REPORT

Commissioning and Monitoring The Building Envelope for Air Leakage

Presented to:

Mr. Pierre Michel Busque

Project Officer

and

Mr. Jacques Rousseau

Project Manager

Canada Mortgage and Housing Corporation

Housing Innovation Division
700 Montreal Road
Ottawa, Ontario
K1A 0P7

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NOTE: **DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE:**

MISE EN SERVICE DE L'ENVELOPPE DU BÂTIMENT ET VÉRIFICATION DES FUITES D'AIR

DISCLAIMER

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Executive Summary

Damage to building envelopes associated with air leakage has substantial consequences for building owners and users. Energy costs increase, user comfort decreases and the owner's repair and capital replacement budgets soar.

Commissioning the air barrier within the building envelope can help control these consequences. The term commissioning, understood by many to be a process which starts at the completion of a project has been modified significantly. Within this document an approach is provided to extend the air barrier commissioning process to the project brief, validation of the design and progressive certification during and possibly following construction.

At the project brief stage the owner must define clear performance requirements for the air barrier. The project design team responds with a progression of validated details from concept to final tender documents that ensures the performance specified in the project brief can be achieved if constructed as specified. During construction progressive certification of the performance of critical materials, components and assemblies is required to assure the project as constructed meets the same performance requirements. At completion the air barrier may or may not be commissioned as a whole.

Throughout the air barrier commissioning process from project brief to final construction, the design team requires the guidance of an individual to define initial performance objectives, complete design validation assessments and witness performance tests during and following construction. This individual may be the project architect or another specialist retained by the design team to assume these responsibilities.

The commissioning process described is intended to provide an owner with an air barrier suitable for the particular building at the completion of construction. To ensure continued performance over the lifetime of the building an approach to performance monitoring, maintenance and repair is also provided in this document.

In recent years there has been much discussion about quality assurance on construction projects and building commissioning procedures. This report should be considered as a primer for further discussion on terminology and procedures necessary to produce a comprehensive commissioning manual for air barriers.

The next phase of this project will build onto this report to describe the commissioning procedure for an actual high rise building. This case study will be available in early 1995.

This project was initiated by Jacques Rousseau and managed by Pierre-Michel Busque of the Housing Innovation division.

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1. INTRODUCTION

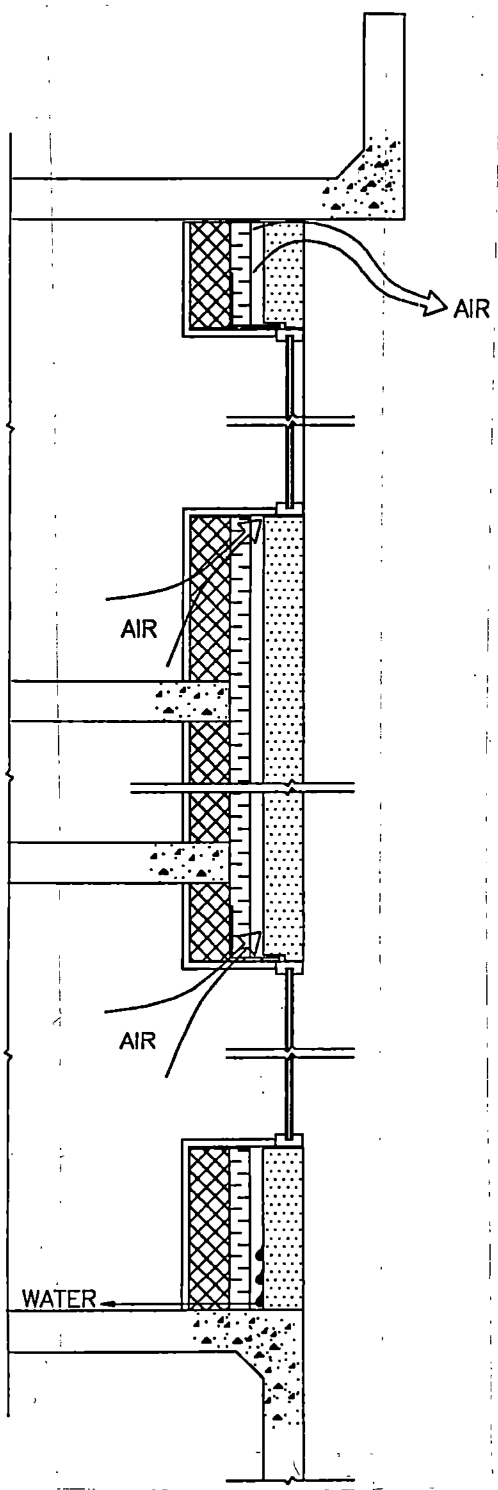

Figure 1

The air leakage characteristics of building envelopes dramatically affect the service lives of many buildings. At the same time building owners' expectations for quality of their indoor environment and durability of their enclosures are rising.

