Quality Assurance for Building Envelope Air Barrier Systems

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ABSTRACT

In the United States and Canada, the growing concern over premature building failures, degraded occupant comfort, and rising energy costs is the driving force behind the need to reduce air leakage in industrial, commercial, institutional, and multi-family residential buildings. Despite more stringent regulations being made at the government level and the development of trade associations to govern the air barrier industry, a quality assurance program needs to be adopted on a national level, both in the United States and Canada, for there to be a significant improvement in the overall quality of these buildings.

This paper discusses the benefits of an effective quality assurance program, and what such a program should entail. Also proposed is a protocol for the inspection and testing of building envelope air barrier systems, including pre-construction, work-in-progress, and post-construction regimens. Studies are referenced that show the degree to which testing improves a building's air permeance.

INTRODUCTION

Throughout the United States and Canada, there is an increasing awareness as to the need for effective air barrier systems in the building envelopes of commercial, industrial, institutional, and multi-family residential buildings. An ineffective air barrier system can have an enormous impact on the durability of a building and may significantly increase long-term maintenance costs. In fact, it is conservatively estimated that over $500 million is spent each year on premature deterioration of roofs and walls in Canada alone,[1] of which air leakage is a contributing factor. In addition, studies have shown that up to 50% of heat loss in commercial and high-rise residential buildings may be attributed to building envelope air leakage (Woods 2001; Scanada and CanAm 1991).

An air barrier system is a component or system of components within the building envelope that controls the movement of air across areas of dissimilar environmental conditions. Air infiltration and/or exfiltration adversely affects the building and/or building owner most commonly through two means:

1. The movement of air from an unconditioned environment to a conditioned environment, or vice versa, will have a negative impact on heating and cooling loads.
2. Air moving from an unconditioned environment to a conditioned environment, or vice versa, may carry moisture in the form of water vapor that may condense within the building envelope and, under certain environmental conditions, may corrode building components, stain walls and ceilings, stimulate the growth of mold, reduce air quality, and damage the exterior facade.

In most cases, there is a consumption of energy. In the first instance, energy is required to condition, or recondition, the interior environment. In the second instance, the embodied energy of the materials discarded is consumed and energy is expended during maintenance of the building envelope components that have failed as a result of the air infiltration/exfiltration. The consumption of energy and building materials leads to the emission of greenhouse gas into the atmo-

[1] Rousseau, J. 1995. Letter to building envelope council members.

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sphere and requires landfill for disposal of deteriorated building materials (Sharp et al. 1997).

To this end, there have been many requirements and/or guidelines made at the federal government level, both in the United States and Canada, regarding the inclusion of air barrier systems and/or the performance requirements thereof. However, even with regulation in place, a protocol must be devised and implemented to ensure that the air barrier system is designed and installed so that it functions correctly and effectively.

BACKGROUND

In 1999, the United States government signed Executive Order 13123 establishing stringent new goals for energy management in federal facilities: a 30% reduction in energy consumption for lighting, heating, and cooling by 2005 (and 35% by 2010, relative to 1985 levels) and a 30% decrease in greenhouse gas emissions from 1990 levels by the year 2010 (AP 1999; Tsai 2000; White House 1999). The order specifically cited "efficient building design, construction, and operation" as a means by which to achieve these goals. At the state level, many are in the process of revising their energy codes (Devine and Blouin 2001). Massachusetts was the first to react, making air barriers mandatory in buildings and basing the requirements of the air barrier system on those as outlined in the 1995 National Building Code of Canada (NBCC): airtightness, continuity, structural integrity, and durability.

The NBCC provides a materials requirement for air barriers; specifically, where a material is to provide the principal resistance to air leakage, the material shall have an air leakage characteristic no greater than 0.02 L/(s/m^2) at a pressure differential of 75 Pa (0.004 cfrn/ft^2 at a pressure differential of 0.3 in. water). Appendix A of the Code also provides recommended maximum air leakage rates for complete air barrier systems in exterior envelopes (see Table 1).

