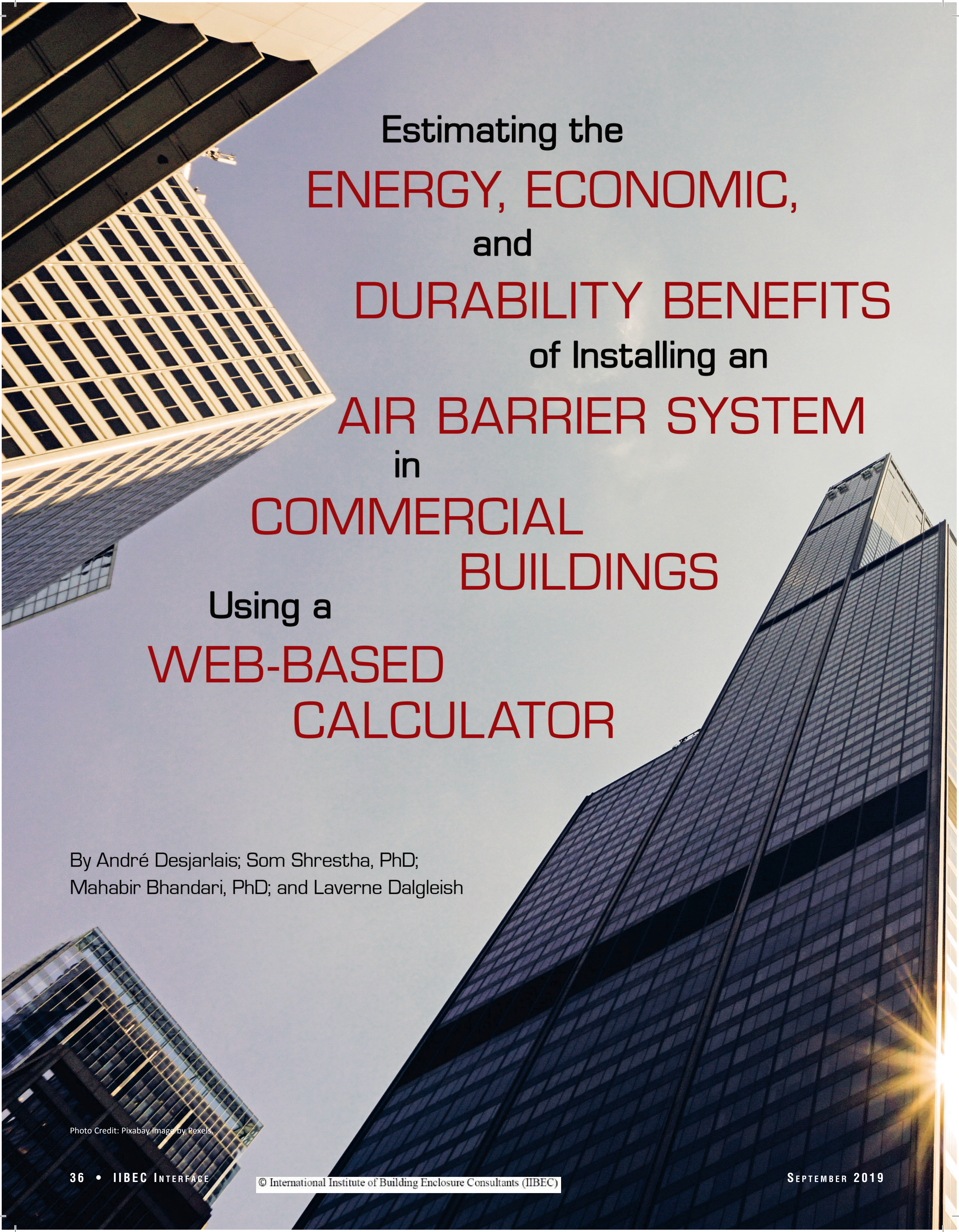
Estimating the ENERGY, ECONOMIC, and DURABILITY BENEFITS of Installing an AIR BARRIER SYSTEM in COMMERCIAL BUILDINGS Using a WEB-BASED CALCULATOR

By André Desjarlais; Som Shrestha, PhD; Mahabir Bhandari, PhD; and Laverne Dalgleish