The building represented by Figure 1 is a typical example. This high-rise condominium was plagued by "flooding" of the ground floor suites each spring. The responsibility for the problem and damage was initially attributed to the contractor. Further investigation showed he had constructed the buildings in accordance with the designer's drawings and specifications. The problem resulted from air leakage into the cold cavities located behind the precast cladding resulting in frost accumulation and subsequent melting in the spring thaw.

In this example the systems chosen to construct the interior walls were unsuitable to control air leakage into the cavities. It has been suggested that "commissioning" the air barrier system could avoid such problems.

Commissioning is normally associated with mechanical and electrical systems in a building. It is the process of verifying the performance of completed systems to determine if it complies with the design documents and the specified performance ratings.

To apply commissioning concepts to an air barrier system we need to establish the performance requirements of the installed system and develop methods of evaluating the design to ensure that if constructed as designed, the intended performance will be achieved. These pre-construction steps do not fall into many accepted definitions of commissioning. For this reason alternate terminology has been used in this document such as validation of design concepts and certification of air leakage of air barrier sub-systems. The term "commissioning" has been reserved for the completed system.

To improve the construction industry's ability to predict the performance and durability of the air barrier system, we must look to providing better information for all involved in building delivery, from the owner through to the eventual user. A methodology must also be developed to encourage designers and builders to advance air barrier system design and construction from an art to a science. Canada Mortgage and Housing Corporation, through various research and development projects, has made significant advances towards this objective. The result of this research forms the basis of a procedure to commission the air barrier system. The procedure proposed is dependent on certain assumptions. These are:

- that the performance indices of the air barrier required in project briefs include air leakage rates[1] and structural loading[2],
- that the performance of the air barrier system design be certifiable through evaluation, testing, manufacturer data or previously demonstrated performance,
- that the construction process incorporate adequate progress testing and field review to ensure compliance with construction documents,
- that remedial action can be undertaken during the design or construction process if the performance evaluation of any of its parts or the whole system fails to comply with the performance requirements of the project brief,
- that the work required to incorporate an engineered air barrier system is not within the normal scope of design services and therefore additional fees are justified. Furthermore the work required to construct an engineered air barrier system is not within the normal scope of construction services and therefore an additional cost is justified in tender prices.

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1 "An Air Barrier For the Building Envelope", Insight 1986, IRC/NRC

2 "Structural Requirements for Air Barriers", CMHC Report

The method that follows illustrates the steps required to design, construct and commission the air barrier system of the building envelope for a residential project.

Air Barrier Specifications in the Project Brief

⇓

Design Validation

⇓

Tender Documents

⇓

Air Barrier Certification During Construction and Final Commissioning

⇓

Post Commissioning Operation, Maintenance and Repair

The extra steps advocated above will be justified by more durable building envelopes that contribute to increased energy efficiency and comfort, and reduced life cycle costs.

2. PROJECT BRIEF: AIR BARRIER SPECIFICATIONS FOR THE BUILDING ENVELOPE

Suggested Content

The project brief is a document that contains the character, the attributes and the constraints governing the design and construction of a new building project. It is developed by the owner's team to document as clearly as possible the expectations and the constraints of the project. The project brief may be simple or intricate depending on the scale and complexity of the project.

On most projects, the brief should contain the following information:

- type of project — office, residential, museum, shopping mall..
- exterior design conditions — temperature, wind loads, sound, dust...
- interior conditions — temperature, humidity, pressure
- zones required for multi-function use, smoke control
- the control functions to be certified and commissioned — air leakage, water leakage, sound attenuation
- realistic performance objectives for the building as a whole and key components, assemblies and systems such as the air barrier
- durability/maintenance expectations

Example:

A new 20 storey residential tower is to be constructed on an Ottawa site. The building will contain 200 suites, a recreational complex with swimming pool, whirl pool, locker rooms, and connected underground parking.

The owners have had successful experience in previous projects with brick veneer-steel stud exterior wall systems and protected membrane roofs.

Exterior design conditions:

- 2-$^1/_2$% January Temperature (-25°C)
- 2-$^1/_2$% July Temperature (30°C)
- $^1/_{30}$ Wind load (.37 kPa)
- Bounded by a major highway on North side of site

Interior Design Conditions:

- Residential suite temperature
  22°C, 30% RH - winter;
  25 °C, 80% RH - summer
- Swimming pool temperature 26 °C, 55% RH winter and summer.
- Underground parking - unheated. Ventilation to the 1990 National Building Code.

It is these requirements that form the basis of a commissionable air barrier system. The designer then must proceed with the development of the air barrier system in parallel with the project development.

