# Online Airtightness Savings Calculator for Commercial Buildings in the US, Canada and China


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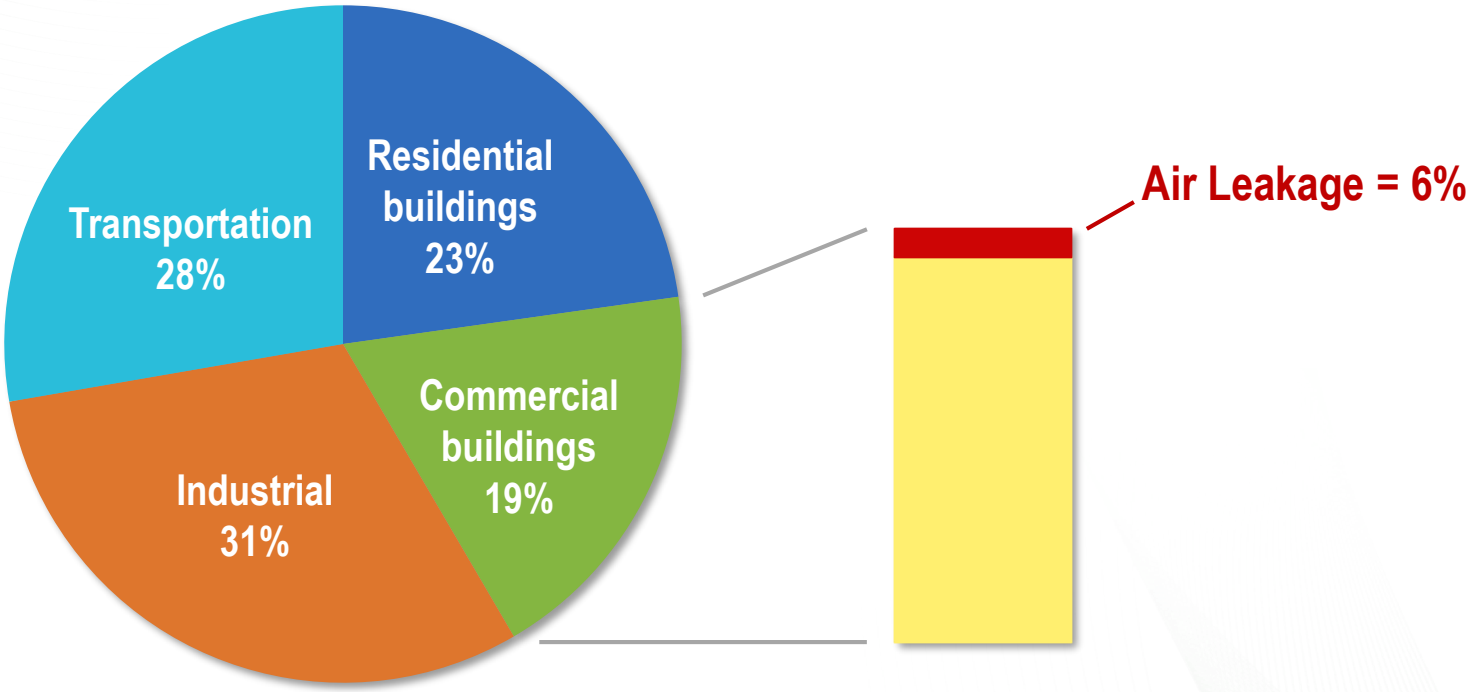
# Background

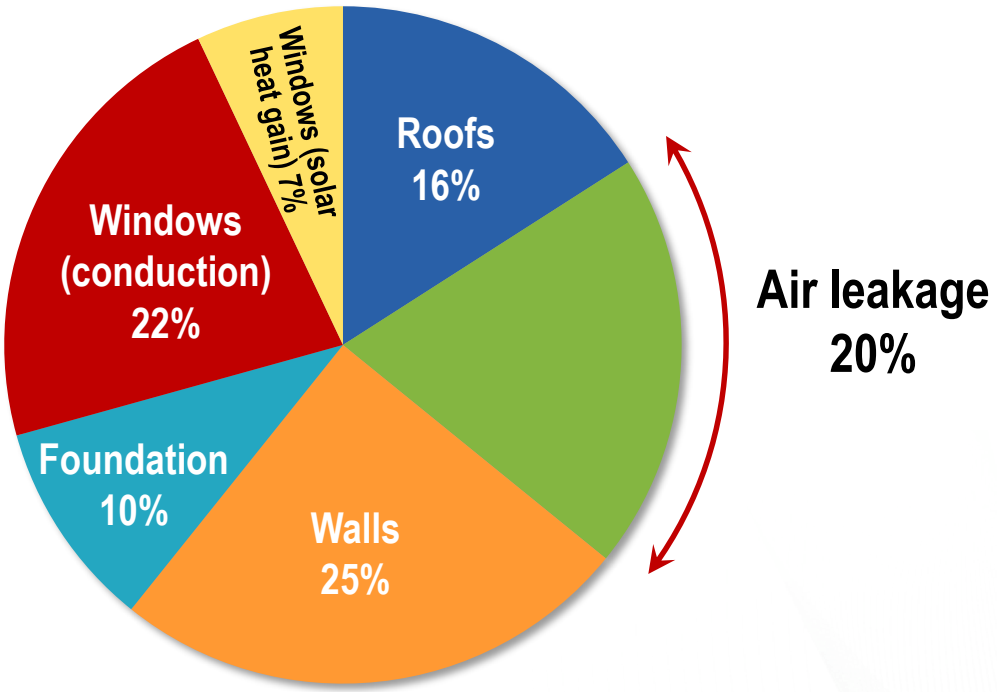
# US Primary Energy Consumption

## Commercial buildings use ~19% of the primary energy




***Source:*** *Windows and Building Envelope R&D: Roadmap for Emerging Technologies, U.S. DOE Building Technologies Office, Feb. 2014*

