Construction

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ABSTRACT

Air infiltration and exfiltration have long been recognized as significant sources of energy loss in both commercial and residential buildings. The most common method used to decrease air infiltration in opaque walls is the use of an air barrier product, which is typically an air impermeable sheet or film added over the entire wall surface.

Another method that can be used to reduce air infiltration in walls is to seal any joints or cracks in the wall. Since a continuous layer of plastic foam board insulation is a common element in many wall systems, the sealing of the insulation board joints to provide the desired air barrier qualities in a wall system is a viable method towards creating a more energy efficient building. This is especially useful when considering the increased reliance on continuous insulation that is emphasized in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings and International Energy Conservation Code Council (IECC).

Two board joint sealing methods were developed and then tested to determine the resulting quality of their air barrier effectiveness. These methods include the use of tapes and sealants. The details of board joint sealing are discussed as well as the corresponding results of laboratory air barrier assembly testing. Both methods of joint sealing were tested using ASTM E2357 “Standard Test Method for Determining Leakage of Air Barrier Assemblies” and the resulting air leakage rate was below the levels specified by various building codes and industry standards. As a result, these methods may provide a simpler, faster, and yet cost effective approach to reduce air infiltration in wall systems.

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INTRODUCTION

Air leakage in buildings can result in increased energy costs, loss of thermal comfort, thermal energy loss, and improper operation of mechanical ventilation systems. This topic has become a focal point of discussion in light of several recently released studies validating this air leakage and quantifying the results. Air infiltration accounts for approximately 15% of the heating load in commercial office buildings (D A VanBronkhorst et al.1995). Proper installation of an air barrier can dramatically reduce the energy consumption and mechanical loads on a building resulting in operational cost savings.

The most recent changes in Energy and Building codes embrace the trend of continuous insulation and air barriers to manage all of the air, moisture, and thermal forces on a building thus improving the efficiency of wall systems and the mechanical ventilation system. In particular, the IECC 2012 and the International Building Code (IBC) 2012 will add air barrier requirements/air changes of the entire assembly instead of a focus on just the material. The Canadian Construction Materials Centre (CMCC) has Technical Guides for similar purposes in Canada.

In the past, materials have been qualified as having the appropriate air barrier properties but were still dependent on proper installation for performance. More recently, there has been increased focus on the installation and integration with interfaces for protection of seams and joints. These potential “leak points” are addressed in the updated Environmental Protection Agency (EPA) Energy Star thermal checklist as well as the most recent building codes.

There are several current methodologies that can be employed to address air leakage in wall construction. Historically, the focus was first on flexible, synthetic wraps used to cover the building wall area. One of the first concepts was introduced in the early 1980s in the form of synthetic housewraps. This did not capture significant market share for many years but during the 1990s this type of air barrier system became more common in the residential market. This method did not penetrate the commercial market until later and even then only to a small extent.

Commercial designers instead turned to membrane technologies that were self-adhered or liquid applied as well as a variety of spray applied foams. All of these have demonstrated material performance but rely heavily on installation and integration for proper assembly performance. Additionally, these materials are expensive and sometimes challenging to install.

Contractors and architects were looking for a method that could provide the thermal and air barrier benefits at a lower cost and with an easier, faster installation. In particular, with brick/block wall construction, something simple that could fit between the brick ties and would easily integrate into the wall assembly was desired.

The recent increase in the use of spray polyurethane foam (SPF) insulation in the exterior wall pointed the way towards methods that would use a single product (spray foam insulation) in lieu of several products (continuous air barrier and thermal insulation boards) to achieve multiple objectives.

Although SPF insulations do offer an air and thermal barrier in one product, there can be several drawbacks to its use depending on the design, geography, and season. Is there additional design method/material that could be used to achieve a simplified air and thermal barrier combination?

Early work with plastic foam insulation boards with taped seams in residential construction suggested that joint sealing of insulation boards could be a successful method to achieve a simpler air/thermal barrier configuration. Ease and speed of installation, a broad application temperature range, and the combined benefit of thermal and air management might provide a cost effective alternative to multi layer air barrier systems. Additional testing was needed to understand precisely if and how this could be achieved.