Separate HVAC systems for the suites, corridors, stairwells and recreational complex are required.

The barrier system of this building envelope is to be designed and constructed to provide a continuous, structurally supported plane of materials to control infiltration and exfiltration in accordance with the following requirements:

- The envelope will incorporate a continuous air barrier system, as per the 1990 National Building Code, Article 5.3.1.
- The maximum air leakage through the air barrier system within the roof area and associated penthouse envelope components is not to exceed 0.15 $l/s*m^2$ @ 75 Pa.
- The maximum air leakage through the air barrier system within the areas of the exterior walls in brick veneer steel stud back-up from the roof to grade (excluding windows, patio doors, etc.) is not to exceed 0.30 $l/s*m^2$ @ 75 Pa.
- The maximum air leakage through the fire floor between the parking garage and the main lobby of the apartment is not to exceed 0.10 $l/s*m^2$ @ 75 Pa.
- The maximum air leakage through the windows and patio doors is not to exceed the prescribed limits of the user guide to CSA-A440.1 standard on windows.

- The maximum air leakage between joints between the air barrier components of various assemblies is not to exceed 0.20 l/s*m @ 75 Pa.
- The air barrier system in all parts of the envelope is to be designed to support maximum wind loads, 30 year return.

The air barrier system must provide the following durability:

within the brick veneer/ steel stud system	30 years
roofs	25 years
windows	20 years
doors	15 years

Maintenance expectations during or beyond these periods are to be defined in the operation and maintenance manual.

3. DESIGN PROCESS: AIR BARRIER

3.1 General

The design process for the building envelope proceeds in the normal manner. Conceptual designs are developed to organize spaces, circulation, siting and general appearance. A conceptual structural system and method of construction are resolved for the building, followed by the development of systems for the roof, walls and windows. It is during this stage that consideration is given to the air barrier system. This includes locations for the air barrier within each assembly, types of materials and the performance attributes to be attained by the design.

To date, the design process for air barriers has ***at best*** resulted in tender drawings and specifications that provide the following:

- specification of air barrier materials with known air permeability characteristics.
- assessment of air pressure loads and details of the air barrier system to allow transfer of these loads to the structure.
- specification of overall building air leakage restrictions and air leakage restrictions on key elements such as curtain walls and windows.
- general requirements regarding continuity of airtightness throughout the envelope. Specific contractual responsibilities for making the various connections between elements may or may not have been defined.

These processes have led to air barrier systems that are not certifiable for the most part until the entire building is complete. Assessing the nature of any failure and taking remedial action at this juncture is extremely costly.

3.2 Suggested Revisions to the Air Barrier Design Process

In order to improve the air barrier design process to allow for certification of air barrier performance during construction and final commissioning, two additional steps are proposed for the design process.

- The air barrier design must be validated for basic characteristics of air impermeability, continuity, structural capacity and durability; and
- An audit process must be completed at the conclusion of the design stage which determines that the air leakage rates of all the elements proposed will, in combination, fall within the overall building specifications for total air leakage.

3.2.1 Air Barrier Design Validation

If a contractor is to be held responsible for constructing an assembly of materials in a manner that provides a specified level of airtightness, it is necessary for the designer to provide proof that the design, if constructed as per the tender documents can achieve the required performance. This "proof" or design validation can rely on several sources, but should strive to validate required air impermeability, continuity, structural capacity and durability. The following sources for this information are suggested:

- Air Permeability of Materials and Systems

  The air permeability of many common construction materials are found in Appendix "A". Where a particular material is not listed, the manufacturer may have conducted tests, or test results may be available from a previous project. Many systems, such as curtain wall and windows have been tested to provide air permeability ratings based on $l/s*m^2$ at a specified pressure difference.

Example of Air Barrier Design Validation

The following example extends the foregoing project brief for a twenty storey residential building into the design validation process for the air barrier. It provides only a sample of the design details that would require validation.

- Air Permeability

  The primary air barrier material to be used on this project is to be 1.3 mm modified asphalt self adhesive membrane applied over exterior grade glass fibre reinforced gypsum board.

  The air permeability for this material is 0.0 $l/s*m^2$ @ 75 Pa from Table 1 in Appendix "A".

  The membrane system is penetrated by brick ties and insulation fasteners. An identical system, tested on site for the same owner demonstrated an air leakage rate of 0.12 $l/s*m^2$ @ 75 Pa. The test rest results are recorded in a report titled "Air Leakage of Wall System for the ABC Building" dated May 5, 1992.

- Continuity

  When materials are joined to become air barrier assemblies, the joints or connections must provide predictable performance. Some of the more common details have been tested for air leakage under previous CMHC research (see Appendix "B").

  Unfortunately many assemblies that rely on sealants and various clamping devices for air leakage control have not been tested. In these cases specific mock-up tests must be undertaken to certify the design will continue to provide the continuity and air leakage values required under the intended loads.

