Bridging The Mechanical / Enclosure Gap

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ABSTRACT

In the United States, the realm of building enclosure design and commissioning is separate and distinct from the realm of mechanical design and commissioning. This paper will illustrate how and why these disciplines have been historically separated and outline the consequences of this division and describe the opportunity that a closer relationship between the two represents in terms of costs and environmental impact.

Building Enclosure Commissioning (BECx) is a mature process designed to ensure a building's exterior and its environmental separating materials and assemblies meet an Owner's Project Requirements (OPR) in terms of durability and air tightness. The results of BECx efforts are both predictable and measurable. How can the BECx process better dovetail with the work of mechanical design and commissioning to inform mechanical design in terms of system type and size?

Today, mechanical systems continue to be designed and evaluated largely independent from a building's predicted or actual air leakage parameters. Given the significant carbon impact associated with the construction of new buildings, durability is a paramount value in the fight against climate change. Similarly, mechanical systems, in addition to providing the environmental conditions necessary for human comfort and health, also present an enormous energy draw and carbon contribution at the global level. While the importance of building air tightness and mechanical efficiency are symbiotically interlinked in terms of their function and importance, there is a fundamental practical and cultural divide in the practice of designing, constructing, and evaluating these systems. This divide represents a void of understanding as well as an enormous opportunity for cooperation among the design and commissioning professionals responsible for a building's enclosure and its mechanical systems.

State-of-the-art BECx processes include testing and metrics such as whole building air tightness protocols that reveal the actual air leakage of a constructed building. These tests can be conducted to include and exclude mechanical systems, thereby providing a wealth of information for the benefit of both designers and owners.

This paper first summarizes the existing BECx process by which building air tightness and durability can be predictably achieved and measured. It goes on to discuss ways the result of these efforts can been incorporated into mechanical design and commissioning efforts. Case studies from the authors' work together on a set of elementary schools in Massachusetts substantiate the assertion that a tight range of predicted results can be reliable in terms of design projections.

The paper will conclude with recommendations for a model with which the correlation of projected enclosure leakage rates can inform both the initial equipment as well projected energy cost of mechanical systems. When available and considered, this information can inform decision making models to dramatic effect: Because first and operational costs of mechanical equipment are variables that are dependent on equipment size, type, and efficiency, owner's equipped with accurate predicted mechanical performance are empowered to understand the impacts of their decisions in terms of payback duration, cash flow modelling, carbon impacts, and lifecycle costs.

KEYWORDS

Air Tightness, Enclosure Commissioning, Blower Door Testing, Infiltration Calculations, Equipment Sizing

1 INTRODUCTION

Understanding and addressing the mechanisms by which air is exchanged through a building enclosure is complex, challenging, and decidedly worthwhile effort (de Sola, Symonds 2019). Building Enclosure Commissioning (BECx) is a process designed to ensure a building's exterior enclosure and its environmental separating materials and assemblies meet an Owner's Project Requirements (OPR) in terms of durability and air tightness. The enclosure commissioning process relies upon a set of belt-and-suspenders tools and processes resulting in qualitative and quantitative assurances of a building's quality of construction in addition to its measured air tightness. In the US, for reasons we will touch upon in this paper, the relationship of the output measurements and feedback of the enclosure commissioning process have stood largely independent from the methods and analyses employed by mechanical engineers to specify and size the mechanical systems that will serve a given building and its users. In other words, there is a significant pool of reliable data readily available to impact mechanical design and the predicted function of mechanical equipment that is significantly underutilized.

A frequently cited statistic among building scientists asserts that the heating and cooling of buildings accounts for as much as 40 percent of the total energy consumed in the US. This is an enormous factor in terms of the total environmental impact of energy production as well as the cost of energy born by buildings. It stands to reason that even small improvements to such a major source of consumption can have a significant global impact. One of the places to look is in the category of air leakage and its direct impact on energy usage. How much energy is literally flying out our collective windows, doors, and holes in the wall? A salient statement on Oak Ridge Laboratory's Energy Savings and Moisture Transfer Calculator website (Oak Ridge, 2023) offers clear perspective: "In aggregate, infiltration accounted for greater energy losses than any other component of the building envelope, including fenestration and is responsible for over 4 % of all the energy used in the United States."