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ABSTRACT

Uncontrolled heat, air, and moisture transfer through the building enclosure has a significant impact on energy usage, comfort, indoor air quality, and building enclosure durability. Air leakage in commercial buildings in the United States accounts for about one quad (one quadrillion Btu) of energy annually, costing approximately $10 billion.[1] As the thermal resistance of commercial building enclosures continues to improve, the relative contribution of air leakage to heating and cooling loads is increasing. A wide variety of air barrier technologies and construction practices to reduce the air leakage in buildings are available to the architect and designer. To promote more energy-efficient and durable building enclosure design, advances in easy-to-use tools for determining the impact of air leakage are needed.

Oak Ridge National Laboratory (ORNL), the Air Barrier Association of America (ABAA), and the National Institute of Standards and Technology (NIST) partnered to develop an online calculator that estimates the potential energy, cost savings (due to energy use reduction), and moisture transport due to improvements in airtightness. The calculator estimates the energy and cost savings potential based on the pre- and post-retrofit air leakage rates for prototype commercial buildings. The tool does not include the energy and hygrothermal impacts of air intrusion or air that flows into and out of the building enclosure from the same side. This article reports on the development of the Energy Savings and Moisture Transfer Calculator. This online tool aims to fill this void, is based on the best science available, and is easy to use.

INTRODUCTION

Commercial buildings in the United States consume about 19 quads of energy per year,[1] which represents about 20 percent of all the energy used in the U.S. annually. Air leakage through the enclosure of these buildings is responsible for approximately 6 percent of their energy use.[1] The air leakage in commercial buildings mainly affects heating energy consumption. The U.S. Energy Information Administration's (EIA's) Commercial Building Energy Consumption Survey (CBECS) indicates U.S. commercial buildings consume 1740 TBtu for air leakage associated with space heating.[2] Previous studies show that infiltration is responsible for an average of 33 percent of the heating load and 3.3 percent of the cooling load in the U.S.[3]

Air barrier systems are combinations of materials designed and constructed to control airflow between a conditioned space and an unconditioned space. The air barrier system is the primary air enclosure boundary that separates indoor (conditioned) air and outdoor (unconditioned) air. There are numerous test methods available for determining the air leakage of an air barrier material and system with ASTM E2178, *Standard Test Method for Air Permeance of Building Materials*[4] and ASTM E2357, *Standard Test Method for Determining Air Leakage Rate of Air Barrier Assemblies*[5] being the most widely used methods in the U.S.

Although air leakage has long been recognized as a key contributor to heating and cooling loads and moisture flow, methods that estimate its effects on energy consumption and durability vary due to the complexity of this task.[6-9] Comprehensive building design and energy simulations should consider the fact that air leakage rates vary due to the operation of heating, ventilation, and air-conditioning (HVAC) systems, occupancy, the size of apertures in the