# Commercial Building Envelope Primary Energy Use




***Source:*** *Windows and Building Envelope R&D: Roadmap for Emerging Technologies, U.S. DOE Building Technologies Office, Feb. 2014*

# Windows and Building Envelope R&D ET Roadmap


| Envelope Technology | Sector |
|---|---|
| **Highest priority R&D areas** | |
| Highly insulating windows | C & R |
| Insulation | C & R |
| Air barriers | C & R |
| **High priority R&D areas** | |
| Dynamic windows and films | C & R |
| Visible light redirection | C |
| Highly insulating roofs | C & R |

R: Residential C: Commercial

# Goals

- Credible, easy-to-use, and free online calculator
- Potential benefits from improved airtightness
  - Calculator → energy and cost savings
  - Other
    - Real estate value
    - Sales
    - Productivity
    - Comfort
- Building owners need compelling reason to invest

# Challenges

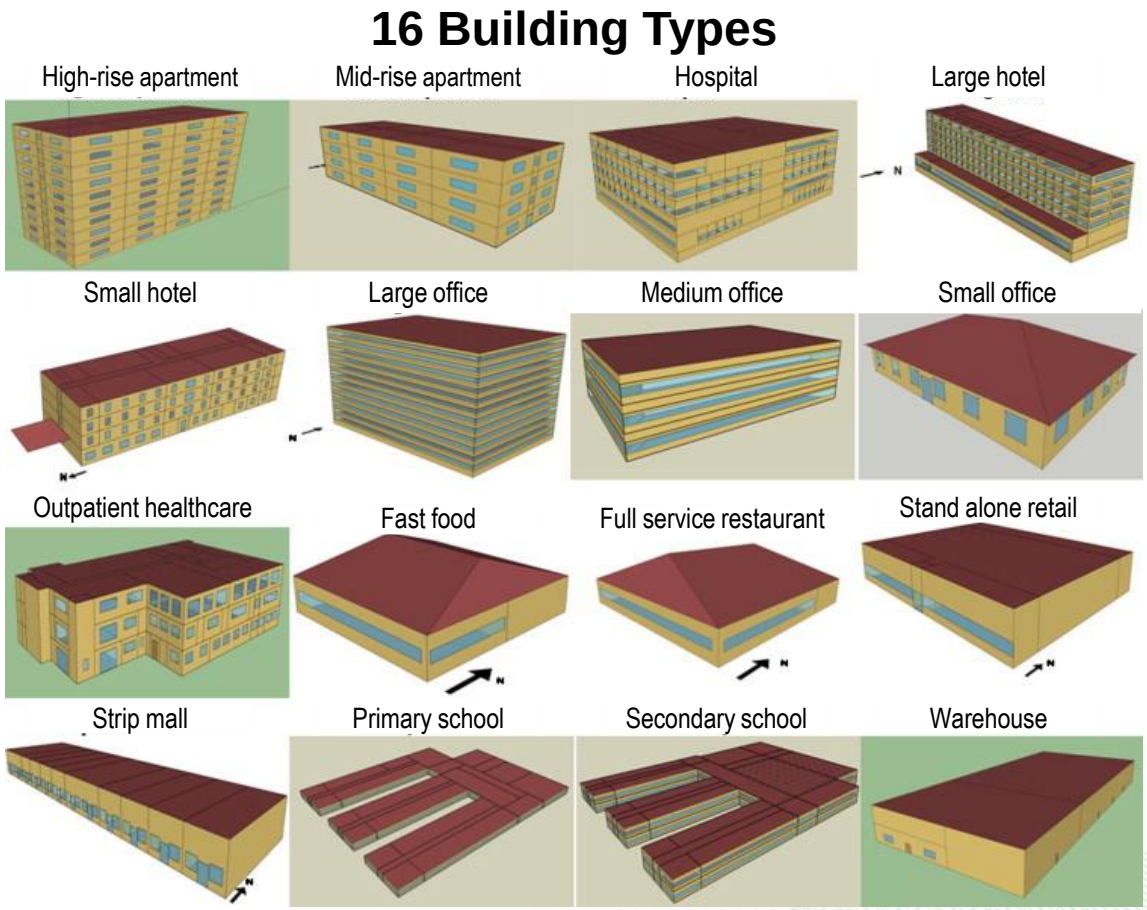
- Air leakage rates depend on multiple variables
  - Envelope airtightness
  - HVAC system operation
  - Occupancy
  - Weather
  - Stack effect
- Typical assumptions
  - Constant leakage rate
  - Leakage rates from simplified algorithms

**Under- or over- estimated energy use**

# Approach

# DOE Commercial Prototype Buildings

- Representative of 80% of new commercial building floor area
- Used specs based on ASHRAE 90.1 – 2013
  - Envelope
  - HVAC system
  - Internal loads
  - Schedules