Our paper theorizes that incorporation of enclosure commissioning-based building performance data into mechanical design informs the selection and can result in reduced size of specified mechanical equipment. The resulting changes to smaller, more efficient equipment will, in turn, meaningfully reduce the global demand on energy and should therefore become a standard industry practice.

A problem arises with such a proposition: designing a system to measured values requires that measured values are available. Mechanical systems are specified in the design phase well in advance of a building's construction and completion where tools are available to measure it. Any proposed process would therefore necessarily rely upon predicted vs measured values. The question becomes, can the BECx process itself provide reasonable assurance to mechanical designers and building owners that high-performance values can safely be used for the purposes of selecting and sizing mechanical systems? For the effort to have meaning, the mechanical systems in question would need to become meaningfully smaller and more efficient. However, smaller systems come with several corresponding risks: if the assumptions regarding a building's leakage and thermal resistance are not achieved in the field, undersized systems would:

- operate outside of efficient parameters
- operate at unsustainable internal loads and wear out quickly
- fail to reach design temperatures, resulting in occupant discomfort

In fact, several of these eventualities could become true over time. For high-performance predictions to be credible and reliable, a robust set of data would first need exist in the form of a statistically significant set of measured results from comparable projects in similar environments utilizing a BECx or similar protocol.

Additionally, to be considered sufficiently reliable for mechanical engineers to place stock in predicted high performance levels, there is another critical factor to consider: durability. It is one thing for a building to demonstrate a high level of performance near its date of completion; it is another thing all together that this performance will endure over time. Therefore, in addition to the introduction of commissioning data assessing performance to the realm of mechanical design, so must predictions of durability.

To address the attendant issues surrounding a need to improve the relationship between enclosure and mechanical systems, we will first look at the BECx process to unravel the focal points of the effort including air barriers and durability, and review the tool set used to achieve qualitative and quantitative assessments of building enclosures. We will then provide an overview of the current thinking used by mechanical designers and commissioning agents as it pertains to high performance buildings. Following this, we will describe three constructed projects featuring the BECx process and discuss their results to demonstrate how a growing body of similar results could be relied upon to inform mechanical design. Finally, we will broach the divide that separates enclosure design and commissioning from HVAC design and commissioning.

2 BECX: FOCUS AND PROCESS

2.1 An Overview of Air Barriers

Long and cold winters combined with severe building envelope failures stemming from early efforts to mitigate energy loss motivated Canada to invest in the research of building envelope assemblies as well as developing testing and verification processes to vet them. Canada's experiential and researched findings have flowed into the U.S. over the last three decades and now recognition of the importance of an air-tight exterior assembly for reducing a building's heating and cooling loads, as well as increasing indoor air quality, is becoming mainstream in the U.S.

Conceptually, an air barrier is like the placement of a balloon around all sides of a building, including the foundation; it is designed to fully encapsulate a building to eliminate the migration of air across its envelope. When functioning as designed this layer—often taking the form of a membrane only 20 - 60 mils thick—can affect dramatic reductions in the energy required for space heating and cooling. The function of an air barrier can be performed by numerous materials and assemblies including glass, metal, sealants, foams, as well as a variety of plastic and rubberized sheets applied in sheets or by spray. Designing and specifying these materials and assemblies is only the beginning; numerous decisions and actions must be performed correctly in order for an air barrier system to function as intended:

- The air barrier materials—including its primers, sealants, and transition materials—must be compatible with those of its substrate, penetrating fasteners, and adjacent assemblies.
- When the air barrier is an applied sheet or membrane, it must be installed over clean and dry substrate under conforming weather conditions—usually dry conditions, not too hot, and not too cold.
- Air barriers must not be overexposed to dust, UV light, accidental mishandling, or field conditions that would otherwise degrade a full life expectancy.
- Air barriers must be correctly installed—not just over opaque wall conditions, but also where they connect to windows, skylights, storefronts, curtainwalls, louvers, vents, HVAC equipment, electrical and plumbing penetrations, the mechanical fasteners of the roof, brick ties, z-girt systems, and lintels, among other conditions.
- Air barriers must span and appropriately flex over movement joints between floors, differentially supported areas of the structure, and expansion joints, they must connect continually and without defect across major adjacent assemblies (e.g., roof-to-wall, wall-to-foundation, foundation-to-floor slab, etc.)

