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

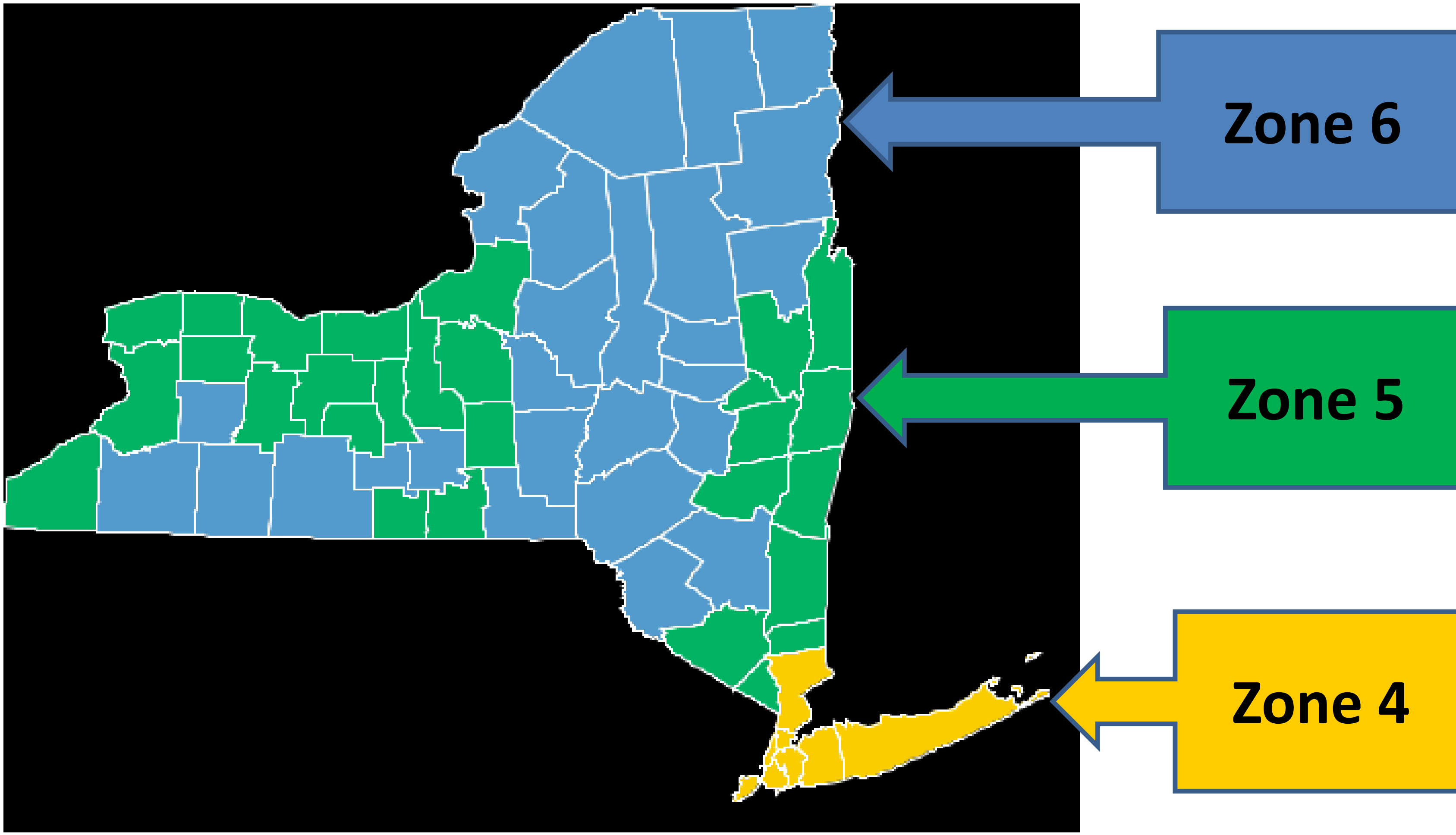
ECCC Intent §101.3

- …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



http://energycode.pnl.gov/EnergyCodeReqs/?state=New%20York

Residential Insulation Table 402.1.1

CLIMATE ZONE	CEILING R-VALUE	WOOD FRAME WALL R-VALUE	FLOOR R-VALUE
4	38	13	19
5	38	20	30
6	49	20	30

http://publicecodes.citation.com/st/ny/st/b1200v10/index.htm

R-value

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

$$R = \frac{T(°F)_{diff} * Area(ft^2) \ * time(hr)}{heat\_loss(\mathrm{BTU})}$$

- 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 $\boldsymbol{i}$ is the individual component of an assembly (e.g. studs in a wall)