- Continuity

  At windows and doors the self adhesive modified asphalt membrane is carried into the rough opening prior to window and door installation. The space between the window or door frame and the adhesive membrane is filled with two component foamed in place polyurethane to maintain continuity at these locations.

  The testing program on the windows was extended to cover the window/wall junction constructed in accordance with these details. Leakage at the window perimeter was shown to be 0.18 l/s* m at 75 Pa. The test results are recorded in a report titled "Air Leakage Test - CDE Windows Inc." dated July 6, 1990.

- Structural Capacity

  Air permeability ratings for a given air pressure load are also provided in Appendix "B" for common low-rise assemblies and elements such as electrical outlets also found in higher buildings. Structural load requirements can also be assessed by reviewing laboratory curtain wall and window test reports. Test reports resulting from previous mock-ups or current laboratory or field tests may also be used.

- Structural Capacity

  The self adhesive membrane proposed was tested under positive and negative pressures of 2.5 kPa in the reports referred to previously. No loss of airtightness was recorded.

- Durability

  Durability of a material, assembly or system depends on the environment in which it is placed. The durability of an air barrier system can be gauged by referring to the service record of similar systems that have been operating in the same environment. Where new materials, assemblies and site procedures are contemplated, detailed review by material and air barrier systems specialists is recommended.

- Durability

  Self adhesive modified bitumen membranes have been in use as air barriers for at least the past eight years. The owner has recorded no durability problems with these membranes provided the original construction was of good quality.

3.2.2 Air Barrier Design Audit

Once the performance of materials, components and assemblies in the air barrier have been validated, an audit of the overall design can be undertaken to establish if it meets the specification for complete building air leakage found in the project brief.

Table 1

	Area	Allowable Air Leakage Rate l/s	Total Allowable Element Leakage l/s	Actual Air Leakage Rate l/s	Total Actual Element Leakage	Validation Method
North Wall						
South Wall						
East Wall						
West Wall						
Punched Windows						
Main Roof						
Penthouse Roof						
Roof/Wall Junction						
Window/ Wall Junction						
Total envelope						

Example Air Barrier Design Audit

Table 1

	Area	Allowable Air Leakage Rate l/s	Total Allowable Element Leakage l/s	Actual Air Leakage Rate l/s	Total Actual Element Leakage	Validation Method
North Wall	750	0.30	225	0.12	90	1
South Wall	750	0.30	225	0.12	90	1
East Wall	1200	0.30	360	0.12	144	1
West Wall	1200	0.30	360	0.12	144	1
Punched Windows	3900	0.10	390	0.08	312	2
Main Roof	900m^2	0.15	135	0.13	117	3
Penthouse Roof	100m^2	0.15	15	0.13	13	2
Roof/Wall Junction	210	0.20	42	0.18	38	4
Window/ Wall Junction	8600	0.20	1720	0.18	1548	2
Total envelope			3472		2496	

Table 1 shows a typical spread sheet that could be devised to allow iteration between the allowable leakage required by the design brief and actual leakage rates for each element that emerge from the design validation described in 3.2.1. Care must be taken at this stage to identify all elements and their intersections correctly. If the actual total envelope leakage does not exceed the total specified in the project brief, the design meets the owner's requirements for total air leakage.

1. Report title "Air Leakage of Wall System for ABC Building" dated May 5, 1992.

2. Report titled "Air Leakage Test - CDE Windows Inc." dated July 6, 1990.

3. Manufacturer's test data of July 10, 1991.

4. Field test on same detail XYZ Building — March 1991.

This simplified example shows how the audit confirms that the air leakage limits established in the project brief are met within the design. Notes on the design validation method are also necessary for record purposes.

4. TENDER DOCUMENTS: AIR BARRIER DETAILS AND SPECIFICATIONS

4.1 General

For most construction projects the air barrier system is described in drawings and specifications. The sections and details show the type of materials and their respective position within each part of the envelope.

The air barrier system is also described within the specification under Section 07195. The type of materials, the preparatory work and installation procedure are presented and references made to other sections. It is from this perspective that a construction quality compliance process is proposed for the air barrier system.

4.2 Specification of Construction Quality Compliance Test Options

Depending on the scale of the project, the contractor may be required to follow one of the following progressively more stringent options to demonstrate compliance with the performance requirements of Section 07195 of the specification. These tests or field review activities, set out in an appropriate section of the specification, are generally conducted by an independent company and paid for by the building owner, except that repeat tests resulting from failure to meet performance requirements are paid for by the contractor.

Option 1

The total air barrier system of the envelope will be tested after substantial completion to determine its air leakage rate. If it is found to leak more than the prescribed limit, it must be investigated by the builder and repaired at his cost. The test procedure to be followed is described in CAN/CGSB2-149.10-M85, "Determination of Airtightness of Building Envelopes by the Fan Depressurization Method".

