Improving the Building Envelope to Meet the Challenges of New Research and Regulation

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ABSTRACT

Recent and proposed revisions to building codes and performance standards, as well as publications authored by independent research groups, are expected to have a major impact on the importance of the building envelope. This paper analyzes these publications and other relevant research and their effects on the design and construction disciplines. It will examine the function and common faults of the building envelope in terms of energy efficiency and outline field-proven methodologies for testing and solving building envelope problems. It will also provide tools for making the business case for envelope upgrades.

OBJECTIVE

In this paper, the author is building a bridge between research and the real world by describing how to assess existing buildings, locate and measure air leakage, specify and implement appropriate envelope upgrade measures and materials, calculate the impact on building air leakage and energy performance using energy-use calculation software and develop a financial prospectus to support return on investment (ROI) forecasts.

INTRODUCTION

In 2005, commercial and residential buildings accounted for 40% of total energy consumption in the United States (U.S. Department of Energy 2006). Yet according to the United States Department of Energy, 40% of the energy used to heat and cool the average building is lost to the phenomenon of uncontrolled air leakage through the building envelope. That means up to an astonishing 16% of our total energy consumption may be wasted every year. Uncontrolled air leakage can also contribute to premature deterioration of building materials, ice damming, spalling, condensation and mold, as well as occupant comfort complaints regarding uneven temperatures, drafts and odor transfer between units, together with stack-effect-induced smoke movement within the building in the event of a fire.

Awareness of energy efficiency, and ways to improve it, is currently at a high in response to the incredible political and media-related attention that is being paid to the topic. This alone is enough to stir interest in promoting energy efficient tactics, but there are other major factors to consider as well in terms of the benefits of specifying and commissioning a high-quality building envelope.

State commercial energy codes in many jurisdictions are changing to reflect the demand for higher energy efficient standards, and the American Institute of Architects' (AIA) *2030 Challenge* (Mazria 2006) encourages the global architecture and building community to adopt energy performance targets to reduce fossil fuel consumption. The fossil fuel reduction schedule as outlined in the Challenge is as follows: 60% in 2010, 70% in 2015, 80% in 2020, 90% in 2025, and carbon-neutral by 2030.

Also playing a role in increasing the importance of energy efficiency in buildings and therefore the building envelope are the increasing awareness and adoption of Leadership in Energy and Environmental Design (LEED®) standards from the United States Green Building Council (USGBC) and an overall growth in 'green' building. According to McGraw Hill

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Construction's *Green Building SmartMarket Report*, 70% of architects, engineers, contractors and owners surveyed projected sales growth increases in the 'green' building arena. This number increased to 90% for USGBC members surveyed.

Despite these promising trends, the role of the building envelope in improving building energy efficiency, durability and occupant comfort, health and safety is not always well understood by building owners or the consultant community serving them, and therefore making the business case for envelope upgrades can be more difficult than with other efficiency tactics.

BACKGROUND

A groundbreaking report published in 2005 by the National Institute of Standards and Technology (NIST), *Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use,* was commissioned by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to investigate the impact of the tightness of the building envelope on energy consumption. The study concluded that existing buildings are far leakier than commonly assumed and benefit significantly from air-sealing retrofits, confirming that continuous air barrier systems can reduce air leakage by up to 83% and energy consumption for heating and cooling by up to 40%. Leaky buildings, the study notes, often develop problems such as "reduced thermal comfort, interference with the proper operation of mechanical ventilation systems, degraded indoor air quality, moisture damage of building envelope components and increased energy consumption.µ Emmerich et al 2005)

In response to the study's findings, the ASHRAE Standard 90.1 Envelope Subcommittee is expected to update to the building air leakage requirements in Standard 90.1-2004 by adding Addendum z, which would require the inclusion of a continuous air barrier system (ASHRAE 2006). This will be the first time that air barrier language has been included in the universally accepted energy efficiency standard. The implications of an update to ASHRAE's standards are wide ranging due to the highly referenced nature of its language in state building and energy codes. At the time of writing this paper, ASHRAE's formal acceptance of Addendum z was still pending.