Zone 5 House on ECCC 2010

R-38 Ceiling

R-20 Walls

50 x 30 x 9 feet

Volume = 13500 ft^3

Floor Area = 1500 ft^2

Ceiling Area = 1500 ft^2

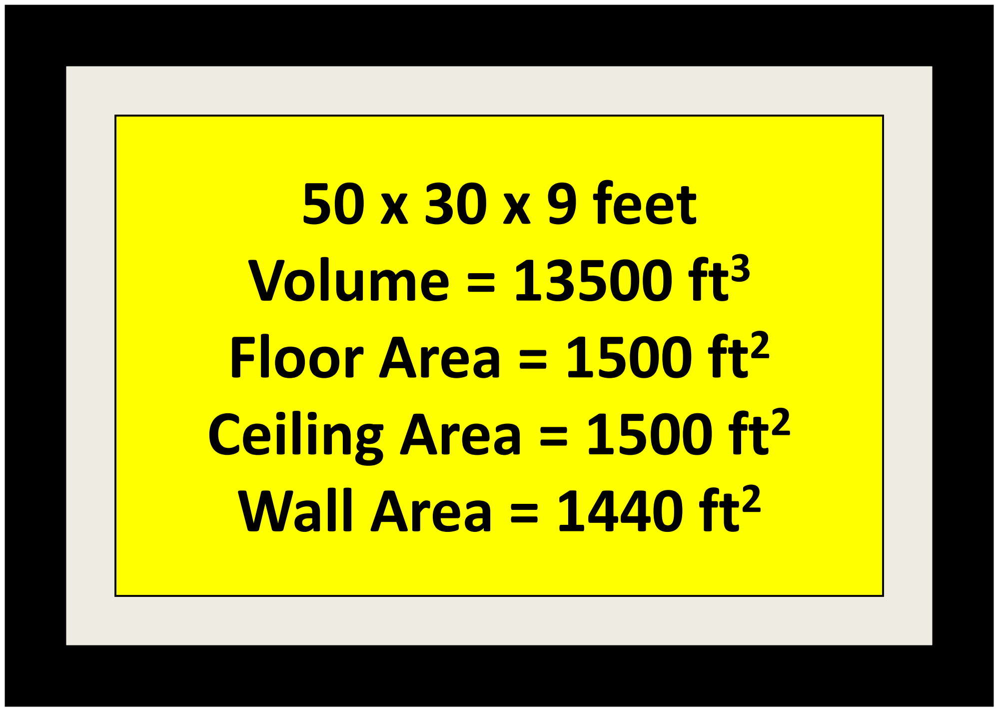
Wall Area = 1440 ft^2

R-30 Floor

Assembly R-value

U=1/38 %i = 1500/4440

U = 1/20
%i = 1440/4440



U = 1/30 %i = 1500/4440

Estimate Assembly R-value

- $R_{Assembly} = \frac{1}{U_{Assembly}} = \frac{1}{\Sigma(U_i \times i\%)}$

Component	R	i%	U_i	U_i x i%
Ceiling	38	33.8%	0.0263	0.00889
Floor	30	33.8%	0.0333	0.01127
Walls	20	32.4%	0.0500	0.01620
			Σ(Ui x i%)	0.03636
			R-Assembly	**27.5**

Average Heat Loss in January (Albany Zone 5)

- $$\frac{heat\_loss(BTU)}{time(hr)} = \frac{T(°F)_{diff} * Area(ft^2)}{R\_value}$$
- Assume T_{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
4. Utility penetrations.
5. Dropped ceilings or chases adjacent to the thermal envelope.
6. Knee walls.
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*:

$$\frac{7ACH_{50}}{20} = 0.35ACH$$

*Air-Tightness of U.S. Dwellings – Sherman and Dickerhoff, 1998

Sensible Heat Loss

$$h_s = 1.08(q.\,dt)$$

q = air volume flow (cfm)

= (0.35 x 13500)/60 = 79 cfm

dt = temperature difference (°F) = 49°F

h_s = sensible heat (BTU/hr)