According to the NBCC, the air barrier system must also be continuous across construction, control, and expansion joints, across junctions between different building assemblies, and around penetrations through the building assembly. As well, where the air barrier system installed in an assembly is subject to wind load, the system must have the ability to transfer that load to the structure. The system must be designed and constructed to resist 100% of the specified wind load, and

TABLE 1
Recommended Maximum Air Leakage Rates (NBCC 1995)

Warm side relative humidity at 21°C	Recommended maximum system air leakage rate, L/(s/m^2) at 75 Pa
< 27%	0.15
27 to 55%	0.10
> 55%	0.05

system load deflection must not result in collapse or permanent deformation of adjoining nonstructural elements. Finally, the system must be durable, meaning that the system must not react adversely to environmental exposures or adjacent materials (Persily 1993).

Throughout this paper, for consistency purposes, the requirements of an air barrier system will be as documented in the NBCC; that is to say, the system must meet requirements for airtightness, continuity, structural integrity, and durability. It should be noted, however, that similar requirements are outlined in Persily's (1993) document, and there is also an ASHRAE standard governing building envelope sealing (ASHRAE 1999).

ON-SITE REALITIES

With prescribed performance requirements for air barrier systems in place, the question is whether today's air barrier systems are meeting said requirements. Based upon the amount of money spent on building repairs and retrofits and on heating and cooling loads per annum, this would appear questionable. It is the combination of system design, materials, and workmanship that determines the performance of the completed system in the short and long run. Problems can be categorized as follows: (1) design flaws, (2) faulty materials and/or workmanship, and (3) damage suffered by the air barrier during the service life of the building and not repaired (Public Works Canada 1993).

An air barrier system must not only meet the minimum performance requirements as outlined in the NBCC but also specifications particular to each project. It is sometimes the case where flaws in system design may inhibit the installed system from performing as required. Generally, problems of inadequate design consist of gaps in the air barrier at major joints, such as roof/wall, wall/foundation, and window and door frames to wall junctions. In some cases, where in theory a design may allow for a functioning air barrier system, in practice, the details may be difficult or even impossible to construct effectively (Quirouette 1982). Also, details and clauses in specifications typically do not consider in-situ difficulties that may arise. For instance, the disruption of air barrier systems by building services (such as electrical) or other wall components and structural penetrations could lead to system discontinuity (Drysdale and Suter 1991).

When selecting materials, designers must understand the chemical and physical properties of the material, and whether these properties may compromise the performance of the system. Designers must also be aware of where the air barrier is being placed in relation to other building envelope components. If a material is installed on the cold side of the wall to act as an air barrier and that material inadvertently acts as a vapor barrier, condensation may form within the walls under certain environmental conditions.

While there is a wide range of commercially available air barrier membrane materials that meet the materials requirements in the NBCC (CMHC 1988), care must be taken to ensure that the materials meet recommendations when installed as a system or as a component within a system. That is, the material must be compatible with other building components, properly seal at joints, junctions, gaps, and penetrations, and, if fabricated on site, done so to manufacturer's recommendations (Dalgleish and Knight 1999).

Despite problems that may exist in design or materials, the quality of the air barrier system depends primarily upon the quality of workmanship during the membrane installation. In most parts of the world, air barrier systems as they have been defined in this paper are a foreign concept, and there has been a distinct lack of education and training in this regard. Even today, trades are seldom responsible for installing the complete air barrier system; different trades are often responsible for individual components and, as a result, have little or no knowledge of the function or requirements of the air barrier system.

Additional problems may arise from this overlapping trade jurisdiction. While different trades are responsible for different components, no one trade is responsible for joining these components. Where communication between trades is poor or confrontational, inadequate tie-ins may be left for the other air barrier trades to connect with, resulting in discontinuity within the system. It is also not uncommon to see finishing materials being installed immediately after the air barrier section has been laid, covering the air barrier before it is complete.