BUILDING THE CASE FOR BETTER BUILDING ENVELOPES

For many years, the problems associated with uncontrolled air leakage in buildings have often been misdiagnosed or unaddressed, and the concept of the air barrier has met with scepticism. The crux of this problem was a lack of verified third-party research that showed the performance difference provided by an energy-efficiency retrofit targeting air leakage. The recent NIST study (Emmerich et al 2005) highlighted research indicating that buildings are subject to larger infiltration rates than commonly believed. Based on previous research, the authors both sought to examine the effect of air leakage on energy use in buildings and to evaluate the cost-effectiveness of measures to tighten buildings.

The study found that the inclusion of an air barrier system in four sampled types and sizes of building can reduce air infiltration by 60% to 100%, representing a large reduction in energy consumption and operating costs: potential gas savings of greater than 40%, and potential electrical savings of greater than 25% compared to the baseline case. (Emmerich et al 2005)

In addition to wasting energy, uncontrolled air leakage can have many other serious consequences:

> The infiltrating air is untreated and can therefore entrain pollutants, allergens, and bacteria into buildings. The accompanying change in air pressures can disrupt the delicate pressure relationships between spaces that HVAC systems create by design, in buildings such as hospitals, where patients' very lives may depend upon maintaining those relationships, and labs, where pollutant control is essential. Disrupted air pressure relationships can move pollutants from spaces where they should be contained, into other spaces where they are not desired. For example, pollutants can move from such areas as storage rooms or garages under buildings into living or working spaces and cause indoor air quality problems. Another serious consequence of infiltration and exfiltration through the building envelope is the condensation of moisture from the exfiltrating air in northern climates, and from infiltrating hot humid air in southern climates, causing mold growth, decay, and corrosion that cause health problems and premature building deterioration. Unlike the moisture transport mechanism of diffusion, air pressure differentials can transport hundreds of times more water vapor through air leaks in the envelope over the same period of time (Quirouette, 1986). This water vapor can condense within the envelope in a concentrated manner, wherever those air leaks may be. (Anis 2006)

The Science Behind Air Leakage

Two conditions are needed for air to leak. First there must be a hole, gap or crack from one side of the envelope to the other. Second, there must be an air-pressure differential, for which there are three causes: wind, stack effect and the HVAC system (see Figure 1).

Wind pressurizes the windward side of the building and depressurizes its back, sides and roof. Wind cannot be controlled, only reduced by plugging the holes in the envelope.

Stack or chimney effect is a buoyancy phenomenon where warm inside air rises through the building and exerts continuous pressure against the roof and upper parts of the exterior walls. The resulting lower pressure at the bottom of the building actually sucks in air. This phenomenon reverses itself in air-conditioned structures during hot weather. The effects are stronger in winter climates due to larger differences between indoor and outdoor temperatures.

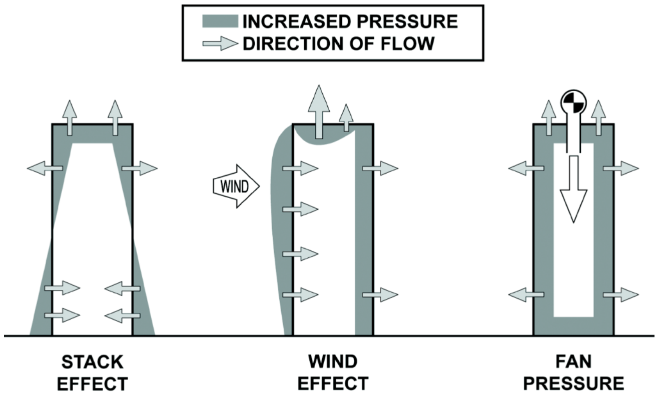

Figure 1 *Forces affecting air leakage.*

The third source of pressure differential is the mechanical system. Makeup air is often brought into a building to replenish exhaust air, but unfortunately, this increases the air pressure at the top of the building and the result is even greater exfiltration in that area.

Diagnostics

There are several methods used to assess where and how air is migrates through a building envelope.

Interviewing Occupants. The first step taken in an air leakage assessment is sometimes a simple interview with occupants. If they are experiencing drafts, odor transfer, or are having trouble maintaining consistent interior temperature or humidity levels, these can help narrow down the causes or primary locations of air leakage.