Studies have shown substantial energy savings resulting from tightening a building's exterior enclosure. Uncontrolled air flow into or out of a building can create performance problems including energy consumption, uncontrolled moisture concentration, and poor indoor air quality. Similarly, the addition of insulation in a balanced wall assembly can significantly increase occupant's thermal comfort as well as greatly reduce the costs associated with building heating and cooling expenses. Savings ranging from 20% to 40% are commonly associated with comparatively tight and well-insulated buildings against their leaky and uninsulated counterparts. With a high-performance exterior, HVAC units can be sized smaller as there is less risk of under sizing them. HVAC units are also capable of more precise control of the internal environment as there is less uncontrolled air flow in and out of the building. This, in turn, leads to higher rates of occupant comfort.

2.2 How Tight Is Tight Enough? The Development of Leakage Rate Standards

As we become increasingly aware of the need for functional air barriers in our buildings as well as the problems deficient installations may pose, efforts to codify and measure standards for air barrier systems have followed. Among the most influential voices to raise awareness of the value and establish standards for air tightness requirements is the U.S. Army Corps of Engineers (USACE). In May of 2012, in collaboration with the Air Barrier Association of America (ABAA), USACE issued a new Engineering and Construction Bulletin outlining requirements for building airtightness as well as building air leakage testing for both new and renovated building projects. The group also instituted a standard for air leakage for whole buildings: 0.25 cubic feet per minute (CFM) with a pressure differential of 75 pascal (1.57 PSF). (Zhivov, A., Bailey, et. al. 2012) The table below shows the minimum standards adopted by some of these.

Table 1: Standards and Requirements for Air Leakage

Standard	**Requirement CFM@75 Pascal/ ft2**
2009 IECC International Energy Conservation Code	.55
2012 IECC	.25
R-2000*	.13
LEED IV Multi-Family **	.09
Passivhaus	.05

*Standard for Energy Efficiency in New Construction developed by Natural Resources Canada

**50 Pascal, 2 Point Option, IECC Climate Zone 5-7

Table References: Genge, C. 2014; USGBC, 2018; USGBC LEED BD+C Homes Air Infiltration 2018

While the standards for permissible leakage vary widely, they are increasingly becoming more stringent. This is reflective of both the increasing understanding of the importance of airtightness as well as the growing body of evidence of test results demonstrating that extremely tight construction is both feasible and practical, even for large buildings.

2.3 Enclosure Durability

The required service life of a building is among the most important factors for an owner to address. An example of a framework is provided in Table 2.

Table 2: Durability Standards by Building Type

Classification	Service Life Requirement	Examples
Temporary	5 years	Annex Facility, Swing Space
Short	25 years	Big Box Stores, Strip Malls
Medium	50 Years	Airports, Hospitals, Data Centers
Long	75- 100 Years	Schools, College, Residence
Permanent	No End of Use Monument	Museums, Court Houses, Government University

Durability should be considered at micro-and macro-level assessment of the mechanisms of deterioration in the context of their placement is necessary. Detailed and specified materials and assemblies must be evaluated against environmental conditions; for example: heat, cold, moisture, UV exposure, storms, flooding, and salinity. Similarly, animals and insects can cause harm.

Easily accessible, low cost, and maintainable materials and assemblies may be appropriate for some low priority regions. Where difficult or impossible to access materials and assemblies are placed in a high priority region, the durability factor approaches the service life of the OPR. For example, mid-wall performance components, which are inaccessible without removal of the wall assembly, must have a durability greater than that of the OPR.

2.4 Overview of Building Enclosure Commissioning

In North America, a robust process designed to steward a building from inception through construction and occupancy is the Building Enclosure Commissioning (BECx) as outlined in ASTM E2813 − 12 Standard Practice For Building Enclosure Commissioning ASTM E2947 – 16 Standard Guide For Building Enclosure Commissioning and CSA Z320 :11 Building

Commissioning. The process features third party design review during the design process, includes submittal reviews, the development of mockup and building testing protocols, construction observation, and post-occupancy support. Buildings utilizing this process perform demonstrably better than those that don't.

A performance mockup that provides an opportunity to construct and test a given assembly in context can provide opportunities to improve both its design and execution. The mockup is tested for air, water, thermal, and structural performance. This can be performed in the laboratory or as a free-standing, fully enclosed mockup on the site.