Although the NBCC recommends maximum air leakage rates for systems, they are merely recommendations, and it would appear some designers or installers do not fully understand how minimal the air leakage tolerance is. Internal studies have shown that without definitive standards or codes governing air barrier systems, or third party inspection and testing, buildings are being constructed that do not meet this recommended air leakage rate. To address these concerns, steps are being taken at numerous levels to improve air permeance rates in buildings. At the government level, more stringent requirements for air barriers and air barrier installations are being developed and implemented in codes and regulations. Continuing education programs, technical information, and design details are being provided for designers to ensure that they are applying the most effective and current technologies. Air barrier trade associations have been formed in Canada and the United States that provide education and training for the workforce, offer contractor licensing and installer certification, and utilize comprehensive quality assurance programs. Finally, manufacturers are testing their materials more thoroughly, both as a material and as a system. In fact, the Canadian Construction Materials Centre (CCMC) has developed a regimen to evaluate materials and systems, the protocol of which also can be performed by independent laboratories or testing agencies (Di Lenardo 1997; Di Lenardo at al. 1996).

THE NEED FOR QUALITY ASSURANCE

It is important to differentiate between air barriers that are "maintainable" from those that are "nonmaintainable." Simply described, a *maintainable* air barrier is just that—it is maintainable. In other words, its position within the building envelope is such that it is exposed and therefore can be serviced without having to remove any exterior or interior finishing; for example, airtight drywall. A *nonmaintainable* air barrier is placed within the wall and is not exposed and hence cannot be serviced without removing exterior or interior finishing and/or other wall components; for example, mid-wall membranes (Knight and Samuda 1996).

The nature of maintainable air barriers makes it generally more difficult to achieve continuity between the individual components that comprise the system. In addition, maintainable air barriers are often exposed to many elements that may be detrimental to the system, such as direct sunlight or extreme weather conditions. Therefore, from the perspective of durability, nonmaintainable systems are preferred in most cases (Persily 1993), and a greater number of buildings are being designed with nonmaintainable air barrier systems. However, because these systems are not exposed, repairing them is impractical and expensive. If the cost to repair an improperly installed mid-wall air barrier can be estimated to be 50 times greater than the cost of a correct first-time installation (Dalgleish 2001), the need for air barrier quality assurance programs cannot be understated.

QUALITY ASSURANCE PROGRAMS

Quality assurance programs, most commonly implemented from the industry level through trade associations, provide a means to ensure that installations are being performed to industry standard. While primarily influencing the quality of installation, these programs can also have an effect upon design and quality of materials. A quality assurance program (QAP) can increase the probability of a properly functioning air barrier system through the following means: (1) specifications, (2) manufacturers/suppliers, (3) contractors, (4) installers, and (5) inspection and testing (NABA 1997).

1. Designers can adopt association specifications into their own, reducing the possibility for design error. Specifications should be frequently reviewed and updated so they represent current industry standards.
2. Manufacturers/suppliers should supply CCMC (or an equivalent agency) evaluations of their materials to trade associations.
3. A licensed contractor operating under the auspice of the QAP is obligated to ensure that all products installed under their jurisdiction are done so by duly trained and experienced installers, operating fully under the terms and conditions of the QAP.
4. Installers must complete comprehensive training and educational programs, including field experience, and

demonstrate that they can install the product according to good industry practice in order to become a certified installer.

5. A protocol for inspection and testing should be in place to ensure that the finished product performs in keeping with NBCC requirements.

It is this fifth point that raises concern, as there is no such standard protocol being utilized on a widespread basis. While there are numerous approved testing methods that can be used to assess the quality of various air barrier system components, there remains a need for a testing regimen to instruct on how to best utilize these methods. If all systems are to be installed to industry standard, under a consistent method of installation, it would only seem reasonable that all installations undergo a consistent format of inspection and testing.

