Estimating the Effects of Energy Conservation on Temperature and Humidity in Buildings

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Where we’re going today

- Energy Conservation Construction Code
- Estimating Heat Energy in Buildings
- Estimating Air Leakage
- Estimating Humidity Levels
- Estimating Thermal Mass
- Estimating Solar Heat Energy
- Review and Conclusions
This is Your House
This is Your House on Energy Codes
I'm Sharon
2010 Energy Conservation Construction Code (ECCC)

• Chapter 1 General Requirements
• Chapter 2 Definitions
• Chapter 3 Climate Zones, Design Conditions, Materials, Equipment and Systems
• Chapter 4 Residential Energy Efficiency
• Chapter 5 Commercial Energy Efficiency
• Chapter 6 Referenced Standards
ECCC Intent §101.3

• ...regulate the design and construction of buildings for the effective use of energy...
• ...use innovative approaches...
• ...the improvement of construction practices, methods, equipment, materials and techniques shall be encouraged...
ECCC §102 Alternate Materials, Methods, Designs, Systems

• ...this code is not intended to prevent the use of any material, method of construction, design or insulating system...

• ...provided it has been approved by the code enforcement official:
  – ...meets the intent of the ECCC
  – ...achieves equivalent or greater energy savings
Climate Zones Table 301.1

# Residential Insulation

## Table 402.1.1

<table>
<thead>
<tr>
<th>CLIMATE ZONE</th>
<th>CEILING R-VALUE</th>
<th>WOOD FRAME WALL R-VALUE</th>
<th>FLOOR R-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>38</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>38</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>49</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

R-value

• A measure of the resistance of building materials and structures to the flow of heat:

\[ R = \frac{T(\degree F)_\text{diff} \times \text{Area}(ft^2) \times \text{time}(hr)}{\text{heat_loss}(\text{BTU})} \]

• The higher the R-value the better the thermal insulation.
U-value

• The coefficient of transmission of heat through building materials and systems;

\[
U = \frac{1}{R}
\]

• The lower the U-value the better the thermal insulation.
  – to convert Imperial (Btu.°F^{-1}.ft^{-2}.hr^{-1}) to metric units
  – multiply U by 5.678 (W.m^{-2}.K^{-1})
Assembly R-value

• A measure of the resistance of assembled structures to the flow of heat;

\[ R_{Assembly} = \frac{1}{U_{Assembly}} = \frac{1}{\sum (U_i \times i\%)} \]

\[ U_i = \frac{1}{R_i} \]

• Where \( i \) is the individual component of an assembly (e.g. studs in a wall)
Zone 5 House on ECCC 2010

R-38 Ceiling

50 x 30 x 9 feet
Volume = 13500 ft³
Floor Area = 1500 ft²
Ceiling Area = 1500 ft²
Wall Area = 1440 ft²

R-20 Walls

R-30 Floor
Assembly R-value

- $U = \frac{1}{38}$, $i = \frac{1500}{4440}$
- $U = \frac{1}{20}$, $i = \frac{1440}{4440}$
- $U = \frac{1}{30}$, $i = \frac{1500}{4440}$

50 x 30 x 9 feet
- Volume = 13500 ft$^3$
- Floor Area = 1500 ft$^2$
- Ceiling Area = 1500 ft$^2$
- Wall Area = 1440 ft$^2$

$U = \frac{1}{30}$, $i = \frac{1500}{4440}$
Estimate Assembly R-value

\[ R_{\text{Assembly}} = \frac{1}{U_{\text{Assembly}}} = \frac{1}{\sum(U_i \times i\%)} \]