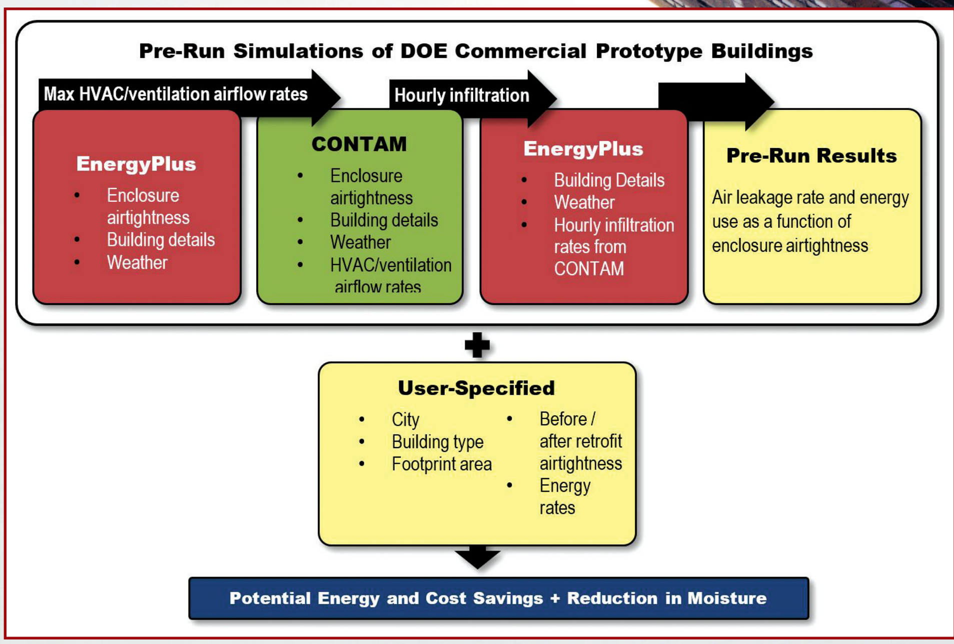

Figure 1 – General procedure to estimate potential energy costs for different levels of enclosure airtightness in DOE commercial prototype buildings.

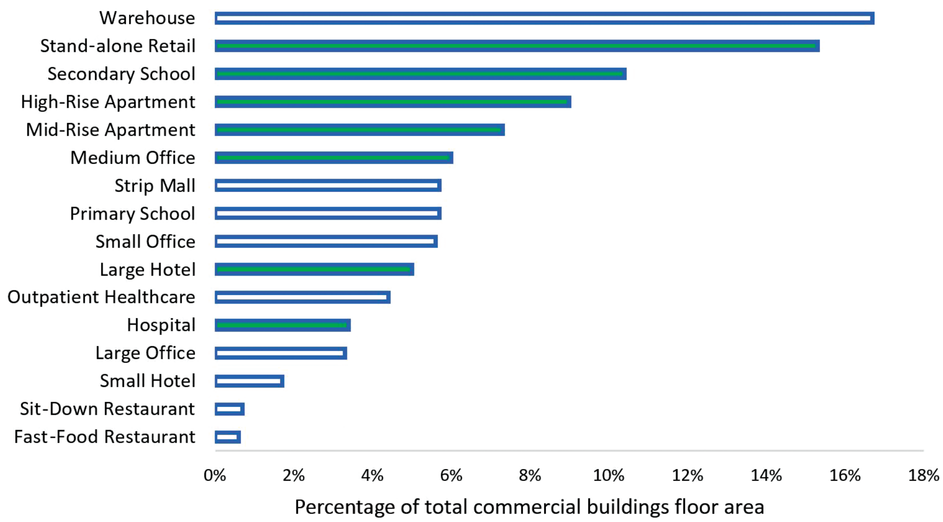

Figure 2 – Prototype buildings as a percentage of total U.S. commercial building floorspace. Green-shaded bars are those for which the calculator includes simulations.

enclosure, and weather (i.e., indoor-to-outdoor temperature difference and wind). Due to the complexity of the analyses and the number of variables involved, typical energy simulations tend to take shortcuts to expedite the analysis, such as assuming constant leakage rates and/or using simplified algorithms, which can lead to under- or over-estimated energy usage.

THE TOOL

The online energy savings and moisture transfer calculator (henceforth referred to as the calculator) for commercial buildings (https://airleakage-calc.ornl.gov/#/) is described in *Figure 1*.

The tool uses a database of EnergyPlus pre-run simulation results for Department of Energy (DOE) commercial prototype buildings.[10] The main difference between the online calculator and the procedure followed in the DOE prototypes is that the calculator utilizes CONTAM-calculated air changes per hour (ACH) or air leakage rates as inputs, whereas the prototypes make simplified assumptions. CONTAM[11] is a multizone airflow and contaminant transport analysis software developed at NIST. This software considers multiple variables, such as weather conditions, enclosure airtightness, and HVAC system operation, to calculate air leakage rates through the building enclosure. The CONTAM-calculated hourly air leakage rates are imported into DOE's whole-building energy simulation software, EnergyPlus,[12] with the CONTAM Results Export Tool.[13] EnergyPlus is then used to calculate the effect of air leakage on energy consumption and moisture transport.

The described procedure is comparable to what was followed by Emmerich et al.[3] and Emmerich and Persily,[14] but the calculator makes this complex procedure available to those who don't have the expertise to calculate hourly air leakage rates. In contrast, typical energy simulations tend to expedite their analyses by assuming constant air leakage rates and/or using simplified algorithms that can lead to less-accurate energy usage estimates. Ng et al.[15] estimate that simplifications in the EnergyPlus models for the prototype commercial buildings lead to underestimations of average electrical and gas use by HVAC systems. Shrestha et al.[16] show that the discrepancy in the predicted cost savings between the simplified tools and the proposed methodology could be as high as 40 percent.