Objectives of Building Envelope Commissioning are driven by building type, performance requirements, expected life cycle, geographic and climatic considerations, desired energy efficiency, and budgetary constraints, which all may vary considerably between projects. As there is much literature describing the tasks that comprise the BECx process, identifying these tasks is beyond the scope of this paper. However, to effectively compare BECx between typical and extreme climates, it is necessary to discuss the key action items common to most BECx programs. While the precise tasks and their frequency differ from project to project, basic practice generally follows a similar series of steps categorized into five phases: Pre-Design; Design; Pre-Construction; Construction, and; Operations and Maintenance (O&M).

A full-service Building Exterior Commissioning (BECx) process, as detailed in NIBS 3-2012 (NIBS 2012), has demonstrated the most impressive and reliable results. Evan Mills, PhD, a researcher at Lawrence Berkeley National Laboratory, called the BECx process "the single most cost-effective strategy for reducing energy, costs, and greenhouse gas emissions in buildings today." (Sullivan, C. 2013)

2.5 Tools For Verifying Air Barrier Performance: Complexity and Challenges

In the U.S., projects have adopted a number of tools and techniques to decrease the probability of deficiencies in the performance plane. Of these, the process involves a qualified third party engaged at the beginning of the design process and serving through the construction process as an envelope auditor. The BECx process is intended to be comprehensive and typically includes the following key steps:

- Exterior envelope design reviews during the design and shop drawing documentation phases
- Development of BECx specifications
- A role in the contractor and subcontractor selection process
- Review of shop drawings
- Design and definition of the exterior functional performance testing protocol for mockups and field tests
- Contractor quality assurance and quality control auditing
- Site observation visits
- Deficiency logging
- Warranty and maintenance monitoring and audits

The BECx approach is sound and affordable relative to potential energy savings and reduced costs of repairs and maintenance; it is currently the best available option for owners to reduce the risks of a problematic exterior envelope. There remain numerous opportunities for problems to occur, however. For example, budgetary limitations limit the site visits made by the specialized consultants, engineers and/or architects, which decreases the possibility of identifying envelope issues as they occur and increases the potential for defects in the performance plane to be concealed behind permanent cladding systems; not every issue can reasonably be caught. The potential for issues to occur, even with consistent auditing, is a compelling reason to include a comprehensive mockup and field-testing protocol. A sensible deployment of recognized ASTM and AAMA protocols, for example: AAMA 501.1, AAMA 501.2, ASTM E1186, ASTM E783, and ASTM E1105, can identify hidden deficiencies during construction.

Whole Building Air Testing: Accumulating data from Whole Building testing are helping the industry to understand the types of envelope issues that persist, even under the highest quality standards. Kevin Knight and colleagues at the Building Envelope Technology Access Centre (BETAC) at Red River College in Manitoba, Canada, have advanced their airtightness testing program by means of laboratory testing as well as the study of previous whole building air testing. Their efforts have produced the following observations (Proskiw, G, Knight, et.al, 2016)

Leaks are common at:

- Exhaust and make-up air fans with one-way dampers
- Roof/wall intersections, especially on walls running perpendicular to roof deck flutes
- Unintentional bulkhead leakage into attic spaces
- Overhead doors, mainly at base and sides, not between sections
- CMU/floor slab intersections
- Curtain wall/floor slab intersections
- Unsealed walls above ceiling lines
- Ductwork and pipe penetrations
- Doors and windows (both broken and unbroken)
- Underground steam lines

Additionally, test results have prompted debate regarding the inclusion, exclusion, or partial inclusion of the mechanical system during the test, as has the idea of a pressure neutral result to simulate real world conditions. Knight and his colleagues have drawn a sensible conclusion to the question. The recommendation from the group is that two distinct sealing schedules be required for the mechanical system:

- Envelope Tests – Evaluate the integrity of the building envelope
    - Mechanical system is sealed
- Energy Tests – Evaluate the impact of air leakage on energy performance
    - Mechanical system is unsealed.

Whole building air testing, in the aggregate, can inform institutional Owners about the propensities of their buildings. The more data that is available, the more useful the tests become. While specific issues may be inaccessible, knowledge of their existence can prepare an Owner on what to watch as well as a sensible maintenance protocol. The data can establish institutional benchmarks both helping measure new projects against previous standards as well helping inform design decisions—appropriate HVAC sizing being among the most recognized.