<table>
<thead>
<tr>
<th>Component</th>
<th>R</th>
<th>i%</th>
<th>( U_i )</th>
<th>( U_i \times i% )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>38</td>
<td>33.8%</td>
<td>0.0263</td>
<td>0.00889</td>
</tr>
<tr>
<td>Floor</td>
<td>30</td>
<td>33.8%</td>
<td>0.0333</td>
<td>0.01127</td>
</tr>
<tr>
<td>Walls</td>
<td>20</td>
<td>32.4%</td>
<td>0.0500</td>
<td>0.01620</td>
</tr>
<tr>
<td>( \Sigma(U_i \times i%) )</td>
<td></td>
<td></td>
<td></td>
<td>0.03636</td>
</tr>
<tr>
<td>R-Assembly</td>
<td></td>
<td></td>
<td></td>
<td><strong>27.5</strong></td>
</tr>
</tbody>
</table>
Average Heat Loss in January (Albany Zone 5)

\[
\frac{\text{heat_loss (BTU)}}{\text{time (hr)}} = \frac{T(°F)_{\text{diff}} \times \text{Area (ft}^2)}{R_{\text{value}}}
\]

- Assume \( T_{\text{diff}} = 70 - 21 = 49°F \)
  - Interior Design Temperature is 70°F
  - Albany January Average Daily Temperature is 21°F
- Estimated Assembly R-value = 27.5
- Assume Insulated Area = 4440 ft\(^2\)
  - no windows, no doors, no thermal bridges...

Average Heat Loss = 7911 BTU/hr
ECCC §402.4 Air Leakage (Mandatory)

- The Building Thermal Envelope shall be durably sealed
- Sealing materials shall allow for differential expansion and contraction
- Caulk, gasket, weatherstrip
ECCC §402.4.1 Building Thermal Envelope

1. All joints, seams and penetrations.
2. Site-built windows, doors and skylights.
3. Openings between window and door assemblies.
5. Dropped ceilings or chases adjacent to the thermal envelope.
7. Walls and ceilings separating a garage from conditioned spaces.
8. Behind tubs and showers on exterior walls.
9. Common walls between dwelling units.
10. Attic access openings.
11. Rim joist junctions.
12. Sill plates and headers.
13. Other sources of infiltration.
Air Sealing §402.4.2.1

- Blower door test (ASHRAE/ASTM E779)
- Acceptable air leakage is less than 7 ACH at 50 Pascal
- Natural air leakage is estimated by*:

\[
\frac{7ACH_{50}}{20} = 0.35ACH
\]

Sensible Heat Loss

\[ h_s = 1.08(q \cdot dt) \]

\( q = \text{air volume flow (cfm)} \)
\( = (0.35 \times 13500)/60 = 79 \text{ cfm} \)

\( dt = \text{temperature difference (°F)} = 49°F \)

\( h_s = \text{sensible heat (BTU/hr)} \)
\( = 1.08 \times (79 \times 49) = 4181 \text{ BTU/hr} \)

Latent Heat Loss

\[ h_l = 4840(q \cdot dw_{lb}) \]

q = air volume flow (cfm)
\[ = (0.35 \times 13500)/60 = 79 \text{ cfm} \]

dw_{lb} = humidity ratio difference
(lb water/lb dry air) = 0.006 – 0.002 = 0.004

h_l = latent heat (BTU/hr)
\[ = 4840 \times (79 \times 0.004) = 1529 \text{ BTU/hr} \]

Average Heat Loss (Winter)

- Insulation heat loss = 7911 BTU/hr
- Sensible heat loss = 4181 BTU/hr
- Latent heat loss = 1529 BTU/hr

Average Heat Loss = 13,621 BTU/hr

- Assembly R-value = 27.5
- Indoor Temperature = 70°F
- Average Temperature (Albany in January) = 21°F
- 7 ACH$_{50}$ = 0.35 ACH
Estimated Hot Air Supply

\[ L = \frac{Q}{1.08 \times (t_h - t_r)} \]

Q = 13,621 BTU/hr

\( t_h = 105 \ °F \)

\( t_r = 70 \ °F \)

\[ L = 360 \ cfm \]
Required Outdoor Ventilation Air

- NY Mechanical Code: Table 403.3
  - 0.35 Air Changes per Hour (ACH)
- ACH x Bldg Volume = Outdoor Air Supply
- \(0.35/\text{hr} \times 13500 \text{ ft}^3 = 4725 \text{ ft}^3/\text{hr} = 79 \text{ cfm}\)