Field Testing. The second step – or first in cases where interviews are unavailable or unnecessary – is to conduct field testing to determine air leakage flow rates. These methods are detailed in ASTM E-1186-03. The most basic – and most common – test is to use a smoke pencil and blower-door fan to depressurize a confined area or unit. Whole-building depressurization can be performed using large fans and turning the entire building into a single, continuous testing zone.

Once the area or building being tested has been depressurized, a smoke pencil – or in the case of a building-wide assessment, dry ice – is used to create a visual path of air leakage, as the smoke will travel in the direction that air is moving.

Another way to visually track errant air flow is to use an infrared (IR) thermographic camera. Warm air exfiltrating through the top of the building in the winter will appear on the camera's viewing screen as a bright spot, and escaping cooler air in the summer appears as a darker zone.

In-situ window testing can also be conducted in which a depressurized (or pressurized) compartment is created around an individual window and air flow is measured, which creates a pressure difference of 75 Pa. Standards now exist in the United States and Canada to cover airtightness – American Architectural Metals Association (AAMA) 101, National Fenestration Rating Council (NFRC) 400 and Canadian Standards Association (CSA) A440.

These tests help to record the air leakage paths in the building, and air leakage flow rates can then be calculated by evaluating the effects of the wind pressure, stack effect and mechanical systems, as well as the hourly weather data for the location and the operating schedule of the indoor air system.

Corrective Measures

While the inclusion of an approved, continuous air barrier system in the design of all new buildings is the best way to eliminate uncontrolled air leakage, retrofit installations of complete air barriers is usually impractical for existing structures. In retrofit situations, the solution to correcting air leakage problems is to seal all of the openings that are reasonably available to be sealed. The following are five critical areas that commonly need attention and must be sealed in the following order:

1. Top of the building:
   - Roof/wall intersections
   - Mechanical penthouse doors and walls
   - HVAC equipment
   - Various roof penetrations
2. Bottom of the building:
   - Underground parking access doors
   - Exhaust and air intake vents
   - Soffits and ground floor access doors
   - Pipe, duct, cable and other service penetrations into core of the building
   - Sprinkler hanger penetrations, inspection hatches and other holes
   - Core wall to floor slab
3. Vertical shafts:
   - Stairwell fire doors
   - Fire hose cabinets
   - Plumbing, electrical, cable and other penetrations within service rooms
   - Elevator rooms, cable holes, door controller cable holes, bus bar openings
   - Garbage chute perimeter and access hatches
   - Hallway pressurization grille perimeters
   - Elevator shaft smoke control grille
   - Service shafts
4. Outside walls and openings:
   - Weatherstripping on windows, doors, balcony and patio doors
   - Window and door trim to be caulked as necessary
   - Exhaust fans and ducting
   - All service penetrations
   - Baseboard heaters
   - Electrical receptacles
   - Baseboards

5. Compartmentalization:
    - Vented mechanical rooms
    - Garbage compactor room
    - Emergency generator room
    - High voltage rooms
    - Shipping docks
    - Elevator rooms
    - Unique environments (These might include infectious areas of hospitals, indoor swimming pools, artifact or archive storage, and computer rooms.)
    - Workshops
    - Garage vestibules or airlocks

Materials. Materials selected for air-leakage control retrofits must offer an air permeance rating of less than 0.004 cfm/ft^2 (0.2 L/sm^2) at 75 Pa when tested at their intended-use thickness in accordance with ASTM E 2178, in order to meet Canadian or Massachusetts codes, and may include:

Polyurethane foam
- One-component foam for gaps smaller than 2-inches
- Two-component foam for gaps larger than 2-inches

Weatherstripping
- Doorsets, sweeps and overheads
- Polyflex v-strips and c-folds
- Foam tapes
- Fin seals

Energy-Use Calculation Software

The above measures are proven methods of sealing buildings to reduce or prevent uncontrolled air leakage. A common problem, however, is persuading building owners, property managers or boards that the investment is worth it. A useful tool for building a bridge between the research and the need to justify the cost to stakeholders is whole-building energy-use simulation software, which helps to create a clear picture of before-and-after energy usage.