# Simulation Tools

- Two powerful tools fuel an easy-to-use calculator
- EnergyPlus
  - DOE's flagship whole building energy simulation program
- CONTAM
  - Multizone airflow and contaminant transport analysis software
  - Hourly air leakage rates
    - Weather
    - Envelope airtightness
    - HVAC operation

# Approach
## Hourly Air Leakage Rate Estimates

# Infiltration Modeling in EnergyPlus

- ZoneInfiltration:DesignFlowRate
  - DOE commercial prototype building models
- ZoneInfiltration:EffectiveLeakageArea
  - DOE residential prototype building models
- ZoneInfiltration:FlowCoefficient
- AirflowNetwork
  - Future effort

**Typically**
**do not take into account**

- Temperature difference
- Stack effect
- Wind direction

# ZoneInfiltration:DesignFlowRate
## DOE Commercial Prototype Buildings

$$Air\ leakage\ rate = (I_{design})(F_{schedule})[A + B|T_{zone} - T_{odb}| + C(WindSpeed) + D(WindSpeed^2)]$$

Default values $A = 0$ $C = 0.224$ $D = 0$

$B = 0$ → Does not take into account effects of temperature difference

# ZoneInfiltration:DesignFlowRate
## DOE Commercial Prototype Buildings

$$Air\ leakage\ rate =$$

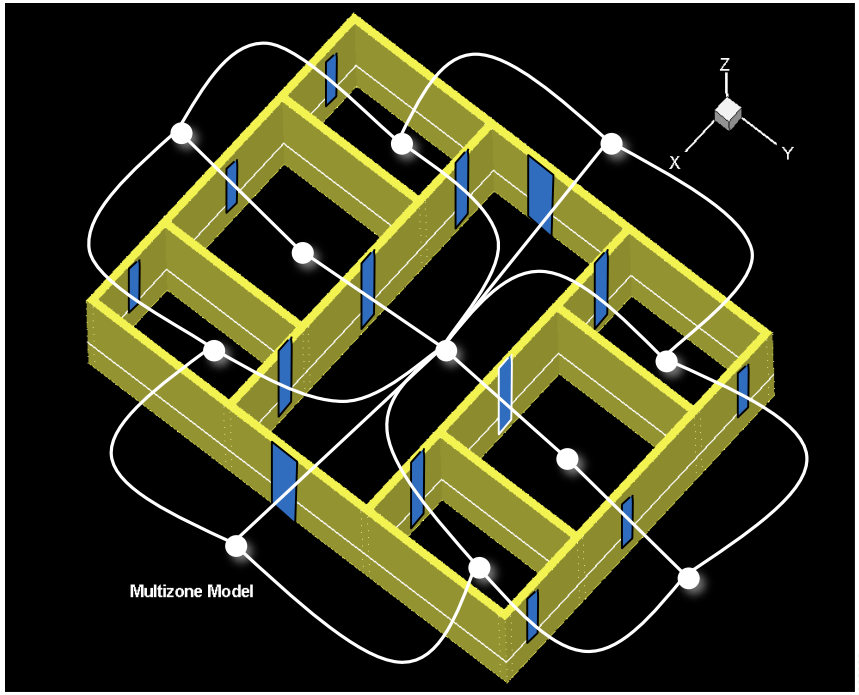
$$(I_{design})(F_{schedule})[A + B|T_{zone} - T_{odb}| + C(WindSpeed) + D(WindSpeed^2)]$$

$I_{design}$ in most DOE prototype buildings building

- Air leakage rate when HVAC is off = 1 L/s·m$^2$ at 75 Pa
- Air leakage rate when HVAC is on = 0.25 L/s·m$^2$ at 75 Pa

# CONTAM

- Continuous development at NIST since 1988
- Multizone software
  - Network or nodal model
  - Pressures and airflows
  - Simultaneous balance of airflow
  - HVAC, wind, stack effect



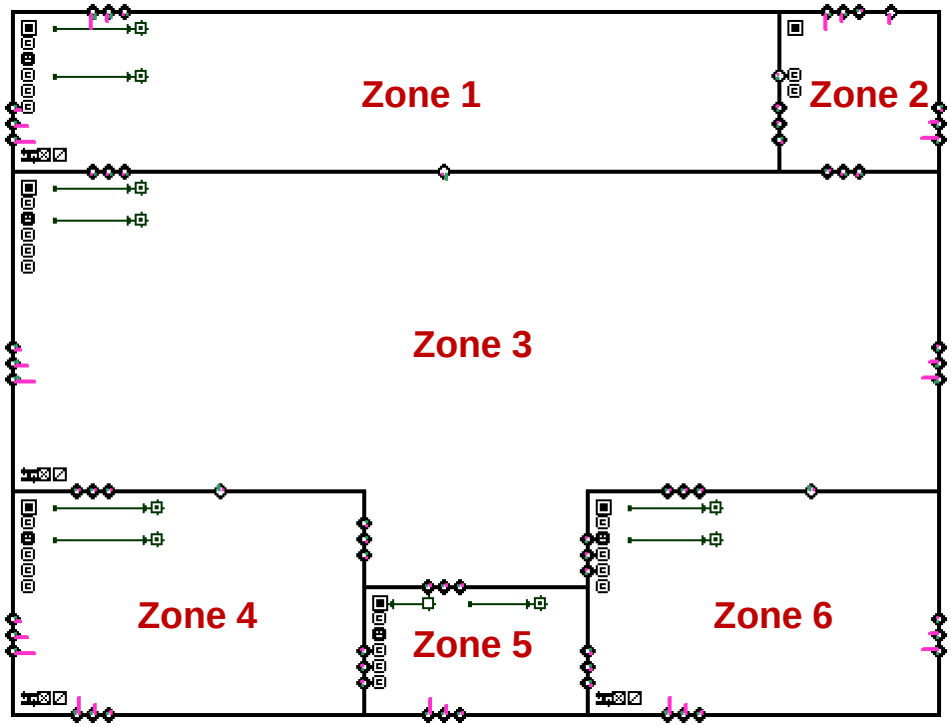
# CONTAM
## Whole Building Air Exchange Rates

$$Whole\ building\ air\ exchange\ rate = \frac{\sum \dot{m}}{\rho_{air} V_{building}}$$