The moisture transport calculation is simplified. The tool is only computing the total amount of water that is transported through the building enclosure component into the interior building space due to air leakage. It is a measure of the potential moisture source but does not look at whether the moisture is accumulating in the building enclosure. Both moisture due to infiltration and exfiltration is calculated and then summed. The thesis is that the greater the amount of moisture transported through the building enclosure, the greater the likelihood of having a durability issue.

As stated earlier, the calculator uses the DOE prototype building models, given that these represent 80 percent of U.S. commercial building floor area.[17] The current suite of commercial prototype building models covers 16 common building types. *Figure 2* shows the prototype buildings as a percentage of total U.S. commercial building floorspace. The calculator includes simulations in its database to cover seven of the building types. These are depicted in *Figure 2* by a solid green-colored bar and represent over 55 percent of U.S. commercial floorspace and represent building types that would typically be temperature conditioned and benefit from an air barrier system.

Characteristic	Description
Floor area	24,750 ft.^{2} [178 by 139 ft.] (2300 m^2 [54 by 12 m])
Number of floors	1
Floor to ceiling height	20 ft. (6 m)
Window-to-wall ratio, %	25.4
Window orientation	South façade
Building Enclosure	
Walls	8-in. (203-mm) concrete masonry block plus insulation per ASHRAE/IES Standard 90.1-2013 plus 0.5-in. (13-mm) drywall
Roof	Roof membrane plus insulation per ASHRAE/IES Standard 90.1-2013, plus metal deck
Window U-factor and solar heat gain coefficient	Per ASHRAE/IES Standard 90.1-2013
Foundation	6-in. (152-mm) concrete slab on ground plus insulation per ASHRAE/IES Standard 90.1-2013
HVAC	
Heating Type	Gas furnace inside the packaged air-conditioning unit
Cooling Type	Packaged air-conditioning unit
Size	Auto-sized to design day
Efficiency	Based on climate location, design heating/cooling capacity, and ASHRAE/IES Standard 90.1-2013 requirements
Thermostat set point	75°F (24°C) cooling / 70°F (21°C) heating
Thermostat setback	85°F (29°C) cooling / 60°F (16°C) heating
Ventilation	Per ASHRAE Standard 62.1-2013

Table 1 – Modeling specifications of standalone retail building prototype.

These prototypes were developed by DOE as a standardized baseline for energy savings calculations. The enclosure assembly and HVAC unit for each of the prototypes vary based on geographical location and the building code that the building complies with. The features of the building models and a detailed description of their development are provided by Goel et al.[7] and the Building Energy Codes Program website.[18] In particular, the calculator uses the prototype buildings that comply with ASHRAE Standard 90.1-2013.[19] For example, building characteristics of a standalone retail building as defined by the prototypical models are shown in *Table 1*. Similar characteristics of other prototype buildings are described in Goel et al.[7] Models that represent typical commercial buildings in Canada are not available in the public domain; therefore, the DOE prototypes were also used there.

The calculator's current database includes 52 U.S. cities and five Canadian cities. The selection of cities was based on a reasonable distribution of major metropolitan areas throughout the U.S.; therefore, not every state or province is represented. If the specific city for which you are interested in obtaining results does not appear on the list, the selection of a city that has similar meteorological conditions (wind, temperature, solar radiation, and rain) is recommended. This is not always the city geographically closest to your target city. Cities in Canada were recommended by our Canadian partners.