PROTOCOL FOR THE INSPECTION AND TESTING OF AIR BARRIER SYSTEMS

To develop a regimen for the inspection and testing of air barrier systems, the following factors must be considered: (1) What does an air barrier review entail? (2) What are the testing criteria? (3) Who should perform the inspection and testing? (4) What testing methods should be utilized? (5) When and how often should inspection and testing be conducted?

The air barrier examination consists of three functions – inspection, qualitative testing, and quantitative testing (Knight and Sharp 1997). It is important to differentiate between "inspection" and "testing." Inspection is a visual examination of a sample area to determine whether said sample area *appears* to be installed adequately. The sample area may consist of a specific detail, a specific component, or the complete system itself. Testing involves taking some form of measurement, qualitative or quantitative, to determine whether or not the detail, component, or system meets the performance requirements for which it is being tested and, in some cases, to what degree.

Currently, there is no widespread generic standard governing air barrier system performance, making it difficult to determine to what extent an air barrier system is to perform and, henceforth, how thoroughly it should be tested. As a minimum, the system should meet the requirements outlined in the NBCC,[2] including the system performance requirements in Appendix A of the Code. Where applicable, the system must meet or exceed any prevailing government regulations, standards, or codes and any specifications particular to that project.

Both the workforce and an independent building envelope consultant should conduct inspection and testing. Installers should test the installation to ensure that it meets specifications. Since the consultant should have a much greater depth of knowledge than the average installer, specifically in the area of building science, the consultant should then conduct inspection and testing both to assess the quality of the installation and to determine whether the installer is capable of performing the work to standard. While installer self-testing is useful in reducing many "minor" deficiencies,

2. In the United States, as outlined in Persily's (1993) *Envelope Design Guidelines for Federal Office Buildings: Thermal Integrity and Airtightness.*

TABLE 2
Test Methods Utilized in Inspection and Testing Protocol

Test Method	Title
ASTM D 4541	Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
ASTM E 283	Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen
ASTM E 330	Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Uniform Static Air Pressure Difference
ASTM E 741	Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution
ASTM E 779	Test Method for Determining Air Leakage Rate by Fan Pressurization
ASTM E 783	Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors
ASTM E 1186	Practices for Air Leakage Site Detection in Building Envelopes and Air Retarder Systems
ASTM E 1186 4.2.1	Building Depressurization (or Pressurization) with Infrared Scanning Techniques
ASTM E 1186 4.2.2	Smoke Tracer in Conjunction with Building Pressurization or Depressurization
ASTM E 1186 4.2.3	Building Depressurization (or Pressurization) in Conjunction with Airflow Measurement Devices, or Anemometers
ASTM E 1186 4.2.4	Generated Sound in Conjunction with Sound Detection
ASTM E 1186 4.2.5	Tracer Gas
ASTM E 1186 4.2.6	Chamber Pressurization or Depressurization in Conjunction with Smoke Tracers
ASTM E 1186 4.2.7	Chamber Depressurization in Conjunction with Leak Detection Liquid

third party inspection and testing concentrates on examining details for continuity, structural integrity, and overall system performance, detecting problems that may not be noticeable on a rudimentary level.

Generally, the building envelope consultant takes a holistic approach when conducting inspection and testing. While trades are concerned specifically with the installation and performance of the air barrier as a system, the third party not only examines the air barrier as it performs but also how the system fits into the building as a whole.

Several American Society of Testing and Materials (ASTM) standards are utilized in the inspection and testing protocol (for ease of reference, all applicable test standards utilized in the protocol can be found in Table 2.). In the past, while test methods were available for pre- and postconstruction testing, there was no practical means for testing *during* construction. The methods that were available, some of which were included in ASTM E 1186, were not practical for work-in-progress for reasons of cost, time, reliability, or on-site practicality. Recent revisions to ASTM E 1186 not only make it possible to test during construction inexpensively and without disrupting the critical path of construction, but some of the methods can be performed by the installers themselves.