$\dot{m} = mass\ flow\ rate\ of\ outside\ air\ entering\ each\ zone$

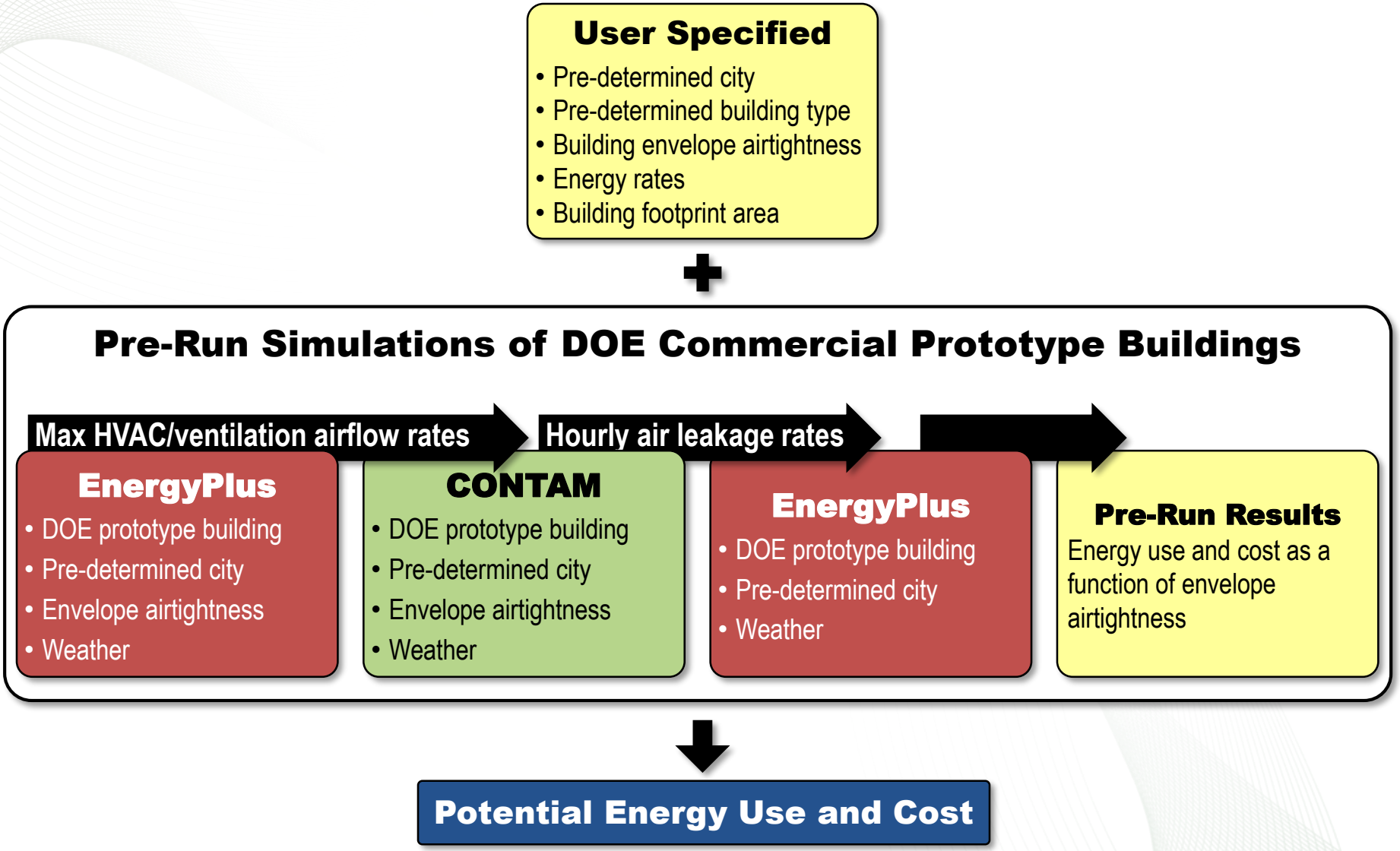
$\rho_{air} = density\ of\ entering\ air$