Table 2 lists the four levels of airtightness that were assumed to build the simulation database. These include the slab and below-grade enclosure area in the normalization of the air leakage rate, which is why they are referred to as "six-sided enclosures," as well as the assumption that the air leakage is equally distributed over all exterior surfaces. The six-sided value is used in many building codes and standards; however, the CONTAM and EnergyPlus models assume no air leakage through the exterior enclosure that is not exposed to ambient air. The baseline value in *Table 2* was calculated using the average leakage rate for commercial buildings reported by Emmerich et al.[3] of 9 L/s·m^2 (1.77 CFM/ft^2) at 75 Pa for a five-sided enclosure. The baseline of 5.4 L/s·m^2 (1.06 CFM/ft^2) at 75 Pa was obtained by multiplying the average leakage rate by the five-sided to six-sided enclosure area ratio of the standalone retail building prototype. Similar ratios were applied to the other prototypical building types. *Table 2* also lists three target levels for improved airtightness at 75 Pa: 2 L/s·m^2 (0.39 CFM/ft^2) is the whole building option in the 2015 International Energy Conservation Code;[20] 1.25 L/s·m^2 (0.25 CFM/ft^2) is the airtightness required by the U.S. Army Corps of

Case	Air Leakage Rate at 75 Pa (L/s·m^2)	Air Leakage Rate at 75 Pa (CFM/ft^2)	Reference
Baseline	5.4	1.06	[3]
1	2.0	0.39	[17]
2	1.25	0.25	[18]
3	0.25	0.05	[1]

Table 2 – Assumed building enclosure airtightness levels for a six-sided enclosure (standalone retail building).

Engineers;[21] and 0.25 L/s·m² (0.05 CFM/ft²) is the leakage rate targeted by the DOE buildings enclosure roadmap.[1]

Emmerich and Persily[14] analyzed the NIST U.S. commercial building air leakage database and found that the 79 buildings categorized as having an air barrier had an average six-sided leakage of 1.39 L/s·m² (0.27 CFM/ft²) at 75 Pa, which was 70 percent below the average leakage of the 290 buildings without an air barrier (i.e., 4.33 L/s·m² or 0.85 CFM/ft² at 75 Pa) and is similar to the second target level above. Zhivov et al.[22] reported the average six-sided leakage for a set of 285 new and retrofitted military buildings constructed to the U.S. Army Corps of Engineers (USACE) specifications to be 0.9 L/s·m²(0.18 CFM/ft²).

Air leakage data for the four different airtightness levels were curve fitted for each building type and geographical location. The calculator will interpolate between the baseline six-sided air leakage and the tightest level of 0.25 L/s·m² (0.05 CFM/ft²) at 75 Pa to any intermediate air leakage value. Extrapolation should not be used because the curve fits are non-linear and not validated beyond the cited endpoints.

To convert energy savings into an economic benefit, the user has the option to either select the default value for energy prices from the following sources or to input their own electricity and natural gas prices. Electricity and natural gas prices were collected from numerous sources. Prices for electricity for U.S. cities are maintained by the U.S. Energy Information Administration, and 2016 year-to-date average prices for commercial customers were used in the calculations.[23] For natural gas, average 2015 prices for commercial customers were obtained.[24] Energy prices for Canada were taken from the rates used to develop the National Energy Code of Canada for Buildings 2011.[25] The calculator does not account for demand charge savings. Updates in the default energy prices are planned for the next update cycle.