With the varying nature of air barrier systems and materials, any generic inspection and testing regimen must be comprehensive enough to be applicable to any type of system. A protocol designed specifically to test maintainable air barrier systems may or may not be suitable for testing mid-wall nonmaintainable systems. For example, assume a maintainable air barrier system such as drywall. A protocol specifying only postconstruction testing may be adequate for this type of system as there are numerous means by which to test an entire building for air leakage. If it is determined through testing that the system is not performing as required, the drywall can be repaired, in most cases, without great expense. Now assume a mid-wall system under the same protocol. There are limited means by which to test this type of system once it has been covered and even if testing were to indicate that system performance was inadequate, it would not only be difficult to determine which component within the system failed, but it would be extremely expensive and time-consuming to repair it. It is therefore obvious that the protocol should include inspection and testing performed in three phases: (1) preconstruction; (2) work-in-progress; and (3) postconstruction.

Preconstruction Phase

Prior to construction, the architect and building envelope consultant should review the plans and specifications to ensure that there are no problems inherent in the design work. Individual details, components, and materials should all be assessed on their theoretical ability to perform as required and examined for continuity within the system and compatibility

TABLE 3
Summary of Inspection and Testing Protocol

PHASE 1:	**PRE-CONSTRUCTION**		
AREA REVIEWED	TEST METHOD(S)	INSPECTOR	TIME/FREQUENCY
Plans and specifications	Review/Orientation Meeting	Third party	Prior to installation
Mock-up	ASTM E283, E 330, E 783	Third party	Prior to installation
PHASE 2:	**WORK-IN-PROGRESS**		
AREA REVIEWED	TEST METHOD(S)	INSPECTOR	TIME/FREQUENCY
Various details	Visual inspection	Workforce	Throughout the day
Various details	Visual inspection	Third party	Prior to any testing
Various details	ASTM D 4541, E 783, E 1186 4.2.6	Third party	Early in construction process
Seams and penetrations	ASTM E 1186 4.2.7	Workforce	Representative sample size
Bond strength	ASTM D 4541	Workforce	Regularly, and when conditions change
Seams and penetrations	ASTM E 1186 4.2.7	Third party	Random, representative sample size
Bond strength	ASTM D 4541	Third party	Random, representative sample size
Various details	ASTM E 783	Third party	Random detail(s)
PHASE 3:	**POST-CONSTRUCTION**		
AREA REVIEWED	TEST METHOD(S)	INSPECTOR	TIME/FREQUENCY
Whole building	ASTM E 741, E 779, E 1186, CAN/CGSB-149.10-M86	Third party	At end of project

with other materials and/or components (for a summary of the inspection and testing protocol, refer to Table 3).

Once satisfied that the plans and specifications are suitable for the particular project, an orientation meeting should be held. Present at the meeting should be the owner, designer, general contractor, subcontractors, and the building envelope consultant. The meeting agenda should include a review of all plans, specifications, and shop drawings; informing trades of responsibilities and what will be required of them; and detailing the inspection and testing protocol.

Before installing any air barrier, the general contractor should build a mock-up of the system, at the discretion of the owner/designer. The persons building the mock-up should be representative of the skill level of the labor force that will be working on the project. The mock-up system should be tested, by a qualified third party, in accordance with ASTM E 283 (performed under laboratory conditions) or ASTM E 783 (performed in the field), or both, to provide a quantitative measurement of the air permeability of the system. By applying a pressure differential against the system as required by these tests, it can also be determined whether the structural stability of the system and the strength of bond between membrane and substrate are sufficient.[3]

The testing of a mock-up in this manner, while used to evaluate the design aspects of the system, does not take into account site variables that may exist during installation, such as climate and environmental conditions, workforce skill level, and materials (which may differ on-site from those used in the mock-up, as specifications frequently allow for a choice of materials). Therefore, it is imperative that inspection and testing also occur during installation. It should be noted that in cases where testing is performed in accordance with ASTM E 783, the mock-up system might be installed as part of the completed building, subject to design specifications.