$V_{building} = total\ volume\ of\ building$



# Approach
## Behind the User-Friendly Interface

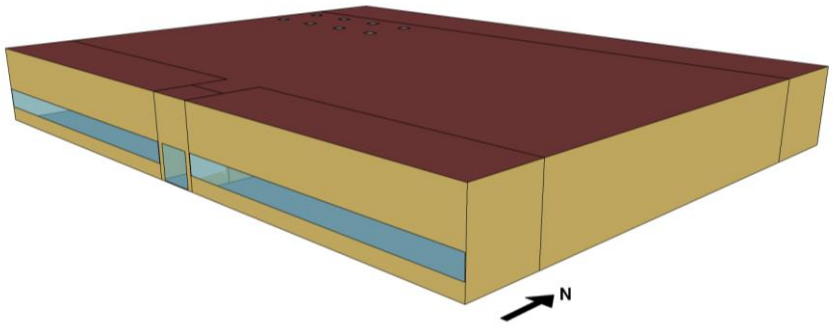
# Calculations Flow

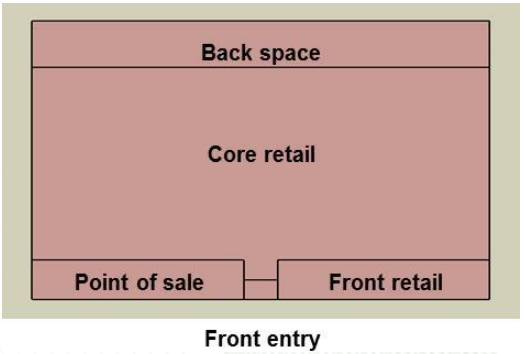


# Example

# Standalone Retail Building Prototype

- Floor area = 2300 $m^2$
- Window-to-wall ratio = 25%
- ASHRAE 90.1 – 2013
  - Envelope insulation
  - HVAC efficiency
- Thermostat setpoint = 23.9°C cooling  21.1°C heating
- Thermostat setback = 29.4°C cooling  15.6°C heating



# Assumed Envelope Airtightness
## 6-Sided Envelope

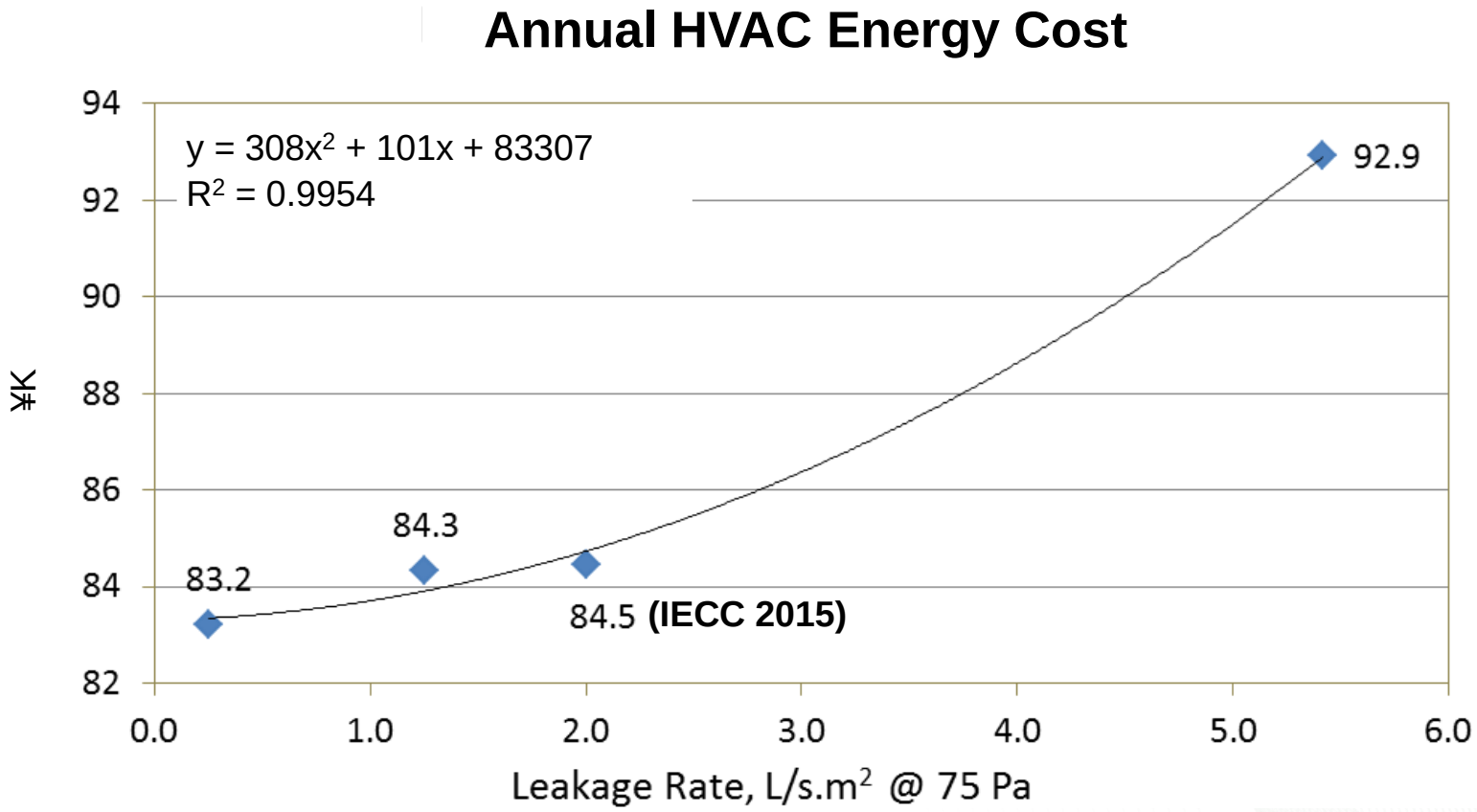
| Case | Air Leakage Rate at 75 Pa ($L/s \cdot m^2$) | Source |
|---|---|---|
| Baseline | 5.4 | Emmerich et al (2005) |
| 1 | 2.0 | IECC (2015) |
| 2 | 1.25 | USACE (2012) |
| 3 | 0.25 | DOE (2014) |