**Estimated Outdoor Air = 79 cfm**

- And from the previous calculation:
  - Indoor Air Recirculated = 360-79 = 281 cfm
Mixing Indoor and Outdoor Air

\[ x_B = \frac{(Q_A x_A + Q_C x_C)}{(Q_A + Q_C)} \]

• \( x_B \) Humidity ratio of mixed air

• Outdoor Air \( Q_A = 79 \text{ cfm} \)
  \[ x_A = 0.00232 \text{ (at 21°F and 100%RH)} \]

• Indoor Air \( Q_C = 281 \text{ cfm} \)
  \[ x_C = 0.00613 \text{ (at 70°F and 40%RH)} \]

• Mixed air \( x_B = 0.00537 \)
Mixing Indoor and Outdoor Air

• Humidity ratio $x_B = 0.00537$
  - 11% RH in heated air at 105°F
  - Approximately 35% RH in room at 70°F

• 0.35 ACH decreases RH in room air
  - Humidity ratio $\rightarrow 0.00232$
  - At 70°F, $x_B = 0.00232$ yields 15% RH
  - Minimum RH is reached within 24 hours

Degradation of Humidity Ratio

Humidity ratio vs. time (hours)
Low RH, Dust, IAQ Complaints

- Dry air removes surface moisture causing static charge.
- Dust deposits on charged surfaces.
- “Dirty ventilation ducts”
Enhancing this Model

- Modeled energy ‘losses’ of a conceptual building following ECCC
  - Table 402.1.1 – insulation requirements
  - §402.4.2 – air sealing and insulation
- How does moisture affect our model?
- Is energy “lost” through the building envelope?
Quantity of Moisture Added to the Air

An average family of 4 will generate about 14 gallons (53 liters) per week through normal household activities

- *Keeping the Heat In. How Your House Works.* Natural Resources Canada 2009

<table>
<thead>
<tr>
<th>Activity</th>
<th>Gallons (liters) per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
<td>1.7 (6.3)</td>
</tr>
<tr>
<td>Dishwashing</td>
<td>0.8 (3.2)</td>
</tr>
<tr>
<td>Bathing/Showering</td>
<td>0.6 (2.4)</td>
</tr>
<tr>
<td>Clothes washing</td>
<td>0.5 (1.8)</td>
</tr>
<tr>
<td>Normal respiration and skin evaporation from 4 occupants</td>
<td>10 (38)</td>
</tr>
</tbody>
</table>
Estimate Rate of Change of %RH

• 14 gallons per week $\rightarrow$ 0.695 lbs/hr
• Building Air Volume is 13,500 ft$^3$ at 0.075 lb/ft$^3$
  ➢ Humidity ratio increases 0.0007 (lbs/lbs) per hour
• No air leakage, RH reaches 100% in 14 hours

• In our Winter model, RH equilibrates around 37% in 19 hours
Humidity Ratio with Indoor Moisture Sources

Humidity ratio vs. time (hours)
Moisture and Health

• Ideal situation
  • Moisture In = Moisture Out

• Winter situation (Indoor RH% < 20%)
  • Relative Humidity stays low
  • Skin, eye, sinus irritations and health complaints

• Humid situation (Indoor RH% > 60%)
  • Poor air exchange – stuffy, odors, fatigue
  • Condensation – visible water damage, mold
The Building Envelope

• It is not a perfect barrier
  – Permeable to air, moisture, and light
• It gains and loses heat energy
  – Thermal Mass
• It gains and loses moisture
  – Wetting and Drying
Convenient Energy Assumptions

• Buildings are heated and cooled by convection
• Insulated surfaces have no heat capacity
• All aspects of the building have the same exterior exposures
Heat Energy in Buildings

- **Convection** – Heating and cooling is supplied by hot or cold air moving into the building