3 MECHANICAL DESIGN CONSIDERATIONS

3.1 Mechanical Design for New Construction

In the northeast of USA, general "rule of thumb" industry practices for the effect of building envelopes on mechanical equipment peak heating loads is shown in Table 3. As shown in this table, the results of improved building envelopes is staggering. Compared to older building envelope design practices, new high performance building envelope designs can support an approximately 400% smaller mechanical peak heating load.

Table 3: Building Envelope Design's Effect on Heating Load Design "Rule of Thumb"

General Design Practices	Peak Heating Load (Btu/ft²hr)	Peak Heating Load (W/m²)
"Old" Designs	40	126
"New" Designs	20	63
High Performance	10	32
Passive House	<10	<32

These approximations should be viewed as general guidelines and not as a replacement for calculating peak heating loads. When performing these calculations, it is important to take into account the climate in which the building is being constructed, building envelop values, building air tightness, and anticipated internal heat loads which will be variable depending on the space type.

One of the largest changes to the design engineering industry, aside from building envelope improvements, is the topic of mechanical heating fuel switching, aka electrification. The rise of this topic coincides with growing social and environmental pressures to reduce the impact of climate change paired with industrial advancements such as heat pump technology. At first glance, designing a new construction building with a fully electrified mechanical heating system appears easy. Buildings can be designed with multiple configurations of infrastructure depending on building size, orientation, and usage. Electricity purchased for the building can be 100% renewable, and the "green" features can command premium rents from tenants. However, most electrical grid infrastructure was not designed or sized to support fully electrified buildings. As the demand for electricity increases, grid electrical infrastructure sizing will become more of an issue which could cause significant delays in the construction of new buildings if they are forced to wait until grid electrical infrastructure upgrades are completed.

The question then becomes, how can the anticipated total energy load of a building be reduced to mitigate or lessen the effect of these electrical grid issues? This is not a new question and most of the new construction industry already acknowledges the importance of building envelopes and their effects on the overall energy consumption of a building. This is evident in the emergence of "Passive House" and comparable design techniques. If the building envelope is designed and constructed to a low degree of heat loss tolerances, mechanical heating, cooling, and ventilation systems do not need to be as robust compared to standard design practices.

Herein lies the importance of mechanical commissioning and building envelope commissioning, as well as the marriage of HVAC and enclosure work. With significant emphasis on mechanical systems and envelopes performing to very high standards, efforts to ensure quality control are critical. Especially when it comes to building envelope as once the building is built, there will be very few options to correct mistakes without significant financial and schedule implications. Waiting to until a building is complete and performing a full building blower door test to see how a building performs without additional building commissioning efforts can be very risky. If tests come back with air leakage above acceptable levels, corrective actions for the building envelope may not be feasible and building mechanical systems may struggle to maintain heating loads. Similarly with mechanical systems, there will be high expectations of performance. With decreases sizing of mechanical equipment, the room for error in system performance is diminished.

3.2 Mechanical Design for Existing Buildings

"Around 80% of the buildings we have today will exist in 2050…" (Grainger, 2022). This is unmistakable throughout Europe and cities worldwide. That said, the buildings may exist, but building envelopes will inevitably degrade over time and mechanical equipment will need to be replaced. Due to the large capital expense required to repair building envelopes and replace mechanical infrastructure, considering sustainability is paramount. These sustainability considerations should include both energy efficiency and maintainability of systems.

When designing for replacement of mechanical systems, several questions must be considered.

- Why is the system being replaced?
  - Is it due to age, reliability, maintainability, operation, energy consumption, etc.?
  - Are there any changes to building codes, energy consumption limits, or Greenhouse Gas equivalent (GHGe) emission limits?
- Does the current system meet the building's requirements?
  - Have there been changes to space use that would require more or less systems capacities?
  - Are there significant heating, cooling, ventilation complaints? If so, where?
- Does the building owner or tenant want to make changes to the building that would affect the current system's effectiveness?
  - Is there a planned renovation that would change space usage? (e.g., office converted to labs)
- Do the existing generation, distribution, and/or terminal units need to be replaced?
  - Will new generation (e.g., water heater) equipment supply the correct temperature fluids to the terminal units?
  - Will the terminal units need to be replaced to receive lower temperature hot water?
- Will new system controls need to be added?
- Is the existing electrical infrastructure adequate to support a fuel switch (e.g., fossil fuel to electricity)?
- Will the electrical grid be able to serve an increased electrical load?
- How will the building envelope affect system performance?