Option 2

The air barrier system of the envelope will be progressively tested to determine the air leakage rate of the individual areas as they are constructed. This may include the roof air barrier, the wall air barrier including windows and other assemblies. The test procedure generally referred to for elements such as these is ASTM E783-91 "Field Measurement of Air Leakage Through Installed Exterior Windows and Doors". Once an air barrier assembly type has been tested it need not be tested everywhere, so long as construction reviews certify that the other areas are constructed to the same quality. The structural performance of the air barrier must be tested selectively or certified by a structural engineer. The procedure to be followed is described in ASTM E-1233-88 "Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Cyclic Static Pressure Difference".

Example of Specifications of Construction Quality Compliance

The specifications for the twenty storey complex in our example will require the following compliance tests during construction.

- Construction of mock-ups of key details at the earliest possible stage in the construction process including: typical wall area inclusive of membrane brick ties and insulation fasteners; window/wall junction; roof/wall junction; penthouse to roof connection.

- Visual review of the mock-ups for conformance with drawings and specifications followed by air leakage and structural air barrier testing. (These tests will be conducted in substantial conformance with ASTM E783-91 or ASTME-1233-88 as appropriate).

- The mock-ups must meet the following requirements for air leakage:

    - wall area 0.30 $l/s*m^2$

    - all joints/connections 0.20 $l/s*m^2$

- Testing will be paid for by the owner except that where the test results are not achieved, additional testing shall be paid for by the contractor.

The mock-ups that pass the foregoing tests will set the standard of workmanship required for the remainder of construction.

Additional testing may be conducted at any stage in the construction process to ensure compliance with the tender documents.

Following substantial completion, the whole building will be tested to determine compliance with the overall building envelope leakage rates.

Option 3

Parts of the air barrier system will be tested progressively as described in 2 above and the structural performance will be certified by test or engineering design. Further, the air barrier system assembly will be tested by on-site mock-ups prior to the construction of the building envelope. The mock-ups are described in the architectural documents and will include a representative section of the roof, the exterior wall, the windows, the soffits and other unique conditions. The mock-up will be constructed only to the extent that the air barrier system is complete such that selective testing can be undertaken. If the air leakage rate and the structural attributes comply with the performance requirements, the construction of the envelope may proceed so long as construction of the air barrier is identical to the mock-ups. If the performance is not as per requirements, the construction quality must be revised until the requisite performance is attained. The process then proceeds in a progressive manner with certified performance for the material, the components, the assemblies and finally the building enclosure as a whole.

Option 4

This includes the details of Options 2 and 3 but in addition, includes a series of site briefings to be organized during the construction, to explain the design objective to the construction team responsible for its assembly. These briefings would include the purpose, function and performance requirements, what test will be undertaken to verify performance, what qualities will be accepted and what qualities will be rejected and why. In addition, a pre-tender meeting will be held for all bidders, so that new requirements can be explained, allowances explained and the role and responsibilities of the specialist during construction and following substantial completion.

5. AIR BARRIER CERTIFICATION DURING CONSTRUCTION AND FINAL COMMISSIONING

5.1 Certification of The Air Barrier During Construction

As construction proceeds on major projects it is generally cost effective to certify performance of the air barrier in stages to ensure the as-built performance meets the design requirements. This process involves careful scheduling of the specified tests, timely reporting and follow-up to ensure the contractor is not delayed.

When appropriate performance is not achieved, immediate review of the design validation is required prior to re-testing.

Example of Air Barrier Certification

The construction stage of the apartment tower project would involve mock-up construction review and testing specified in the tender documents. This progressive certification during construction is suggested to ensure adequate construction quality early in the air barrier construction process.

5.2 Commissioning The Air Barrier

As the building nears completion the overall performance of the air barrier system may now be commissioned. Commissioning the air barrier system consists of testing its performance attributes. The final performance tests to be undertaken must determine the maximum air leakage rate through the envelope as a whole and the ability of the air barrier system to withstand structural loads. These tests are both prescribed by the tender documents.

Example of Commissioning

The apartment building provided in the example has very limited mechanical systems and would not be required to pass a final commissioning test. This approach is more appropriate where the building has large mechanical systems that can be utilized to generate pressure differences across the building envelope and measure overall flow rates. As such the final test becomes a check on the progressive testing that has followed the construction process.

Should the building envelope not pass the final test, a specialist is empowered to investigate and find the location(s) of the extraneous leakage and to direct the contractor to undertake the necessary repairs. It is understood through the owner/builder contract that the costs of any repeat testing will be paid by the builder or contractor. It is for this reason that progressive evaluation and certification of various areas, components, systems and assemblies become important to the builder to avoid any major surprises.