# Evaluated Cities

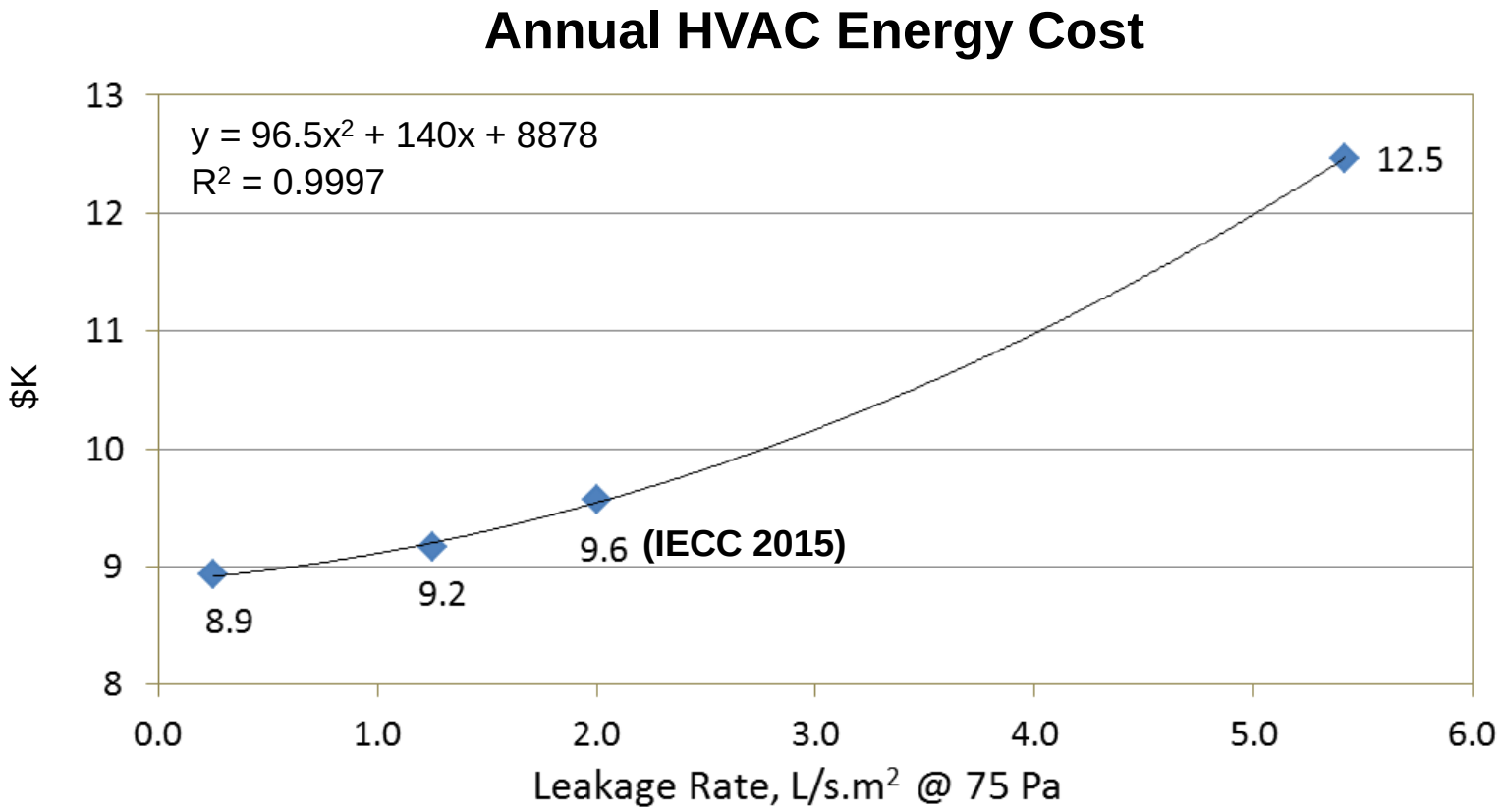
| City | DOE Climate Zone | Prototype Building Model Used in Calculator | Electricity Price | Natural Gas Price |
|---|---|---|---|---|
| Shanghai, China | 3A (warm, humid) | Memphis, TN | $0.0933/kWh[a] | $8.86/1000 ft$^3$ [b] |
| Chicago, IL | 5A (cold, humid) | Chicago, IL | C$0.14/kWh[c] (≈$0.10/kWh) | C$0.1605m$^3$ [d] (≈$3.4/1000 ft$^3$) |
| Winnipeg, Canada | 7 (very cold) | Duluth, MN | ¥0.781/kWh[e] (≈$0.12/kWh) | ¥3.65/m$^3$ [f] (≈$15.9/1000 ft$^3$) |

[a] http://www.eia.gov/electricity/sales_revenue_price/
[b] http://www.eia.gov/dnav/ng/ng_sum_lsum_a_EPG0_PCS_DMcf_a.htm
[c] https://www.ovoenergy.com/guides/energy-guides/average-electricity-prices-kwh.html
[d] http://www.economicdevelopmentwinnipeg.com/uploads/document_file/natural_gas_rates.pdf?t=1433529826
[e] http://news.asean168.com/a/20150413/5318.html
[f] http://gas.gold600.com/