PURPOSE

To determine if foam plastic insulation board edge sealing techniques can be used to achieve adequate air barrier performance in a commercial wall assembly as measured using a standard air barrier test method, ASTM E2357 “Standard Test for Determining Air Leakage of Air Barrier Assemblies”.

TEST DESIGN

Unlike residential construction, commercial construction utilizes a wide variety of materials and configurations in exterior wall design. The original objective was to determine the efficacy of this sealing method for use in concrete masonry unit (CMU) base wall construction. Either steel stud or block wall could be used as the back up for the test assembly. However, it was realized that a judicious choice of the testing configurations could allow the results to be applied to other types of commercial wall assemblies, such as steel stud assemblies. This eventually led to the selection of a steel stud back up wall with gypsum exterior sheathing as the base wall to support the air/thermal barrier components as this was considered to be the worst case scenario and the results could be leveraged to the more rigid substrate of block walls. In this case, the gypsum layer acts as the face of the block wall in brick/block construction.

The worst case scenario for this type of wall section was deemed to be one with the greatest linear footage of board edges or gaps in the test specimen per unit of wall area. Thus, insulation boards with the smallest individual board size were selected for the test. Several grades of XPS insulation are manufactured to 406 mm (16 in) width to fit between the brick tie anchors in a brick and block wall system which represents this smallest size. Although the back-up for the test specimen was a steel stud wall, the XPS products for block wall construction were chosen to provide the highest number of board edges. i.e. the most linear feet of board joint per unit area of wall. In all cases the XPS insulation boards were fastened 406 mm (16 in) on center (OC) in the horizontal direction and 203 mm (8 in) OC in the vertical direction.

ASTM E2357 “Standard Test Method for Determining Air Leakage of Air Barrier Assemblies” is the current method by which assembly air barrier properties are measured. This test exposes a 3.05 m (10 ft) x 3.05 m (10 ft) sample wall section to varying degrees of air pressure differential including pressure fluctuations. This method not only tests the air barrier properties of a system, it also tests the air barrier durability of a system.

Figure 1: ASTM E2357 Test Apparatus

Figure 2: Base wall prior to installation of foam plastic insulation

Plastic foam thermal insulation in board stock form served as the base material whose joints were sealed to achieve the air barrier properties for the assembly. There are a variety of plastic foam insulation types on the market so one type needed to be selected for the actual testing. Extruded Polystyrene (XPS) foam insulation has been used in commercial wall assemblies to provide thermal insulation for many years. It is known that XPS material meets the ASTM E2178-11 "Standard Test Method for Air Permeance of Building Materials" air barrier material requirements and thus when the joints are properly treated it should perform as the air barrier in a wall assembly so XPS was chosen as the insulation type. Also, XPS is somewhat more flexible than polyisocyanurate (PI) insulations so it was thought that XPS would represent a worst case scenario as opposed to PI, especially considering that the flexing of the insulation may open up joints between boards leading to failure.

The board joint treatment type for the test was butt edge in all cases. Tongue and groove or shiplap was not chosen as butt edge joints were believed to represent the worst case scenario.

The 3.05 m (10 ft) x 3.05 m (10 ft) test wall sections were constructed using 92 mm (3.625 in) steel studs 1.22 mm thickness (18 gauge)/308 mm (16 in) OC and assembled with 12.7 mm (0.5 in) thick gypsum panel exterior sheathing. XPS insulated foam sheathing, 38.1 mm (1.5 in) thick and 308 mm (16 in) x 2438 mm (96 in) in size, was then mechanically attached using Wind-Lock, ci-Lock DTW-3S3 fasteners. Boards were installed tightly butted together. In all cases, this meant that board gaps were less than 1.6 mm (0.0625 in). Penetrations were introduced as mandated by the ASTM standard and protected using foam sealant and butyl flashing tape. Pos-I-Tie 50.8 mm (2 in) barrel length self-tapping brick ties were placed in each wall as prescribed in the test standard.

Two methods of joint sealing were considered: taping and sealing. A 0.5 mm (0.02 in) thick butyl adhesive based flashing tape was selected as the tape for the joints for its adhesive and longevity properties. There are many sealing materials that could be used on the insulation board joints. A one component polyurethane foam sealant was seen as an easy to install and inexpensive joint sealant material.