Following all testing, the specialist will approve the builder's certificate of compliance for the air barrier system and commissioning certificate. It certifies that the design, construction and performance of the air barrier system in its entirety, including materials and workmanship, were tested and found to perform within the envelope performance limits prescribed by the owner's project brief.

6. POST COMMISSIONING OPERATION, MONITORING AND REPAIR

6.1 Operating Information

6.1.1 Description of the Air Barrier System

Before entering into a monitoring program it is important to have an accurate description of the air barrier system of the building envelope. The description should focus on the types of materials, their location within each assembly and the means by which they are linked together to provide a continuous building envelope plane.

Most important in the description is a clear understanding of the various joint designs. The most important joints will be the roof/wall connection, usually at a parapet. This joint may be made of various types of materials including sheet steel, asphaltic membranes, plastic or rubber membranes, but in most instances it is likely to be hidden and not easily serviced.

The location of the air barrier is equally important. If it is on the inside and is accessible, then it is serviceable. But it is also subject to damage, which may go undetected for some time, even though it is easily repaired. Air barriers hidden in the construction may require access to provide maintenance.

6.1.2 Operating Limits for the Air Barrier System

A building operation manual should also describe the intended operating limits for the air barrier. These can be found in the project brief and should provide details of the allowable relative humidity within various spaces and the maximum pressure difference allowed across the envelope from inside to outside.

6.2 Monitoring Procedures

6.2.1 General

To ensure that the air barrier system performs its functions adequately over time, a program of monitoring and testing may ensure durability. Monitoring means to inspect, observe, and verify that the performance of the system continues to meet the attributes that were originally measured during the air barrier certification and commissioning process. A variety of different methods for monitoring and testing air barrier systems follow.

6.2.2 Indirect Monitoring

Indirect monitoring may be undertaken through visual observations of the roof and facades for symptoms that relate to increased air leakage or by examining locally damaged areas. These symptoms include:

- efflorescence on bricks, icicles below window sills and from the weepholes in masonry
- rust stains appearing at various locations which are not related to the direct surface water runoff of rain but rather to the continuous condensation of moisture exiting to the outside
- expansion of masonry products suggesting an increase in moisture content
- stains on exterior finishes
- melting of snow and ice, or just simply the appearance of hoar frost or steam from locations where there should be none.

A second method of indirect monitoring involves recording the energy usage for space heating within the building. If all the energy bills for space heating of a building are noted when the building is new, a base level of energy use may be determined. It can then be used for comparison purposes in detecting any deterioration in the performance of the air barrier system. If the air barrier system is damaged and increased air leakage occurs, especially during the winter, there will be a corresponding increase in energy use reflected in the energy bills.

6.2.3 Direct Monitoring

Direct monitoring is more expensive than indirect monitoring. It involves the use of instrumentation and equipment installed at strategic locations to monitor the factors that govern the performance of the air barrier system. Typically, these are air pressure differences, temperature and humidity in cavities with respect to outdoor and indoor conditions. Measures would include placing pressure taps, thermocouples and humidity sensors in roof cavities, in two or three locations and monitoring these by way of electronic equipment. Monitoring may be periodic or continuous.

By examining the air pressure difference across the air barrier with respect to the wind conditions across the roof or wall, an initial pressure difference index may be determined. This index can be used for direct comparison purposes periodically to determine the performance of the air barrier during the life of the building. Similarly, by monitoring the temperature and humidity in construction cavities, a relation can be drawn between the air pressure difference, the temperature and humidity and the amount of air leakage increase taking place.

Such instrumentation can be installed in the roof, in the exterior walls, and at critical locations at grade but air leakage occurring in areas not being monitored, these would be undetected and would show up as symptoms and damage at some later date. To complement this method, it is suggested that other methods of direct testing be used including tracer gas techniques and fan pressurization.

Another method of monitoring the overall performance of the air barrier system is to perform a thermographic scan of the building. This scan would examine the exterior walls and roof, during a time when exfiltration is most prevalent or in winter. Air leaks usually show up in a pronounced manner and the location of leakage.

6.2.4 **Testing**

If and when an area of the roof or wall is suspected of increased air leakage, it may be necessary to undertake testing to localize the problem and to determine the repair required to reinstate its performance. The most usual test methods include the pressurization of an area in combination with the use of smoke, smoke pencil, and sometimes thermography. This method will induce air leakage and with the use of smoke or thermography, the locations of leaks can be traced to the most probable cause. This is usually followed by test openings and inspection. Test openings and inspections are usually expensive. They may be undertaken from the inside, or from the outside. From the outside they often require swing stage equipment and contractors to demolish or take apart parts of the exterior cladding. From the inside it is usually disruptive to the occupants and may require that they be moved temporarily while inspection and repairs are undertaken.