=1.08 x (79 x 49) = **4181 BTU/hr**

http://www.engineeringtoolbox.com/cooling-heating-equations-d_747.html

Latent Heat Loss

$$h_l = 4840(q.\,dw_{lb})$$

q = air volume flow (cfm)

= (0.35 x 13500)/60 = 79 cfm

dw_{lb} = humidity ratio difference

(lb water/lb dry air) = 0.006 – 0.002 = 0.004

h_l = latent heat (BTU/hr)

=4840 x (79 x 0.004) = **1529 BTU/hr**

http://www.engineeringtoolbox.com/cooling-heating-equations-d_747.html

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

$$L = \frac{Q}{1.08 * (t_h - t_r)}$$

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/hr x 13500 ft^3 = 4725 ft^3/hr = 79 cfm

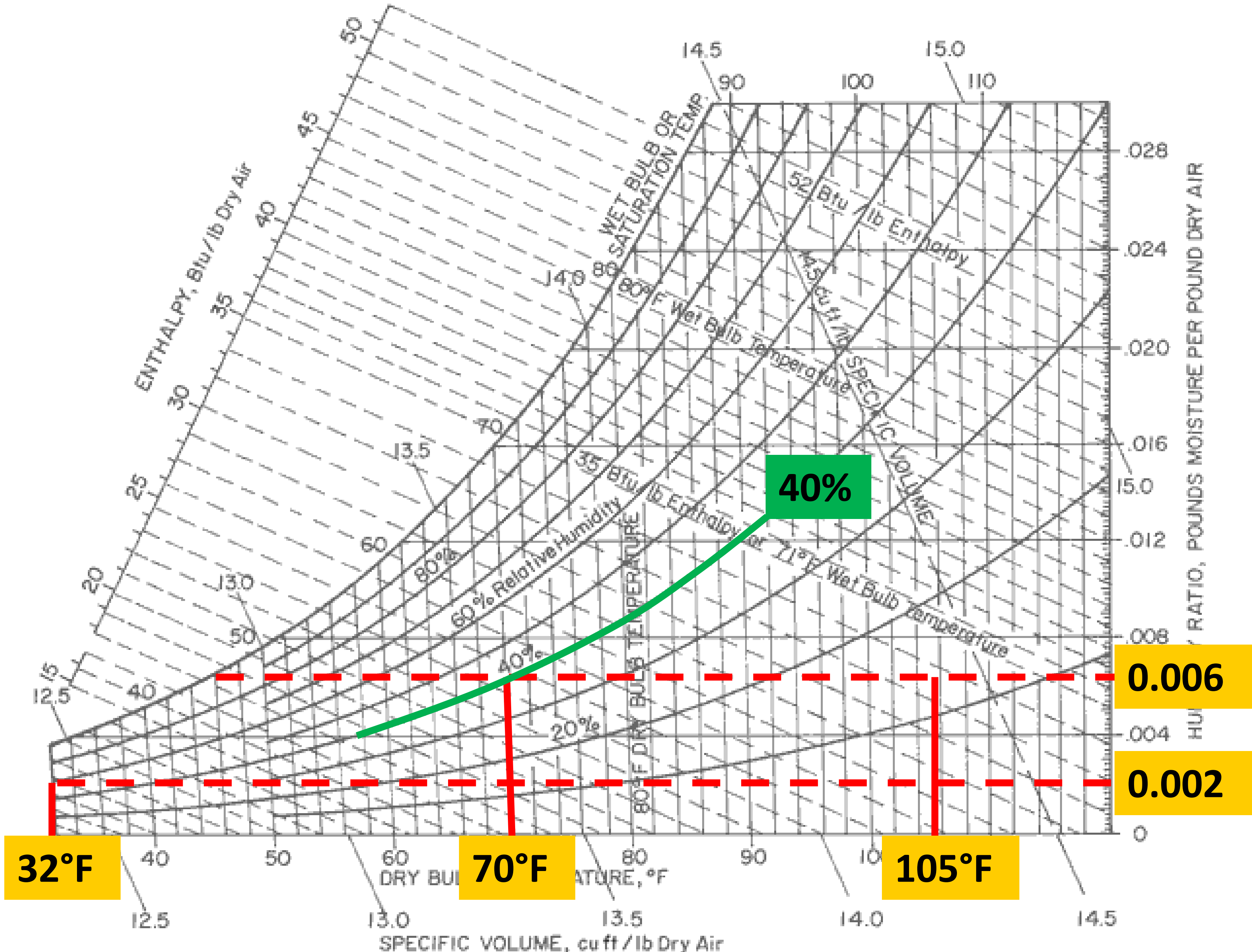
Estimated Outdoor Air = 79 cfm

- **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 cfm
  - x_A=0.00232 (at 21°F and 100%RH)
- Indoor Air Q_C=281 cfm
  - x_C=0.00613 (at 70°F and 40%RH)
- Mixed air x_B = 0.00537