Most of these questions can be answered by the design engineer and building owner with an acceptable level of certainty except for building envelope performance. Without performing existing building envelope commissioning and associated repairs, assumptions regarding building envelope performance will need to be made. These assumptions will normally by based on initial design criteria, tenant feedback, and visual observations. Due to these uncertainties and assumptions, many design engineers will just replace the system in-kind, but if fuel switching is also desired, replacement in-kind and considerations for downsizing of equipment may not be an option. This may lead the design engineer to oversize the replacement system to ensure that acceptable indoor conditions are met. In turn, this oversizing of equipment places additional stress on existing electrical infrastructure which may require costly electrical infrastructure upgrades.

A more thorough method of addressing uncertainty in building envelope performance is via the building envelope commissioning process. Through this process, critical information on building envelope performance is gathered and taken into consideration by engineering design professionals. Key testing components of this process are:

- Blower Door Testing ASTM E779 to identify total building air leakage.
- Fenestration Testing such as ASTM 783 to identify local air leakage. This can be combined with ASTM E1176 smoke detection to help source issues.
- Thermal Imaging Investigation ASTM C1153 to identify areas of concern for thermal bridging and heating/cooling energy loss. An additional benefit of this testing process is identifying areas of concern for water leakage into a building.

With this information, levels of certainly can be increased and the design engineer can make more accurate peak heating load calculations resulting with more appropriately sized mechanical infrastructure.

4 CASE PROJECTS AND VALUES

In the course of their collaboration over more than 10 years, the companies of this paper's authors have performed mechanical and enclosure commissioning on well over 20 institutional buildings together. As a result, a growing body of both qualitative and quantitative data to substantiate a basis of standards and predictability for our subject building types, specifically, K-12 academic buildings in Massachusetts, USA is available to us. Additionally, while our body of results for whole building air testing is still relatively small— the test is still gaining traction as a routine practice—the results have been both impressive and consistent. We now recognize that extremely tight high-performance academic buildings are not only possible but can be routinely achievable based upon the BECx process that we have consistently adopted for the vast majority of these projects. As a result, we have adopted an ambitious standard for air tightness, .1 CFM at 75 PA, that is specified as a performance requirements for all new academic projects supported by the state of Massachusetts. This rate represents just 25% of the allowable air leakage as dictated by the current building code for the state.

Table 4: Air Tightness Standards by Building Type

Case	**Building Type**	**Measured Air Leakage Rate at 75 PA**
1	Elementary School	.06
2	Library	.06
3	University Academic Building	.09
4	Elementary School	1.2*

*Project was constructed during the COVID pandemic; several of the BECx activities were not completed.

5 CONCLUSIONS

Building exterior enclosures are among the most critical, expensive, and energy consumptive of a building systems to construct. They represent an enormous carbon footprint, and they contribute mightily to overall energy usage. It is no trivial matter to make good decisions on this topic given both micro and macro considerations.

Governmental and other institutional / portfolio owners are challenged to evaluate the status of buildings with value-based and actionable terms. The escalating attention on energy efficiency, climate change, geo-political stability / national self-sufficiency, energy costs, and the increasingly competitive appeal of sustainable resources has placed additional focus and weight on high-efficiency and robust high-performance options for both enclosure and HVAC components.

Evaluating decisions for new and existing building stock in value-based terms requires data and the collaboration of multiple disciplines. Two of the most relevant of these to energy use are for enclosure and HVAC system design and evaluation.

We understand from the extensive studies performed on buildings over the years that among the pathways for energy loss, convective heat and cooling loss via air leakage is the most significant source of thermal transfer; buildings with the highest preponderance of leaky conditions are perform the worst in terms of thermal and energy efficiency.

The incorporation of measured air leakage and durability data into HVAC models can result in more efficient mechanical systems with low risk based upon the consistent results of the BECx processes outlined above.

We are optimistic that new means of calculating loads based on these inputs will become normalized over time as the data from tests such as Whole Building Air Testing becomes standardized and that increased reliance on such data will result in significant energy savings with benefits to both owners and the environment.

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