Web-Based Energy Savings Calculator for Building Envelope Air Tightness

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Presentation summary

• Why is air leakage important?
• Web-based tool that estimates energy savings associated with air tightness
• An example
Buildings use a lot of energy

40% of all energy and 75% of all electricity used in the US

Source: US Department of Energy
Windows and Building Envelope R&D ET roadmap
Residential Buildings
• ~1600 TBtu staged energy savings by 2030

Commercial Buildings
• ~800 TBtu staged energy savings by 2030
Develop an air leakage calculator
Objective

• Create an easy-to-use online tool using the simulation results of the best-in-class building energy simulation tool EnergyPlus and the whole building airflow simulation tool CONTAM.

• Online calculator estimates the potential energy and cost savings from improvements in airtightness.

• Further increase market penetration of air barriers.
Calculations flow

Pre-Run Simulations of DOE Commercial Prototype Buildings

Max HVAC/ventilation airflow rates

EnergyPlus
- Envelope airtightness
- Building details
- Weather

CONTAM
- Envelope airtightness
- Building details
- Weather
- HVAC/ventilation airflow rates

Hourly infiltration

EnergyPlus
- Building Details
- Weather
- Hourly infiltration rates from CONTAM

Pre-Run Results
Energy use and cost as a function of envelope airtightness

User Specified
- City
- Building type
- Footprint area
- Before / after retrofit airtightness
- Energy rates

Potential Energy and Cost Savings
Infiltration modeling in EnergyPlus

- `ZoneInfiltration:DesignFlowRate` (used in DOE Commercial Prototype Building Models)
- `ZoneInfiltration:EffectiveLeakageArea` (used in DOE Residential Prototype Building Models)
- `ZoneInfiltration:FlowCoefficient`
- `AirflowNetwork`

Impact of temperature difference, stack effects, and wind direction are ignored.
ZoneInfiltration: DesignFlowRate

\[
Infiltration = \left( I_{\text{design}} \right) \left( F_{\text{schedule}} \right) \left[ A + B \left| T_{\text{zone}} - T_{\text{odb}} \right| + C \left( \text{WindSpeed} \right) + D \left( \text{Windspeed}^2 \right) \right]
\]

- BLAST used the following values as defaults:
  \( A = 0.606, \ B = 0.03636, \ C = 0.1177, \ D = 0 \)
- DOE-2 used the following values as defaults:
  \( A = 0, \ B = 0, \ C = 0.224, \ D = 0 \)
- DOE Commercial Prototype Building Models use
  \( A = 0, \ B = 0, \ C = 0.224, \ D = 0 \)

Impact of temperature difference and wind direction are ignored.
CONTAM

- Continuous development at NIST since 1988 (J Axley, GN Walton, WS Dols, BJ Polidoro, L Wang and DM Lorenzetti)
- Macroscopic/Multizone (Network or Nodal model).
- Calculation of pressures and airflows in whole buildings.
- Simultaneous balance of airflow.
  - Non-linear method to determine node pressures and inter-node airflows.
  - Driving forces: HVAC system flows, wind and stack pressure.
Calculating whole building air change rates

Whole-building air change rates

\[ = 3600 \times \frac{\sum m}{\rho_{air} V_{bldg}} \]

- \( m \) = mass of outside air entering in each zone
- \( \rho_{air} \) = density of entering air
- \( V_{bldg} \) = total volume of building

CONTAM Results Export Tool

Hourly infiltration rates for
EnergyPlus
Comparing results from two methods

HVAC energy cost for a prototype standalone retail building in Winnipeg
Welcome to
Web-Based Energy Savings Calculator for Building Envelope Air Tightness

Uncontrolled heat, air, and moisture transfer through the building envelope has a significant impact on energy usage. A comprehensive strategy for concurrently regulating these factors will have a major impact on reducing energy consumption. The DOE Windows and Building Envelope Research and Development Roadmap for Emerging Technologies shows that in 2010, infiltration was responsible for 4 quads of space conditioning primary energy use in the residential and commercial sectors. In aggregate, infiltration accounted for greater energy losses than any other component of the building envelope, including fenestration and is responsible for over 4 percent of all the energy used in the United States. Furthermore, the Roadmap shows that the payback for the addition of air barrier systems would have a payback that is much less than 5 years.

The Roadmap further states that "computational tools are critically important for the design of commercial buildings with energy efficient envelope materials. As new technologies are developed, models and simulation tools must be updated to account for increased performance." An impediment for the wider adoption of air barrier systems into buildings is the lack of a simple credible tool that can be employed by building architects, designers, and owners that accurately estimates the energy savings that could be expected if an air barrier system was added to the design. This calculator fills this void, is based on the best science available, and is easy to use.