Software such as this uses air-leakage flow rates to calculate the building heat loss/heat gain and to estimate peak demand and energy use. Proposed retrofit air sealing measures are applied to the base model to provide estimated potential reductions in both demand and consumption savings. The result is a report that shows the savings to be gained by an air-leakage control strategy. Field testing on high-rise buildings, which were monitored after air-leakage retrofit work was completed, showed a degree of accuracy within five percent between the forecasted and realized savings. The value of this program is best described with an example of its use in the field, as described below:

Energy-Use Calculation Field Study. The building in this case study is a condominium in the Greater Toronto Area in Ontario, Canada. Climate data for the closest local weather measurement station is shown in Table 1.

Results of Assessment. An assessment of the building revealed major air leakage paths at exterior doors, window joints, duct penetrations, interior doors, roof/wall intersections, conduits passing through floors and elevator shafts, and vents on the roof. Air-sealing measures included weatherstripping common area doors, re-weatherstripping windows, sealing and caulking soffit/wall joints, fire cabinets and around windows. The condominium was assessed to have an air leakage area of 5.4185 m^2 (58.3 ft^2), or 2.9 cm^2/m^2 of envelope area, classifying it as below-average tightness. (Canadian Mortgage and Housing Corporation, 1975)

Figure 2 shows a month-by-month summary of potential energy cost savings generated by the implementation of the above-listed air sealing measures. As seen in Table 2, the estimated total cost of air-leakage control measures was $84,400 USD ($99,846 CAD). In this building, air-sealing upgrades would reduce the utility bills (mainly natural gas) by $17,394 ($20,580 CAD), based on current energy costs, resulting in a simple payback period of about 4.9 years. The annual space-heating cost savings would be about 14% of the total natural-gas bill.

Table 1. National Climate Data and Information Archive— Climate Normals 1971–2000 for Lester B. Pearson International Airport

Temperature:	Annual	**Wind:**	Annual
Daily Average (°C)	7.5	Days with Winds >= 52 km/hr	23.8
Precipitation:		Days with Winds >= 63 km/hr	7.2
Rainfall (mm)	684.6	**Humidity:**	
Snowfall (cm)	115.4	Avg. Vapor Pressure (kPa)	17.4
Precipitation (mm)	792.7	Avg. Relative Humidity-0600LST (%)	252
Wind:		Avg. Relative Humidity - 1500LST (%)	532.7
Speed (km/h)	14.7	**Pressure:**	
Most Frequent Direction	NW	Average Station Pressure (kPa)	1216.7
Direction of Maximum Gust	NW	Average Sea Level Pressure (kPa)	2153.6

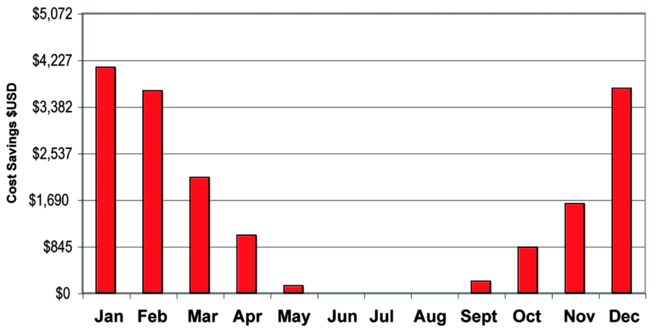

Figure 2 *Summary of energy-use calculation software analysis. This bar graph illustrates the forecasted cost reduction, by month, that will be attained by performing air leakage control retrofits to the building envelope.*

The financial forecast of the project used the following assumptions (figures shown in Table 3) to estimate (Scanada Consultants, Ltd, 1991) energy and cost savings:

- Air-sealing measures would be about 60% effective in curtailing air leakage based on previous field experience
- Weather data based on 30-year climate normals and monthly average weather data for the area (see Table 1)
- Fuel prices and calculated cost savings using utility data provided for the building
- Building operating data and schedules as provided by property management
- Overall building interactive effects (solar and internal gains and other loads) and purchased space heating consumption estimated at about 67% of total heat losses

Incentives. Many jurisdictions offer energy efficiency upgrade incentives that can contribute to the business case and increased rate of return on investment for air sealing retrofit projects. A comprehensive listing for the United States is available on the US DOE Energy Efficiency and Renewable Energy Web site, www.eere.energy.gov. For Canada, consult Natural Resources Canada's Office of Energy Efficiency website at www.oee.nrcan.gc.ca.