Two test specimens were built for each type of system tested (as per the ASTM E2357 protocol). One specimen had no penetrations and as such was a test of the system components as installed strictly in the opaque area of the wall. The other specimen had standard penetrations scattered across the test area. These penetrations represented a window, a duct, a pipe, and an electrical conduit. These penetrations tested the air barrier's ability to seal to standard types of penetrations (and the methods used to achieve this sealing). Henceforth these two specimens will be referred to as the Opaque Wall and the Penetrated Wall.

Test Wall 1: Joints Sealed with Tape

A 0.5 mm (0.02 in) butyl flashing tape was chosen as the tape to seal the edge joints in the XPS insulation boards. The flashing tape is 101 mm (4 in) wide and is applied by first removing the protective paper from the adhesive and then applying directly to the XPS insulation. After application the tape is pressed and smoothed into place to achieve a good bond with the substrate.

Figure 3: Installing the XPS insulation

Figure 4: Several XPS boards installed

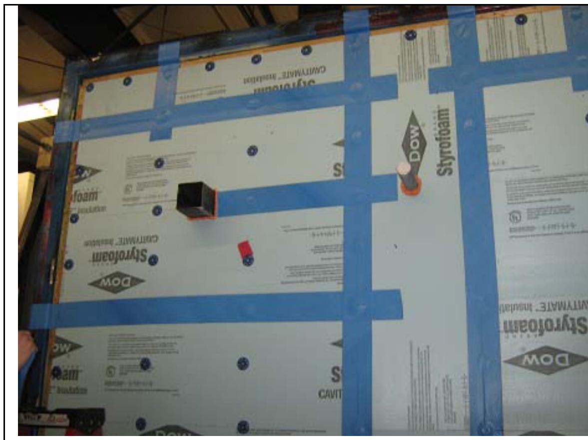


Figure 5: Flashing tape applied to joints

Figure 6: Completed wall with sealed penetrations

Test Wall 2: Joints Sealed with Foam

A one component polyurethane expanding foam sealant which is readily available in the construction market was chosen to seal the edges of the XPS foam insulation boards. As each insulation board was installed, the foam sealant was applied to the exposed edge. This foam sealant requires less than 10 minutes to be tack-free and is trimmable in 30 minutes which eliminates any concern with the installation timing with subsequent insulation boards (a two component foam sealant cures in seconds requiring swift installation of subsequent boards which is a practical problem in the field).

Figure 7: Foam sealant applied to edge

Figure 8: Installation of XPS and foam sealant

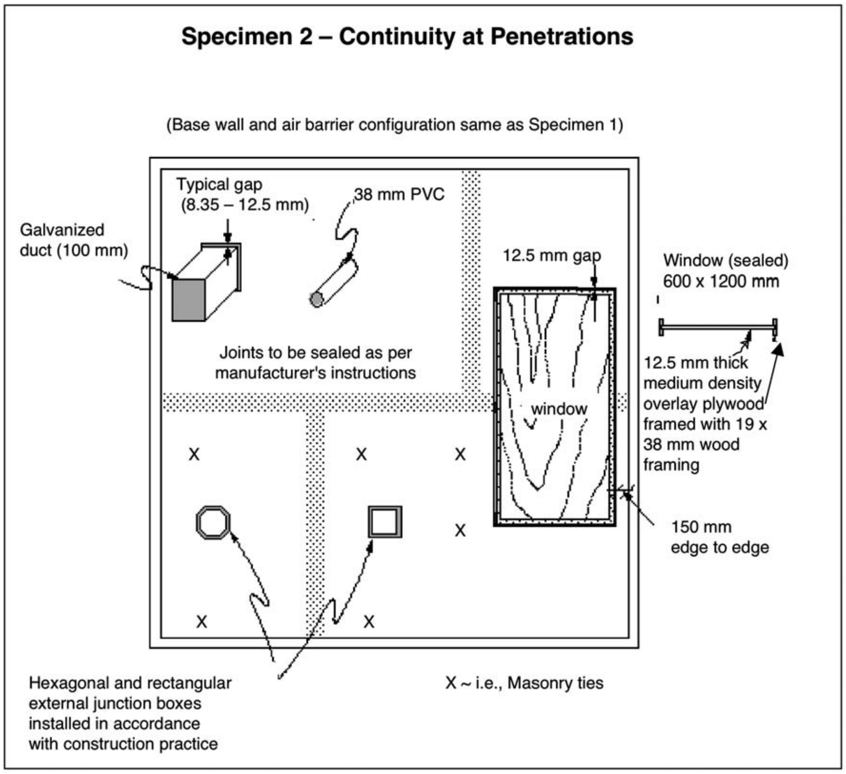
	
Figure 9: Completed installation	Figure 10: Completed wall with penetrations sealed