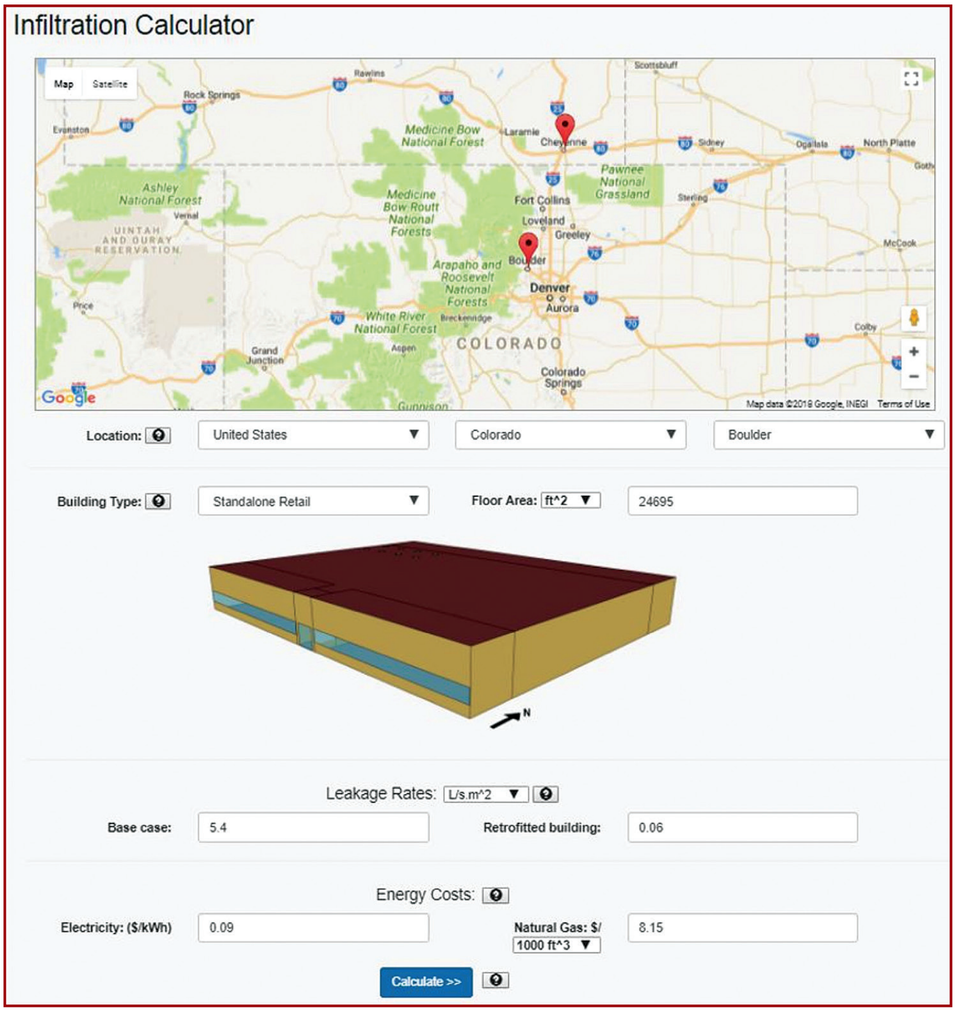

Figure 3 – Input page for the Energy Savings and Moisture Transfer Calculator.

THE WEBSITE

Figure 3 depicts the input page of the Energy Savings and Moisture Transfer Calculator. The user decides whether to input data and see results in the metric system or in traditional imperial units. One is then prompted to select a geographical location. This selection can be made either by using drop-down menus or by manipulating the map screen. Cities included in the database are highlighted with red flags on the map. The user then selects the commercial building type from the drop-down menu. He/she selects from the following list of building types: standalone retail, mid-rise apartment, medium office, high-rise apartment, hospital, large hotel, or secondary school. Once selected, the default footprint of the building is displayed. This footprint can be changed to any other size. The calculator determines the annual energy savings and moisture transport per square foot of wall area and will adjust the results based on different footprints. The user is then prompted to input two levels of airtightness: the baseline and the target air leakage after completing the air barrier retrofit. The calculator will assess the energy savings, economic, and moisture transport differences between these two set levels. Recommendations can be obtained by pressing the "Help" button. Energy costs are input when the user selects the city for evaluation. State or provincial energy costs for electricity and natural gas are input from the database. However, if the user has better energy costs, one can input them in lieu of the default state and provincial values. Then you can press "Calculate" and...

The output screen is shown in *Figure 4*. A summary of the user selections is posted at the top of the page. The calculator determines the equivalent leakage area (ELA) for the baseline case and the improved airtight construction, along with the amount of energy saved and the total savings in the appropriate currency. The ELA is defined as the area of a sharp-edged orifice that would leak the same amount of air as the building does at a pressure of 10 Pa. Finally, the calculator computes the total amount of moisture that would be transported through the enclosure into the building interior space for both the baseline and retrofit cases.

SUMMATION

An online airtightness calculator has been developed to estimate the energy and economic benefits of an air barrier system along with its contribution to reducing the potential moisture load that a building enclosure must endure. The tool uses a database of EnergyPlus pre-run simulation results for DOE commercial prototype buildings and is simply computing the total amount of water that is transported through the building enclosure component due to air leakage. This calculator is different from other common methods used in enclosure analysis in that it uses hourly air leakage rates that are estimated by considering key variables such as building leakage rate, weather conditions, and HVAC operation. The calculator provides energy cost estimates as a function of building enclosure airtightness for DOE commercial prototype buildings in cities in the U.S. and Canada. The calculator is a powerful, credible, and easy-to-use tool that designers and contractors can utilize to estimate the energy and financial savings that building owners could achieve by reducing air leakage and the improved durability they could attain by reducing the potential moisture load.