DISCUSSION

As the NIST report illustrates, air leakage is a problem common to more buildings in the U.S. than previously thought:

> Despite common assumptions that envelope air leakage is not significant in office and other commercial buildings, measurements have shown that these buildings are subject to larger infiltration rates than commonly believed. Infiltration in commercial buildings can have many negative consequences, including reduced thermal comfort, interference with the proper operation of mechanical ventilation systems, degraded indoor air nents and increased energy consumption. (Emmerich et al. 2005)

Table 2. Summary of Energy-Use Calculation Software Analysis*

Installation Costs	$84,400.67 ($99,846 CAD)
Cost Savings	$17,394 ($20,580 CAD)
Simple Payback (years)	4.9
Fuel Savings	2,795,684ft3 (79,153 m3)
Environmental Savings	
CO_2	195,131lb (88,510kg)
Methane	4,475lb(2,030kg)

* This table outlines the forecasted return on investment (ROI) attainable by performing air leakage control retrofits to the building envelope, showing a simple payback of 4.9 years.

Table 3. Assumptions Used to Generate Forecasts*

Fuel Costs	$9.1832 $/ft^3(0.2600$/m3)
	$0.0486 per kWh heating
Degree Day	4,100 0C-Days heating
Air Sealing Equivalence	60%
Use Pattern	14 hours per day

* This table shows the estimated values used to ascertain the energy savings forecast, including fuel prices, building operating data and weather data for the area based on 30-year climate normals.

Retrofitting is the best possible solution in scenarios where energy efficiencies are being sought to improve a building's performance. There are, however, limitations on the effectiveness of retrofitting measures. At this time, there is no specific provision for air barriers or building envelope improvements in LEED standards, although they may contribute to obtaining energy use credits in the program with a post-retrofit evaluation to verify performance. In addition, expected energy efficiency performance can be affected by human factors, such as the behavior of occupants and building caretakers. Cost can be a deterrent to building owners or boards of directors, but the return on investment for a building envelope retrofit can be as low as five years or less depending on the scope of the project. Extensive energy-efficiency retrofits involving boiler replacements or other mechanical system upgrades to complement the tighter building envelope may take much longer to return on the investment.

It is important to remember that buildings function as a system, and for the system to enjoy optimal functionality and performance, each element has to work properly. If one part of the system fails, it will hinder the other elements' abilities to perform to maximum potential.

CONCLUSION

Should ASHRAE Building Envelope Subcommittee 90.1-2004 Addendum z be finalized after public review, it will have a significant effect on the building and construction industry. Many states will adopt the new standard into their building codes and many may even adopt even more stringent codes, as Massachusetts and California have already done. The new Addendum has the potential to encourage owners and operators of existing buildings to retrofit their buildings with the goal of improved energy efficiency.

The human benefits of a tighter building envelope – provided it is understood that the building must perform as a whole – include greater occupant health, comfort and life safety by reducing the spread of allergens, pollutants, odors and even the spread of smoke during a fire. The structure can benefit from greater soundness and reduced deterioration of materials due to the presence of mold and mildew.

Finally, the environmental benefits include reduced energy usage, a strategy that has been advocated to reduce the effects of climate change and dependence on non-renewable resources.

The time has come for the industry to recognize the integral role of the building envelope in improving the efficiency, durability, safety and profitability of our national building stock. Educational programs are available for design professionals, tradespeople, facility managers and building owners from organizations such as the Air Barrier Association of America (ABAA), the Building Performance Institute (BPI) and the AIA. A host of resource material is available on the Internet and at industry events.

Understanding the effects of air leakage and how to eliminate this phenomenon allows us to take an active step toward not only proactively meeting changing performance standards, but also to addressing the climate change issue and desirability for more environmentally-friendly buildings.

RECOMMENDATIONS

More work is required to validate and adjust as necessary the usability of forecasting software being used in the field. The ability to forecast with reasonable accuracy is becoming increasingly important as public and political demand for energy-efficient building performance continues, as is the current situation, to grow. Energy-use forecasting for buildings needs to be tested, validated and even standardized in order to bring this technology to mainstream use. The end-goal is the growth of energy-efficient buildings. Choices of systems and materials should be made based on scientific evaluation of their verified performance in situ, as opposed to marketing claims or lobby groups. Objections have been raised about mandated air barriers; however, science is proving that these systems make a significant contribution to improving the energy efficiency of buildings.

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