TEST PROCEDURE

ASTM E2357 requires air leakage testing in both the exfiltration (negative pressure) and infiltration (positive pressure) modes. Upon being properly mounted and sealed into the test apparatus, the specimens were subjected to positive and negative pressures of 25, 50, 75, 100, 150, 250, and 300 pascals (Pa) (this corresponds to 0.52 to 6.3 psf).

The standard requires testing of two walls, one with penetrations and one without. The walls are 3.05 m (10 ft) x 3.05 m (10 ft) and require specified penetrations to be installed per the standard including a galvanized duct, polyvinyl chloride (PVC) pipe, window, and two external junction boxes.

Figure 11: ASTM E2357 Penetrated Wall Design



The wall system is then tested for durability (Wind Pressure Conditioning) in the face of high wind pressures by simulating strong "wind gusts" using varying pressures and periods of time. This aspect of the testing determines if the air barrier can sustain its properties even when subjected to short term/high pressure conditions.

Positive and negative sustained loads of up to 600 Pa (12.5 psf) for one hour each are applied to each specimen. 2000 cycles of pressure (1000 positive and 1000 negative) were applied at 800 Pa (16.7 psf). A safety test is then performed with positive and negative pressures up to 1200 Pa (25 psf).

The test specimen is finally tested for structural performance by being subjected to 1440 Pa (30 psf) in both directions and the physical deflection of the wall is measured.

In summary, the specimen is tested for air barrier performance, then conditioned by cyclical wind gusts to ascertain the durability of the air barrier system, then tested again for air leakage to determine if the cyclical conditioning degraded the air barrier performance of the assembly.

RESULTS

75 Pa (1.57 psf) is considered to be the standard pressure differential at which the air infiltration results are reported. Most U.S. codes and related industry organizations have followed the National Building Code of Canada's accepted air leakage requirements of 0.02 L/(sm$^{2)}$ (0.04 cfm/ft^2) at 75 Pa (1.57 psf) for an air barrier assembly. The Air Barrier Association of America (ABAA) has also defined air barrier assembly requirements with the maximum leakage allowance leveraged from the National Building Code of Canada. The Massachusetts Comercial Energy Code was the first to mandate air barrier systems in non-residential construction. Requirements in the 2009 International Building Code (IBC) outline that an air barrier system must "have an air leakage characteristic not greater than 0.02 L/(sm^2) (0.04 cfm/ft^2) measured at an air pressure difference of 75 Pa (1.57 psf) or conform to CAN/ULC-S741 "Air Barrier Materials – Specification". The following table shows the results for both the penetrated and opaque wall specimens for the taped edge sealing method. All results are well below the maximum allowed air leakage rate based on recognized industry requirements.

Table 1: Air Leakage for Initial Taped Joint Wall Specimens

Air Leakage Results at 75 Pa for Initial Test For Taped Joint Wall Specimens		
Specimen	Airflow Direction	Air Leakage Rate (L/sm^2)
Opaque Wall	Negative	0.0055
	Positive	0.0068
Penetrated Wall	Negative	0.0087
	Positive	0.0051

Table 2: Air Leakage for Initial Foam Sealed Joint Wall Specimens

Air Leakage Results at 75 Pa for Initial Test For Foam Sealed Joint Wall Specimens		
Specimen	Airflow Direction	Air Leakage Rate (L/sm²)
Opaque Wall	Negative	0.0808
	Positive	0.0688
Penetrated Wall	Negative	0.0032
	Positive	0.0087

After the initial air infiltration testing, the durability of the wall specimens is tested by using a variety of cyclical pressures as was mentioned earlier. The results of this test are reported in deflection in millimeters, i.e. to what degree the wall moved in response to the high level cyclical pressure changes.