Work-in-Progress Phase

As the majority of failures in building envelope air barrier systems are a result of faulty installation, the work-in-progress phase of the protocol must represent the most comprehensive degree of inspection and testing. For this reason, inspection and testing will be performed both by the workforce and third party and is conducted throughout the construction schedule, both at designated times and randomly. This phase includes visual inspections and qualitative and quantitative testing.

Visual Inspections. Prior to air barrier installation, a certified installer should inspect the material and substrate. The installer must make sure materials that are fabricated on site, such as two-part membrane systems, have been done so to manufacturers' recommendations and are compatible with all adjoining materials, the substrate, and the bonding agent. The substrate should be dry, cleaned, and primed (to manufacturers' specifications) prior to any material being applied. The temperature of the substrate should also be monitored. Finally, the installer should be aware of in-progress building conditions and where the exposed air barrier is in relation to environmental conditions. As a general rule, visual inspection by the workforce should be an ongoing process throughout the project, performed on a daily basis, to make sure that proper installation practices are being observed.

Third party visual inspection should be performed early in the installation process to detect for obvious deficiencies such as flutes or areas of unbonded or discontinuous membrane. This should be conducted prior to any third party testing, as it would be senseless to test areas one knows to be faulty. Once it has been established that no (or a limited number of) deficiencies can be identified visually and that the sample area is in keeping with designers' specifications, testing may proceed. As the installation progresses, further visual inspections should be made randomly, but on a regular basis.

Quantitative Testing. During this phase, the purpose of third party quantitative testing is twofold—to test whether the *system* as installed on site meets specification and to set a project benchmark for the system air leakage allowance that can be demonstrated to the trades. ASTM E 783 provides a numerical result for the acceptable amount of air leakage for the system. For the same detail, testing using smoke tracers can be performed in accordance with ASTM E 1186 4.2.6 to provide that same benchmark, visually, for the installers.

The manufacturer of the material and/or the designer establishes the quantitative benchmark for membrane-substrate adhesion strength, which can then be tested in accordance with ASTM D 4541 once material has been applied to the substrate.

Qualitative Testing. The earlier in the construction schedule that a problem can be identified, the less costly it is to rectify. By that rationale, the greatest percentage of testing should occur on the front end of the project. For instance, if testing determines that the strength of bond between the air barrier and substrate is insufficient, there may be a problem with that particular material as it is being used on the building, and a substitute can be chosen without an abundant waste of material.

On the first day of installation, installers should test a sample of seams and penetrations (a sample size representative of the size of the project) for air leakage, using leak detection liquid, in accordance with ASTM E 1186 4.2.7. The size of the sample area is dependent upon site variables such as changing of materials or workforce, change in building conditions (for instance, installing membrane on a different substrate), extreme environmental conditions, building function, and project specifications. If no major problems exist, for the remainder of the project, unless specifications call for complete airtightness, only similarly sized sample areas need be tested. ASTM D 4541 can then be used by installers to provide a qualitative result for membrane-substrate bond strength by testing whether the material remains attached when a prescribed force is applied to the surface area. This test

[3] ASTM E 330 should be used in this application.

TABLE 4
Estimates of Potential Reduction in Leakage Area (Sharp et al. 1997)

	Typical			Achievable Goal		
	Percent leaking	ELA per tie (cm^2/tie)	Overall ELA (cm^2/m^2)	Percent leaking	ELA per tie (cm^2/leak)	Overall ELA (cm^2/m^2)
Cast-in-place ties, masonry	75	0.040	0.168	30	0.009	0.038
Cast-in-place ties, drywall	90	0.089	0.374	40	0.008	0.034
Through-wall ties, masonry	25	0.0015	0.0063	3	0.0002	0.0008

should also be performed whenever installation conditions change.