Start your evaluation
Calculator input
The tool: location

The first phase in the development of the calculator analyses the air tightness energy benefits in 52 cities in the US, 5 cities in Canada, and 5 cities in China. Selecting the country unlocks the states or provinces where the air tightness benefits have been determined. Choosing the state or province unlocks the cities within that state that have been evaluated. The selection of cities was based on trying to obtain a reasonable distribution of major metropolitan areas throughout the country; therefore not every state or province is represented. If the specific city you are interested in obtaining results from does not appear on the list, select a city that has similar meteorological conditions (wind, temperature, solar radiation, and rain). This is not always the city geographically closest to your target city.
Proposed cities
The tool: building types

The calculator uses the DOE commercial prototype building models (DOEa 2016). These prototypes were derived from the DOE commercial reference building models (DOEb 2016) and represent about 80% of new construction. Moreover, these prototypes cover 16 commercial building types, including mid- to high-rise residential buildings in 17 climate locations defined in ASHRAE Standard 90.1-2013. The variables that are prescribed in these models include building envelope components, HVAC equipment types and efficiency, and occupancy schedules. As ASHRAE Standard 90.1 evolves, Pacific Northwest National Laboratory modifies these models with input from ASHRAE 90.1 Standing Standards Project Committee members and building industry experts. Features of the building models and a detailed description of their development are provided in the Building Energy Codes Program website (DOEa 2016). Click on the building image to see a summary of these features.

The first phase in the development of the calculator covers three prototype building models: standalone retail, medium office, and mid-rise apartment. Models that represent typical commercial buildings in Canada and China are not available in the public domain; therefore, the DOE prototypes are also used in these two countries.
The tool: floor area

The air leakage calculations have been performed on a building whose size is defined by the DOE commercial prototype building models (DOEa 2016). However, the energy and monetary savings associated with improved air tightness was calculated on a per unit floor area basis. To determine the annual savings of your particular building, the actual floor area can be input into this window in lieu of the default floor area from the prototype building.
### DOE commercial prototype building models (ASHRAE 90.1-2013) used

<table>
<thead>
<tr>
<th>Building</th>
<th>Total Floor Area, ft²</th>
<th>Number of Floors</th>
<th>Construction Volume Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standalone Retail</td>
<td>24,695</td>
<td>1</td>
<td>15.3%</td>
</tr>
<tr>
<td>Mid-Rise Apartment</td>
<td>33,700</td>
<td>4</td>
<td>7.3%</td>
</tr>
<tr>
<td>Medium Office</td>
<td>53,600</td>
<td>3</td>
<td>6.0%</td>
</tr>
<tr>
<td>High-Rise Apartment</td>
<td>84,360</td>
<td>10</td>
<td>9.0%</td>
</tr>
<tr>
<td>Hospital</td>
<td>241,410</td>
<td>5</td>
<td>3.4%</td>
</tr>
<tr>
<td>Large Hotel</td>
<td>122,132</td>
<td>7 (including basement)</td>
<td>5.0%</td>
</tr>
<tr>
<td>Small Hotel</td>
<td>43,200</td>
<td>4</td>
<td>1.7%</td>
</tr>
<tr>
<td>Large Office</td>
<td>498,600</td>
<td>13 (including basement)</td>
<td>3.3%</td>
</tr>
<tr>
<td>Small Office</td>
<td>5,500</td>
<td>1</td>
<td>5.6%</td>
</tr>
<tr>
<td>Outpatient Healthcare</td>
<td>40,950</td>
<td>3</td>
<td>4.4%</td>
</tr>
<tr>
<td>Restaurant Fast Food</td>
<td>2,500</td>
<td>1</td>
<td>0.6%</td>
</tr>
<tr>
<td>Restaurant Sit Down</td>
<td>5,502</td>
<td>1</td>
<td>0.7%</td>
</tr>
<tr>
<td>Stripmall</td>
<td>22,500</td>
<td>1</td>
<td>5.7%</td>
</tr>
<tr>
<td>Primary School</td>
<td>73,960</td>
<td>1</td>
<td>5.7%</td>
</tr>
<tr>
<td>Secondary School</td>
<td>210,900</td>
<td>2</td>
<td>10.4%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>49,495</td>
<td>1</td>
<td>16.7%</td>
</tr>
</tbody>
</table>
## Standalone retail building specs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area (m$^2$)</td>
<td>2300 (Length 54.3 m × width 42.4m)</td>
</tr>
<tr>
<td>Number of floors</td>
<td>1</td>
</tr>
<tr>
<td>Floor to ceiling height (m)</td>
<td>6.1</td>
</tr>
<tr>
<td>Window-to-wall ratio (%)</td>
<td>25.4</td>
</tr>
<tr>
<td>Windows on south-facing façade</td>
<td></td>
</tr>
<tr>
<td>Building Envelope</td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>20.3 cm concrete masonry block + insulation per ASHRAE 90.1 + 1.3 cm drywall</td>
</tr>
<tr>
<td>Roof</td>
<td>Roof membrane + insulation per ASHRAE 90.1 + metal decking</td>
</tr>
<tr>
<td>Window U-factor and SHGC</td>
<td>Per ASHRAE 90.1</td>
</tr>
<tr>
<td>Foundation</td>
<td>15.2 cm concrete slab-on-grade + insulation per ASHRAE 90.1</td>
</tr>
</tbody>
</table>
| Air leakage rates for prototype buildings (not used in the present study) | HVAC off = 1 L/s-m$^2$ at 75 Pa  
HVAC on = 25% of HVAC off rate = 0.25 L/s-m$^2$ at 75 Pa |
| HVAC                                                |                                                                             |
| Heating type                                        | Gas furnace inside the packaged air conditioning unit                       |
| Cooling type                                        | Packaged air conditioning unit                                             |
| Size                                                | Autosized to design day                                                    |
| Efficiency                                          | Based on climate location and design cooling/heating capacity and ASHRAE 90.1 requirements |
| Thermostat setpoint (°C)                            | 23.9 cooling / 21.1 heating                                                |
| Thermostat setback (°C)                             | 29.4 cooling / 15.6 heating                                                |
| Ventilation                                         | Per ASHRAE 62.1                                                             |
The tool: air leakage rates