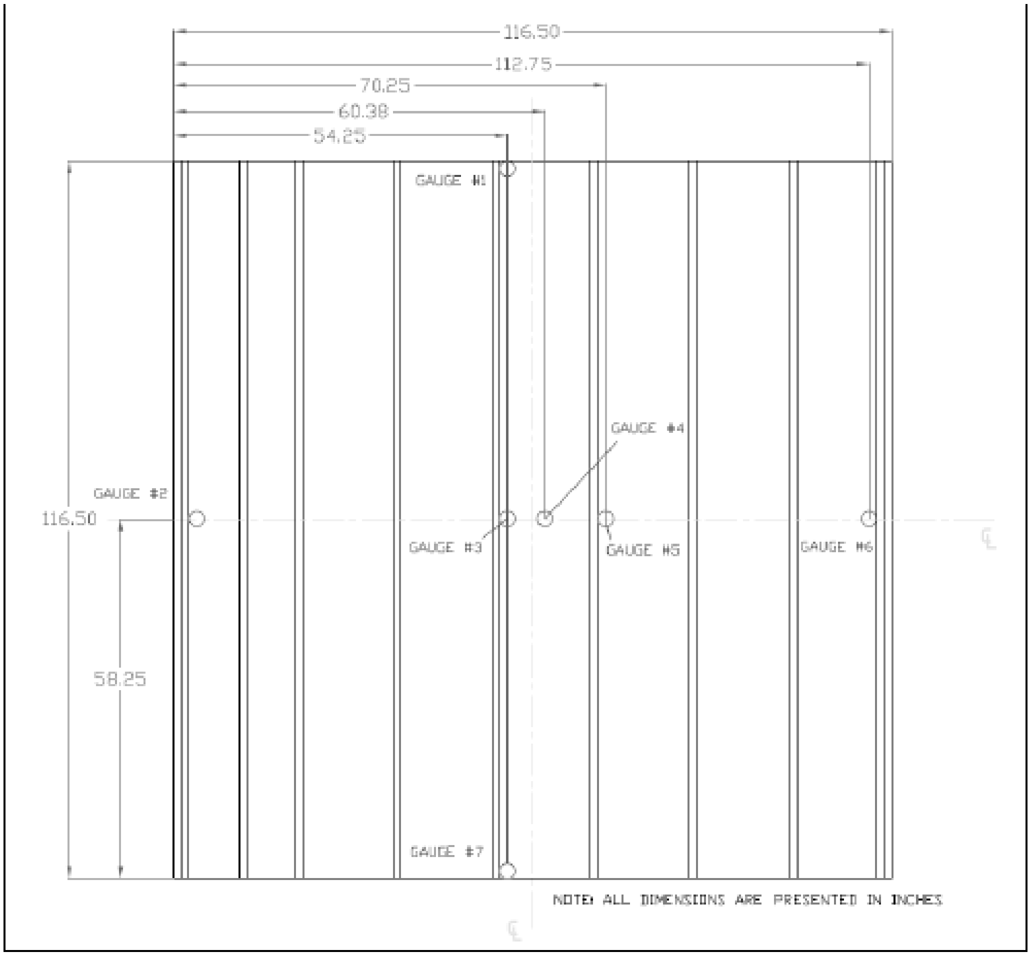


Figure 12: Deflection Gauge Map

Deflection represents the ability of the wall to structurally maintain its integrity in the face of the load. Deflection measurements were taken on sustained loads up to 600 Pa (12.5 lb/sf) and gust loads up to 1200 Pa (25 lb/sf). Deflection at the steel stud, which is primarily a reflection of steel movement in the wall system, was 10 mm (0.4 in) at 600 Pa (12.5 lb/sf) and 13 mm (0.5 in) at 1200 Pa (25 lb/sf) in the taped joint wall. Deflection at the steel stud was 7 mm (0.27 in) at 600 Pa (12.5 lb/sf) and 12 mm (0.47 in) at 12 Pa (25 lb/sf) in the foam sealed joint wall. Deflection of the cavity between the steel studs was 8 mm (0.3 in) at 600 Pa (12.5 lb/sf) and 13 mm (0.5 in) at 1200 Pa (25 lb/sf) in the taped joint wall, which is primarily a reflection of the flexural strength of the insulation. Deflection of the cavity between the steel studs was 7 mm (0.27 in) at 600 Pa (12.5 lb/sf) and 12 mm (0.47 in) at 1200 Pa (25 lb/sf) in the foam sealed joint wall. Insulation deflection may be mitigated by the presence of the drywall. The deflection was very similar between the opaque and penetrated walls overall, however, the foam sealed joint wall configuration had slightly less deflection than the tape joint sealed wall. In both cases, there was no indication of damage or loss of performance in the wall indicating that this methodology is a sound one for air sealing walls.