- **Conduction** – Heat energy is lost or gained by conduction through the building frame

- **Radiation** – Heat energy is lost or gained by radiation through glazing and onto roofs
Heat Capacity and Thermal Mass

• Thermal Mass is the ability of a substance to hold heat energy (§402.2.4 Mass walls)

• High Thermal Mass comes from →
  – High Heat Capacity
  – High Density
  – Low Conductivity
  – Low Reflectivity (“Albedo”)

• Thermal Mass is NOT the same as Insulation

## Thermal Mass vs. Insulation

<table>
<thead>
<tr>
<th></th>
<th>Styrofoam</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific Heat Capacity</strong></td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td><em>(Btu/lb m.°F)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td><em>(lb/ft³)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heat Conductivity (κ)</strong></td>
<td>0.02</td>
<td>0.5</td>
</tr>
<tr>
<td><em>(Btu/ft.hr.°F)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reflectivity (Albedo)</strong></td>
<td>0.7</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Thermal Mass of a Solid Wall

Area = 270 ft$^2$
Volume = 135 ft$^3$

Concrete wall
20,000 lbs
200,000 Btu
14,000 Btu/hr

Styrofoam wall
270 lbs
4,000 Btu
550 Btu/hr

Indoors 70°F

Jan. Average Temp.
Outdoors 21°F
Solar Exposure

The Sun’s Path in the Sky

June 21

East

Dec. 21

West

South

North
Solar Exposure Data

  – Solar Radiation
  – Climatic Conditions
  – Illuminance

http://rredc.nrel.gov/solar/pubs/bluebook/
Albany, NY
WBAN NO. 14735

LATITUDE: 42.75° N
LONGITUDE: 73.80° W
ELEVATION: 292 feet
MEAN PRESSURE: 14.6 psia

STATION TYPE: Primary

Shading Geometry
(Not to Scale)

Average Incident Solar Radiation (Btu/ft²/day), Uncertainty ±9%

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>560</td>
<td>830</td>
<td>1140</td>
<td>1470</td>
<td>1720</td>
<td>1890</td>
<td>1900</td>
<td>1630</td>
<td>1290</td>
</tr>
<tr>
<td>Std.Dev.</td>
<td>56</td>
<td>75</td>
<td>85</td>
<td>115</td>
<td>148</td>
<td>136</td>
<td>102</td>
<td>83</td>
<td>101</td>
</tr>
<tr>
<td>Minimum</td>
<td>370</td>
<td>610</td>
<td>900</td>
<td>1220</td>
<td>1430</td>
<td>1600</td>
<td>1610</td>
<td>1320</td>
<td>900</td>
</tr>
<tr>
<td>Maximum</td>
<td>670</td>
<td>1050</td>
<td>1280</td>
<td>1700</td>
<td>2030</td>
<td>2170</td>
<td>2090</td>
<td>1820</td>
<td>1450</td>
</tr>
<tr>
<td>Diffuse</td>
<td>330</td>
<td>460</td>
<td>590</td>
<td>730</td>
<td>850</td>
<td>910</td>
<td>880</td>
<td>770</td>
<td>610</td>
</tr>
<tr>
<td>Clear-Day Global</td>
<td>780</td>
<td>1140</td>
<td>1650</td>
<td>2160</td>
<td>2520</td>
<td>2650</td>
<td>2550</td>
<td>2240</td>
<td>1770</td>
</tr>
</tbody>
</table>
Solar Heat Gain of a South Wall

Area = 270 ft²
Volume = 135 ft³

Concrete wall
20,000 lbs
200,000 Btu

Indoors 70°F

560 Btu/ft²/day

Insolation Rate:
Concrete 10,000 Btu/hr

After 9 hours:
Wall Temperature +22°F

Jan. Average Temp.
Outdoors 21°F
Effect of Thermal Mass on IAQ

Where we’ve been today

• Energy Conservation Construction Code
• Estimating Heat Energy in Buildings
• Estimating Air Leakage
• Estimating Humidity Levels
• Estimating Thermal Mass
• Estimating Solar Heat Energy
• Review and Conclusions
Review – ECCC of NY State