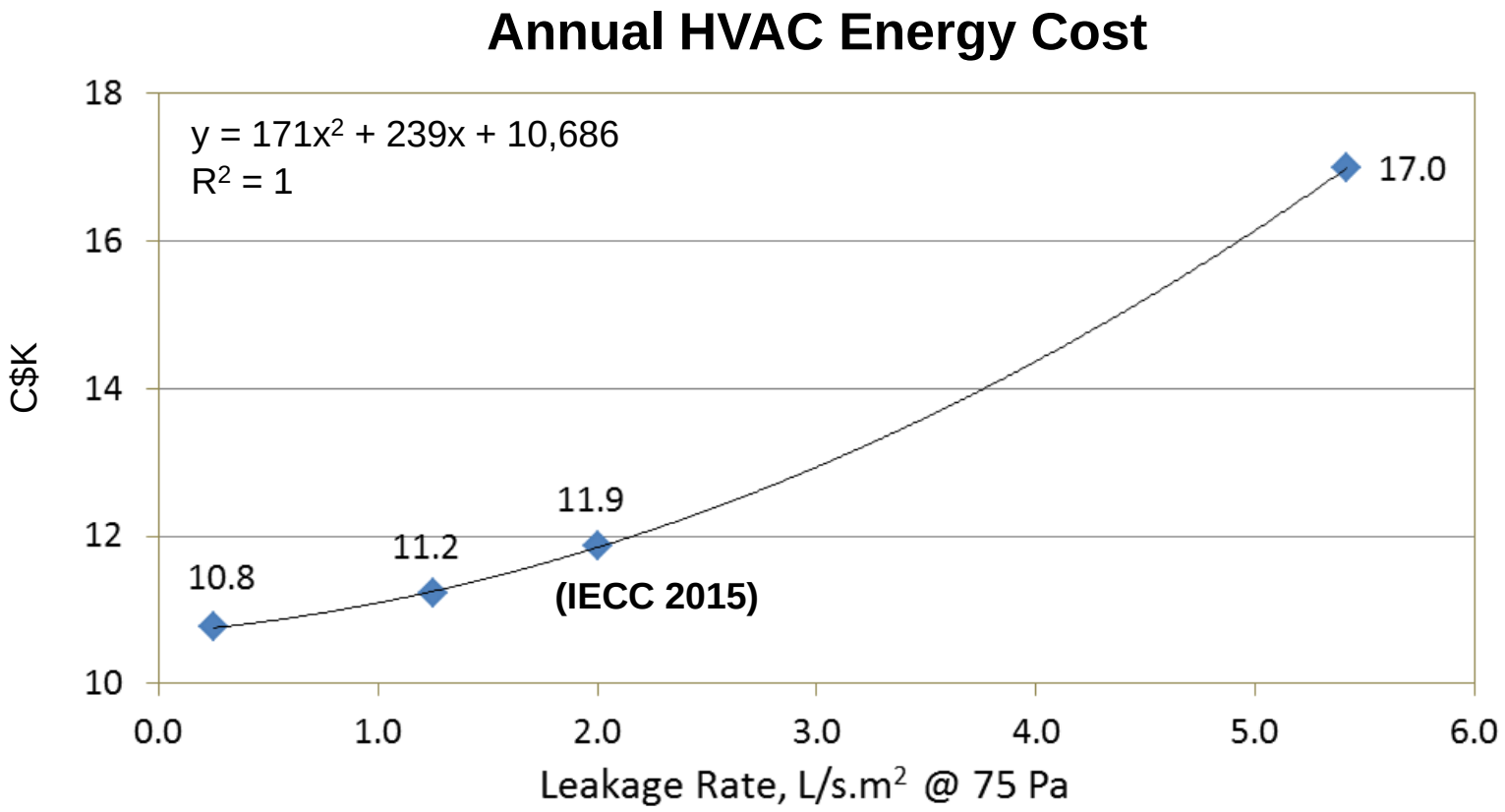
# Preliminary Shanghai Results



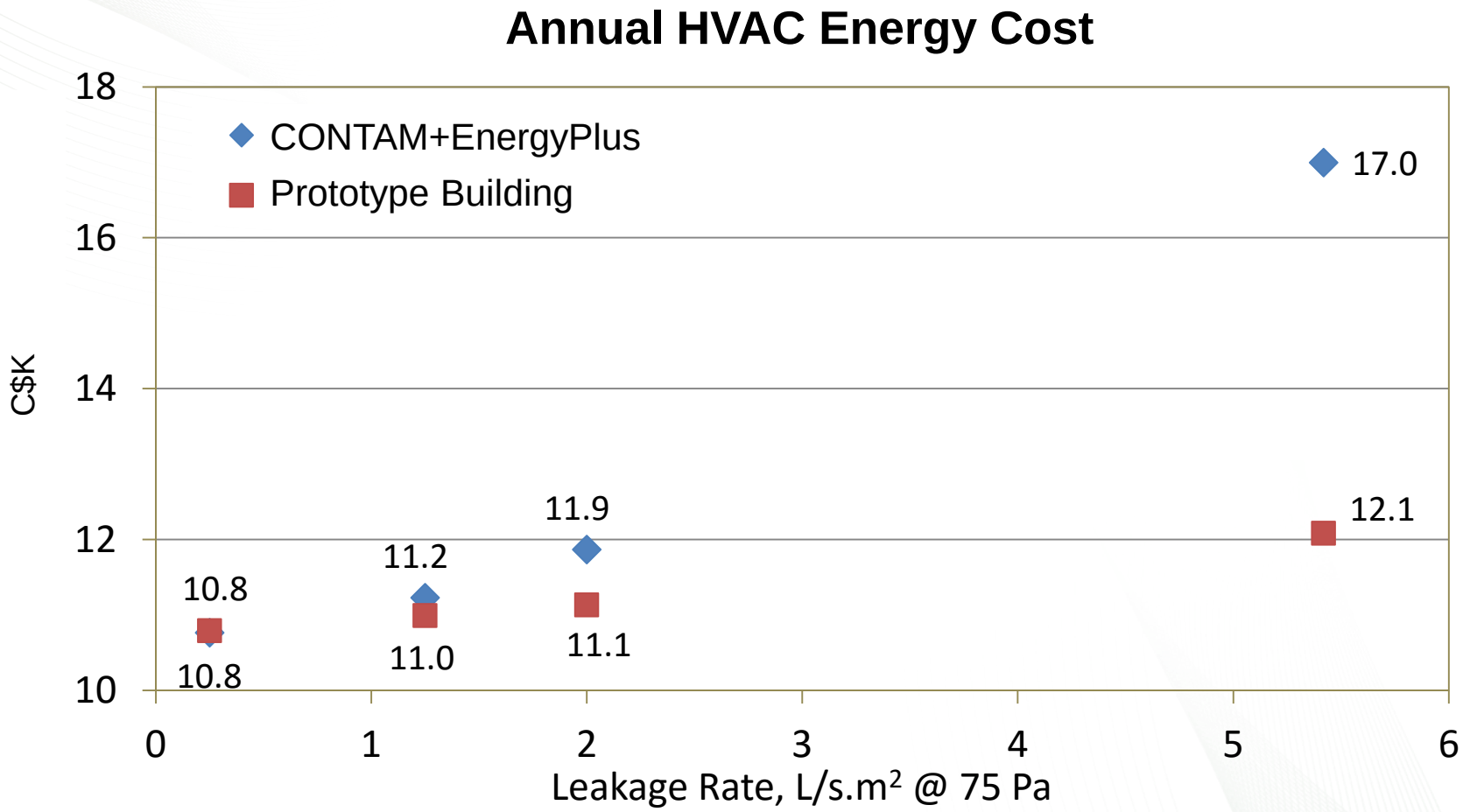
# Preliminary Chicago Results



# Preliminary Winnipeg Results



# Comparison of Winnipeg Results



# Calculator Update – Phase 1

# Locations

- City selection
  - Major metropolitan areas
  - Climate zone
- Cities
  - US = 52
  - Canada = 5
  - China = 5

**Proposed US Cities**

# DOE Commercial Prototype Buildings

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

# Air Leakage and Energy Rates

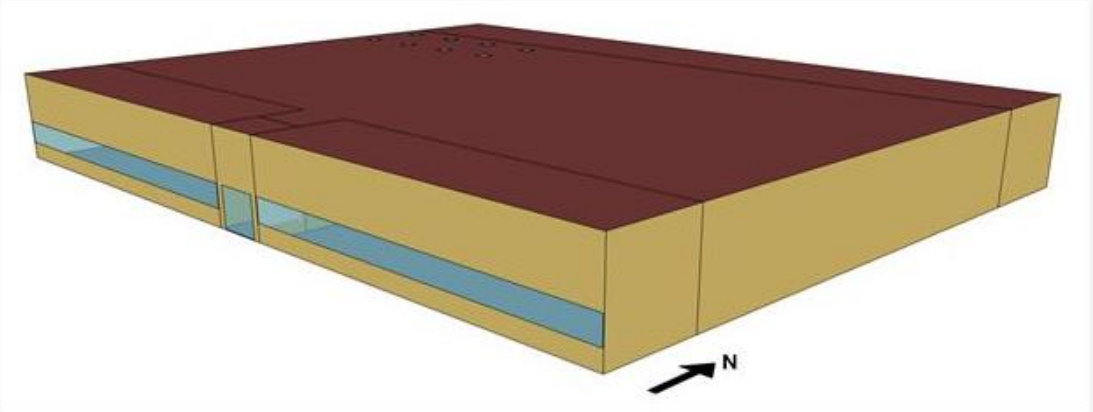
- User selects from default values or enters rates
- Air leakage rates for 6-sided envelope
  - Minimum allowed rate = 0.25 L/s·m$^2$ @ 75 Pa
- Electricity and natural gas prices
  - US:  Energy Information Administration
  - Canada:  National Energy Code of Canada for Buildings 2011
  - China:  various sources

# Summary of Inputs

**Location:** Canada | Manitoba | Winnipeg

**Building Type:** Standalone Retail

**Floor Area ($ft^2$):** 24692




## Leakage Rates ($L/s.m^2$ at 75 Pa)

**Base case:** 5.4

**Retrofitted building:** 2.0

## Energy Costs

**Electricity (C$/kWh):** 0.14

**Natural Gas ($C$/m^3$):** 0.16

Calculate >>

# Calculator Output

## Predicted Savings

14750 kWh Electricity and 19220 $m^3$ Natural Gas

C$2048 Electricity and C$3085 Natural Gas

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# Discussion

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