After the specimen had been subjected to a series of high stress loads described above, the specimens are then again measured for air leakage to determine if there has been any damage from the stress testing that has affected the properties and performance of the assembly. Once again, according to ABAA, the maximum air leakage rate must be less than 0.02 L/sm2 (0.04 cfm/ft^2) after conditioning. As noted in the charts below, the post stress wall assembly air leakage was well within the required limits.

Table 3: Air Leakage for Post Conditioning Test for Taped Joint Wall Specimens

Air Leakage Results at 75 Pa for Post Conditioning Test For Taped Joint Wall Specimens		
Specimen	Airflow Direction	Air Leakage Rate (L/sm^2)
Opaque Wall	Negative	0.0083
	Positive	0.0051
Penetrated Wall	Negative	0.0094
	Positive	0.0097

Table 4: Air Leakage for Post Conditioning Test for Foam Sealed Joint Wall Specimens

Air Leakage Results at 75 Pa for Post Conditioning Test For Foam Sealed Joint Wall Specimens		
Specimen	Airflow Direction	Air Leakage Rate (L/sm^2)
Opaque Wall	Negative	0.0803
	Positive	0.0700
Penetrated Wall	Negative	0.0191
	Positive	0.0100

The final phase was a structural test to determine if the wall system can survive a very high wind gust exposure of 1440 Pa (30 lb/sf) or the equivalent of 108 mph. Although deflection was measured during this phase of the test, pass or failure criteria hinge on visual presence of structural damage in the wall system. This wall system did not exhibit any visual damage to the integrity of the structure after exposure.

INSTALLATION PRACTICALITY

Although this wall system performed well in all of the required test phases of ASTM E2357, any wall system must be practical to construct in addition to meeting the required test phases for use in a commercial market. A standard 203 mm (8 in) block wall with wall ties spaced 406 mm (16 in) vertical OC in the mortar joints was constructed to investigate practicality of installing air sealed installation joints and to examine potential application issues. 406 mm (16 in) wide insulation boards were installed between the wall anchors and the board joints were sealed with the one component expanding foam sealant system. This method proved to be easy and fast to construct satisfying the original hypothesis of an economical and effective installation to obtain both a thermal insulation and air sealing layer using insulation board products.

Attempts were made to duplicate this design using flashing tape as the joint sealant for the insulation boards. This method proved to be difficult to construct as the anchors interfered with smooth taping of the board joints. This dramatically increased the installation time to seal the board joints around the anchors making this system much less practical in its current form. However, should a system be designed that did not use pre-installed wall anchors flashing tape sealing of board joints may be practical.

As a final demonstration of installation practicality, this system was installed on prototype commercial projects in the field to validate the cost and time effective installation theory at the jobsite. Comments from contractors were reflective of the time savings and ease of installation compared to other types of thermal/air barrier configurations in the market.

CONCLUSIONS

Air-sealing insulation board joints using one component foam sealant or flashing tape was tested via ASTM E2357 and the results successfully passed the industry recognized air leakage requirements as outlined in the 2009 IBC and ABAA. Walls were tested with both positive and negative pressure cycles up to 1200 Pa (25 lb/sf) and maintained the air infiltration resistance performance requirements. Subsequent evaluations of the practicality of insulation installation using this methodology demonstrated ease of pace of installation resulting in a viable, economical application.

FUTURE WORK

1. Additional testing of the steel stud wall assembly without the gypsum board per ASTM E2357.
2. Long term durability and other appropriate age testing of the one component sealant method assembly.

REFERENCES

D A VanBronkhorst, A K Persily, S J Emrnerich, 1995. Energy impacts of air leakage in US office buildings. 16th AIVC Conference, Sept. 1995, p.2.