- ECCC is intended to achieve the effective use of energy in buildings
- ECCC applies to new construction and to addition, alteration or renovation of any building system or sub system
  - Exempts registered historic buildings
- Requires approval by the code enforcement official
  - Must meet Code or [Alternate] meet the intent of the Code AND achieve equivalent energy savings
Review – Heat Energy in Buildings

• Insulation heat loss (Btu/hr)

\[
\frac{\text{heat\_loss}(\text{BTU})}{\text{time}(\text{hr})} = \frac{T(\text{o}^\circ\text{F})\text{diff}\times\text{Area}(ft^2)}{R\_value}
\]

• Sensible heat \((h_s)\)

\[
h_s = 1.08(q\cdot dt)
\]

• Latent heat \((h_l)\)

\[
h_l = 4840(q\cdot dw_{lb})
\]
Review – Estimating Air Leakage

• ECCC NYS §402.4 Air Leakage (Mandatory)
• 2010 ECCC NYS less than 7 ACH@50 Pascal (7 ACH_{50})
  – 2013 ECCC (Draft) less than 3 ACH_{50}
• Estimating ‘Natural Air Leakage’ from ACH_{50}
  – Sherman and Dickerhoff, 1998

\[
\frac{ACH_{50}}{20} = ACH
\]
Review – Estimating Humidity

• An average family of 4 will generate about 14 gallons (53 liters) as water vapor per week
• Winter situation (Indoor RH% < 20%)
  • Relative Humidity stays low
  • Skin, eye, sinus irritations and health complaints
• Humid situation (Indoor RH% > 60%)
  • Poor air exchange – stuffy, odors, fatigue
  • Condensation – visible water damage, mold
Review – Estimating Thermal Mass

• Thermal Mass is the ability of a substance to hold heat energy (§402.2.4 Mass walls)

• High Thermal Mass comes from →
  – High Heat Capacity
  – High Density
  – Low Conductivity
  – Low Reflectivity ("Albedo")

• Thermal Mass is NOT the same as Insulation
Review – Estimating Solar Heat

- Estimate Insolation rate from ‘Solar Radiation Data Manual for Buildings’ – NREL
- Estimate surface albedo
- Estimate surface temperature gain using specific heat capacities
- Note building aspect dramatically impacts solar heating
This is Your House
This is Your House on Energy Codes
Actually, Your House is a Humidor
References

• NY Energy Conservation Construction Code  

• LBNL – Residential Building Systems  
  – http://homes.lbl.gov/

• Building Science Corporation  
  – http://www.buildingscience.com/

• Conservation Physics  
  – http://www.conservationphysics.org/

• NREL – Renewable Resource Data Center  
Quiz

• Which of the following are exempt from the requirements of the Energy Conservation Construction Codes?
  – New construction of a motel
  – Replacing the windows of an apartment building
  – Adding roof insulation to the Schuyler Mansion State Historic Site
  – Building a house addition with straw bale walls
Questions

• How does the U-value change with increasing air leakage?
  – Increase
  – Decrease
  – Stays the same
Questions

• You receive a complaint of surface stains around the hot air supply vent during winter. The problem might be:
  – Electrostatic surface charges caused by dry hot air coming from the vent
  – Mold
  – Dirty furnace filters
  – An unknown source of soot
Questions

• Sunlight coming through a clear glass window provides radiant heat – which of the following will increase in temperature?
  – The interior pane of the window
  – The indoor air
  – The indoor surfaces illuminated by the sunlight
Questions

• A blower door test of a new home shows 6 air changes per hour at 50 Pascals. Does the home meet the requirements for 2010 NYS ECCC?
  – Yes, but only if the test was performed by a BPI certified technician
  – Yes, but only if the test method was ASHRAE/ASTM E779
  – No, a visual inspection of the air barriers and insulation is also required
Questions and Comments?