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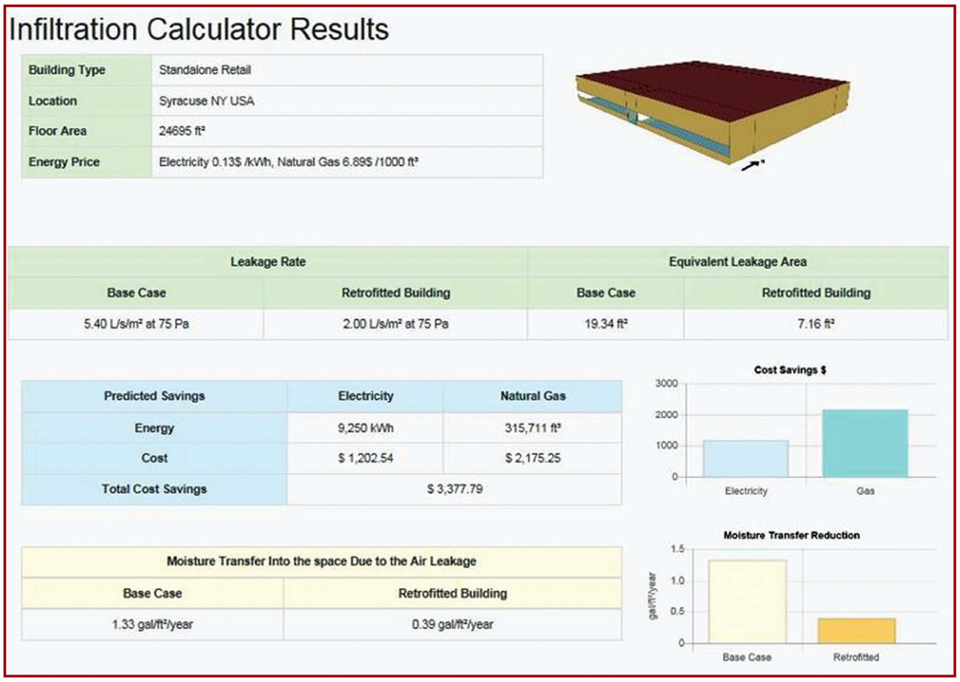

Figure 4 – Output page for the Energy Savings and Moisture Transfer Calculator.

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André Desjarlais is the program manager for the Building Envelope and Urban Systems Research Program at the Oak Ridge National Laboratory in Oak Ridge, TN. Areas of expertise include building enclosure and material energy efficiency, moisture control, and durability. Desjarlais is a founding director of the RCI Foundation. He has been a member of ASTM since 1987 and was awarded the title of Fellow in 2011. He has also been active in ASHRAE since 1991.


Som Shrestha

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Laverne Dalgleish has been involved in the construction industry for over 30 years and has specialized in energy efficiency of building enclosures. He has been involved with the International Organization for Standardization (ISO) and has participated in building research projects with ORNL, Syracuse University, University of Waterloo, and NRC of Canada. He has worked on a number of utility demand-side management programs with various government departments, such as the U.S. DOE, Natural Resources Canada, the EPA, Environment Canada, and Canada Mortgage and Housing Corporation.

AAMA and IGMA to Merge as FIGA

The memberships of the American Architectural Manufacturers Association (AAMA) and the Insulating Glass Manufacturers Alliance (IGMA) have voted to proceed with combining into one organization with a new name: Fenestration and Glazing Industry Alliance (FIGA). They will retain separate brand equity in certain services such as technical standards and certification programs. IGMA was created in 2000 as a result of the merger between the Insulating Glass Manufacturers Association of Canada (IGMAC) and the Sealed Insulating Glass Manufacturers Association (SIGMA). Today, IGMA represents 140 members across North America. AAMA was founded in 1936 and represents over 300 members producing window, door, skylight, glazing, curtainwall, and storefront products and components.