The regimen for third party qualitative testing conducted during this phase is similar to that conducted by the trades, although third parties can utilize a wider range of testing methods, some of which may be impractical for trades to perform. There are several test methods in ASTM E 1186 that can be used to detect air leakage, most notably sections 4.2.2 and 4.2.6, which can be used to test the air permeance of specific details. Seams and penetrations, and membrane-substrate bond strength, are tested in accordance with ASTM E 1186 4.2.7 and ASTM D 4541. Again, a greater majority of the testing is concentrated on the front-end in order to detect any major problems early in the construction process.

Postconstruction

Once the building is complete, there are a variety of ASTM and Canadian General Standards Board (CGSB) tests that can be used to determine the overall airtightness of the building (Quirouette and Scott 1993). Quantitative tests can be performed in accordance with ASTM E 741, ASTM E 779, and ASTM E 1186 (sections 4.2.1 and 4.2.2) or CAN/CGSB-149.10-M86. All of these tests are conducted by an independent third party.

The purpose of postconstruction testing is to determine the overall air leakage characteristic of the building, which can be used to estimate the energy efficiency of the building. However, while testing can provide accurate and reliable results for the airtightness of the whole building, it may not paint a complete picture. It is possible for a building to meet the airtightness requirement when the test is run despite having one or more components in the system that may have failed as an individual component. Even if a significant amount of air leakage is detected, it would be very difficult, based solely upon the test results, to determine which component or components have failed. So while testing is helpful in determining whether the system has been constructed effectively, it does emphasize the need for testing during all phases of the construction process.

THE EFFECT OF TESTING

A 1997 study (Sharp et al. 1997) set out to determine the effect that routine inspection and testing have on building envelope air leakage and the monetary and environmental impacts resulting from said inspection and testing. The study was conducted under both laboratory and field conditions.

The study identified the results associated with routine airtightness testing of specific construction details as follows:

1. When air barriers are tested, the number of leaks at details decrease.
2. When air barriers are tested, the average size of leaks at details decrease.
3. Air barrier testing of a detail identifies materials and/or construction practices that have a negative impact upon airtightness levels.

The study used masonry ties as an example of a detail that could be tested for air leakage because data on percentages leaking in samples was found to exist. The ties were tested in accordance with ASTM E 1186 4.2.7 and the results generated indicated that potential reduction in the leakage area of the ties was estimated to be between 77% and 91% (see Table 4.). The study proceeded to estimate that results would be similar for most other details. Based upon these results, the study concluded the following:

1. Air leakage levels decreased in buildings where air leakage tests were conducted.
2. The result of this improved airtightness was a significant reduction in heating loads, a reduction in greenhouse gas emissions, and an increase in the building envelope life cycle.

CONCLUSION

It is apparent that in order to improve the longevity of our buildings, reduce energy costs, and improve occupant comfort, the air permeance of these buildings must improve.

For this to occur, air barriers need to be installed correctly so they meet or exceed the increasingly stringent regulations implemented by government and trade associations. To this end, designers should mandate that all air barrier installations are performed in keeping with the quality assurance programs of recognized trade associations.

For years, the missing piece of the puzzle was a complete protocol for the inspection and testing of air barrier systems. While there were recognized testing methods in place, many were impractical for on-site applications during the construction process or for use by the workforce. This paper has proposed such a protocol, making use of both workforce and third party inspection and testing that can be used prior to construction, during the construction process, and after installation is complete.

For an inspection and testing protocol to be effective, it requires commitment and cooperation from all the industry stakeholders. At the site level, contractors must ensure that self-testing is being performed, and any deficiencies corrected. The emergence of air barrier trade associations provides an excellent means for installers to improve their knowledge and skill level and, hence, the quality of their installation. At the design level, designers must provide realistic budgets for inspection and testing and educate the owners on the importance of such a regimen. They must work in conjunction with trade associations to take advantage of the quality assurance programs that these associations provide. Finally, at the government level, codes and standards must be continuously reviewed and revised to reflect the increased need for improved airtightness in buildings.

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