6.2.5 **Diagnosis and Repairs**

When a symptom or damage indicates that excessive air leakage is the cause, there are a few important operating conditions to verify before embarking on a program of construction repair. First, has there been a significant change in the operating pressure of the building? This means that the supply air ventilation to the building may have changed and it may have been increased substantially because of installation of new equipment or adjustments to old equipment. The air pressures must be restored to former levels before embarking on envelope repairs.

If the indoor humidity has changed significantly because of new equipment or changes in use, then these conditions must also be restored to their former level or the roof/wall system may require upgrading to support the new conditions. When air barrier systems fail it is usually a local condition. For example, a poly sheet may have been intended as the air barrier material of choice, but a sudden gust of wind pressure has ripped the material from its attachments because it was unsupported. When this happens, it is pointless to repair the poly as it may happen again at any time. It is best to re-examine the wall section design and to correct the deficiency with a new approach using more robust materials and better attachments.

At times, failures will occur because of creep loading. This is a condition of low air pressure difference, caused by stack effect or fan pressurization and the eventual detachment of a joint material such as a tape, sealant or membrane. When this occurs, and the connections are deep within the construction, the most cost effective solution is to dismantle and repair. No other treatment is known to improve this situation except to alter operating conditions of indoor temperature, pressure and humidity to the dismay and comfort of the occupancy.

It is beyond the scope of this report to prepare a manual of repair for all types of air barrier systems. However, the most important questions are: what type of air barrier system was designed for this particular building? what part of the building is in need of repair? and, what is the simplest procedure to repair the air barrier system?

The inside and outside air barrier systems are relatively easy to service and not necessarily expensive to repair. However, they are vulnerable to damage from the occupancy and the exterior environment loads. The air barrier systems that are within the construction are usually inaccessible and may require substantial effort to repair.

7. COSTS

The cost of developing a commissionable air barrier are difficult to define precisely because it is a new concept and the principal factors that govern the quality and success of the process are widely variable. The cost, however, can be divided into two parts: consulting fees and technical upgrade costs.

The consulting fees would include a specialist to work with the owner, designer, builder and eventual property manager (or owner again). This specialist may be an additional member on the team with specialized building envelope skills or if these skills are resident in the design team, the function could be handled internally. His tasks would involve development of the design brief with the owner and designer; assist the design team to develop and validate the design of the air barrier system from concept to construction documents. He is further required to work with the builder during assembly and testing and finally to lead the commissioning process during completion of the project. He may also be required to start up and initiate a monitoring program for the air barrier system.

In addition to a specialist, the designer (architect) would be entitled to an increase in fee for the extra work required to develop and validate his air barrier design to specific performance requirements. There would undoubtedly be a cost for additional documentation of construction details and supplementary specifications as well as instruction to the builder concerning the field verification of workmanship and the commissioning tests.

Similarly, builders are is entitled to an increase in tender price to include the necessary briefings, mock-ups, testing and field reviews required of the validation process. His price should include the final commissioning costs, and a contingency allowance for unforeseen requirements. The construction costs of the air barrier system can vary significantly but some increase in cost is likely since specific performance targets must be achieved.

8. CONCLUSIONS AND RECOMMENDATIONS

The concept of a commissionable air barrier system is attractive and needed by the construction industry. Many air barriers forming part of building envelopes today are not performing as effectively as they should be and we are only partially capable of predicting better air leakage performance on alternate designs.

Current thinking that field testing of the building envelope for airtightness performance will improve the quality of performance of the air barrier is not realistic. This is because test results, although needed for research and development, are not enforceable consequences since most tender documents do not prescribe performance limits. Contractors are not required, by drawings and specifications, to build envelopes and air barriers in particular, to measurable performance. More importantly, the technology of design for an air barrier system and its details is not developed well enough to allow designers to predict their performance with respect to air permeability and air pressure loads. But, in fairness to the design community, it must be conceded that there are no minimum performance requirements established by building codes and therefore the state of the art practice relies on each designers understanding of the standard of performance necessary.

Owners, on their part, do not generally understand this technology, although there are more and more owners recognizing the need for better than minimum standards and certainly are willing to consider improved technology.

To develop, design and build a commissionable air barrier system for the building envelope, the process must begin with the owner through a project brief that specifies the quantifiable performance requirements for all parts of the air barrier system. Without these criteria, there can not be a commissionable air barrier system.

The designer must then develop the air barrier system to meet the performance objective of the project brief. The design concept and related details must be validated through testing, previous experience, analysis or some other method. The designer must demonstrate continuity, air impermeability, structural support and durability of the system. He must also develop the necessary construction documents to allow builders to understand the new challenge and to allow sufficient funds to pay for the new technology.