The user has the option to either select one of the default values listed below or to input their own air leakage rates if they have that information available or want to evaluate the potential energy savings from improved air tightness.

The tool will interpolate between the baseline air leakage rates (5.4 L/s⋅m² (1.06 CFM/ft²) for standalone retail, 6.2 L/s⋅m² (1.22 CFM/ft²) for medium office, and 6.7 L/s⋅m² (1.33 CFM/ft²) for mid-rise apartment) and 0.25 L/s⋅m² (0.049 CFM/ft²) at 75 Pa. No extrapolation is allowed.

The following table lists the four levels of airtightness that were assumed in the simulations. These include the slab and below-grade envelope area in the normalization of the air leakage rate, which is why they are referred to as 6-sided envelopes, as well as the assumption that the air leakage is equally distributed over all exterior surfaces. The 6-sided value is used in many building codes and standards; however, the CONTAM and EnergyPlus models assume no air leakage through the exterior envelope that is not exposed to ambient air.
### The tool: air leakage rates

<table>
<thead>
<tr>
<th>Case</th>
<th>Air Leakage Rate at 75 Pa (L/s·m²)</th>
<th>Air Leakage Rate at 75 Pa (CFM/ft²)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>5.4</td>
<td>1.06</td>
<td>Emmerich et al (2005)</td>
</tr>
<tr>
<td>1</td>
<td>2.0</td>
<td>0.39</td>
<td>IECC (2015)</td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
<td>0.25</td>
<td>USACE (2012)</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>0.049</td>
<td>DOE (2014)</td>
</tr>
</tbody>
</table>

Emmerich and Persily (2014) 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 6-sided leakage of 1.39 L/s·m² (0.27 CFM/ft²) at 75 Pa, which was 70% 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. Zhivov (2013) reported the average 6-sided leakage for a set of 285 new and retrofitted military buildings constructed to the USACE specifications to be 0.9 L/s·m² (0.18 CFM/ft²).
The tool: energy costs

The user has the option to either select the default value for energy prices from the following references or to input their own electricity and natural gas prices.

Electricity and natural gas prices were collected from numerous sources. Prices for electricity for US 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 (EIA, 2016a). For natural gas, average 2015 prices for commercial customers were obtained (EIA, 2016b). Energy prices for Canada were taken from the rates used to develop the National Energy Code of Canada for Buildings 2011 (NECB 2011). 2015 electricity costs for China were obtained from Chinese sources.
Infiltration Calculator

Location: Canada

Building Type: Standalone Retail

Floor Area (ft²): 24692

Leakage Rates (L/s.m² at 75 Pa)

Base case: 5.4

Retrofitted building: 2.0

Energy Costs

Electricity (C$/kWh): 0.14

Natural Gas (C$/m³): 0.16
Predicted Savings

14750 kWh Electricity and 19220 m³ Natural Gas
C$2048 Electricity and C$3085 Natural Gas
Preliminary results - Shanghai

HVAC Energy Cost, Shanghai

\[ y = 308.1x^2 + 100.98x + 83307 \]
\[ R^2 = 0.9954 \]

HVAC energy cost for a prototype standalone retail building in Shanghai
Preliminary results - Chicago

HVAC Energy Cost, Chicago

\[ y = 96.5x^2 + 139.99x + 8878.2 \]

\[ R^2 = 0.9997 \]

HVAC energy cost for a prototype standalone retail building in Chicago

y-axis: Thousands
x-axis: $\text{Leakage Rate, L/s.m}^2 @ 75 \text{ Pa}$
Preliminary results - Winnipeg

**HVAC Energy Cost, Winnipeg**

\[ y = 171x^2 + 239x + 10,686 \]

\[ R^2 = 1 \]

HVAC energy cost for a prototype standalone retail building in Winnipeg
Acknowledgments

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- Gina Accawi, ORNL
References

- DOE Commercial Prototype Building Models
  https://www.energycodes.gov/commercial-prototype-building-models


Discussion

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