Most designers are not skilled with the engineering of an air barrier system. It is recommended that the owner engage a specialist to assist and guide if necessary, the designer through this process.

Contractors are accustomed to being instructed on what to do, when and how. They are prepared and poised to sequence and assemble a higher quality product, but it must be recognized that contractors are not designers and they may never understand fully why a particular design was developed in a particular manner. However, through briefings and progressive testing and reviews builders will be able to construct air barrier systems with the required performance, and they will adapt to the new requirement of commissioning activities and understand the purpose of the commissioning tests.

Successful commissioning of the air barrier system depends on the co-operation of all parties on the project, and in particular, the designer and the contractor.

To further advance the application of air barrier technology to building envelopes and to attain commissionable systems, it is recommended that:

1. A project be initiated to apply the process described above to a hypothetical medium rise apartment building. It should be done in co-operation with an architectural firm and reviewed by an owner and contractor.

2. A performance standard for the air barrier system should be developed.

3. More development and testing of generic air barrier systems and details should be undertaken so that designers can select sections and details with proven performance rather than require lab testing every time.

4. Better and simpler methods of field testing should be developed for continuity, air permeability and structural qualities of the air barrier component, assemblies and systems.

5. Construction assembly techniques should be developed and demonstrated to illustrate the strengths and weaknesses of workmanship.

6. The consequences of indoor humidity, air pressure differences and outdoor temperatures should be further studied to establish the maximum air leakage rates that can be tolerated without affecting moisture and energy performance of building envelopes significantly.

7. The cost and benefits of better air leakage control for various types of occupancies and building durability should be studied.

MORRISON HERSHFIELD

Richard L. Quirouette, B.Arch.
Building Science Specialist

David L. Scott, B.Arch.
Building Science Specialist

APPENDIX A
AIR PERMEABILITY OF CONSTRUCTION MATERIALS

Air Permeability of Construction Materials

No.	Description	Air Permeability l/s * m² @ 75 Pa
1	2 mm, smooth surface roofing membrane	0.0
2	2.7 mm, modified asphalt membrane, torch-on-glass fiber reinforced, Aluminum V.B.	0.0
3	1.3 mm, modified asphalt, self adhesive membrane	0.0
4	2.7 mm, modified asphalt membrane, torch-on-polyester reinforced	0.0
5	9.5 mm plywood sheathing	0.0
6	38 mm, extruded polystyrene insulation	0.0
7	25.4 mm, foil back urethane insulation	0.0
8	24 mm, phenolic insulation board	0.0
9	42 mm, phenolic insulation board	0.0
10	12.7 mm, cement board	0.0
11	12.7 mm, foil backed gypsum board	0.0
12	8 mm, plywood sheathing	0.007
13	16 mm, flakewood sheathing	0.007
14	12.7 mm, moisture resistant gypsum board	0.009
15	11 mm, flakewood board	0.011
16	12.7 mm, particle board	0.016
17	Reinforced non-perforated polyolefin	0.020
18	12.7 gypsum board	0.020
19	15.9 mm, particle board	0.026
20	3.2 mm, tempered hardboard	0.027
21	Expanded polystyrene, Type 2	0.119
22	30 lb roofing felt	0.187
23	15 lb non-perforated asphalt felt	0.271
24	15 lb perforated felt	0.396
25	Semi-rigid glass fibre insulation with olefin paper, one side	0.488
26	11 mm, fiberboard, plain	0.822
27	11 mm, fiberboard, asphalt impregnated	0.829
28	Spun bonded olefin film	0.960
29	Perforated polyethylene # 1	4.032
30	Perforated polyethylene # 2	3.231
31	Expanded polystyrene insulation (1)	12.237
32	Tongue and groove planks	19.117
33	Glass wool insulation	36.733
34	Vermiculite insulation	70.493
35	Cellulose fibre insulation (5 ply-on)	86.946

APPENDIX B
CERTIFIED AIR BARRIER DETAILS

Certified Air Barrier Details

No.	Description	Air Leakage @ 75 Pa			Structural Loading
		l/s	l/s * m	l/s*m^2	kPa
	CMHC Details I				
1	Header joist, traditional		0.22		±1.0
2	Header joist, poly		0.05		±1.0
3	Header joist, ADA		0.02		± 1.0
4	Header joist, EASE		0.04		± 1.0
5	Electric outlet, Traditional	0.09			± 1.0
6	Electric outlet, Poly	0.02			± 1.0
7	Electric outlet, ADA	0.38			± 1.0
8	Electric outlet, EASE	0.03			± 1.0
9	Window frame opening (Std)		0.60		± 1.0
10	Window frame, Poly Approach		0.07		± 1.0
11	Window frame, ADA		0.01		± 1.0
12	Window frame, EASE		0.06		± 1.0