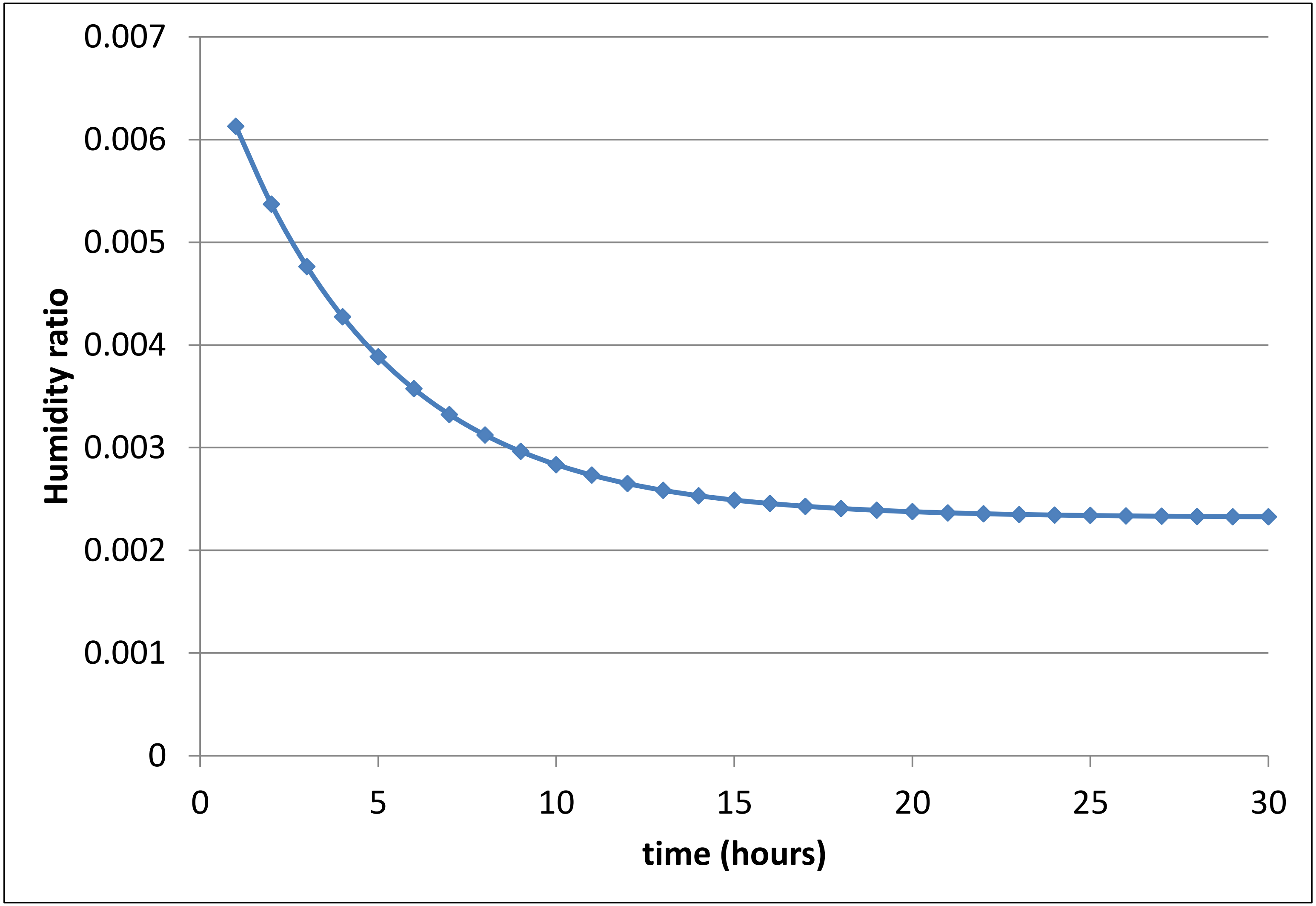

ENTHALPY, Btu/lb Dry Air
WET BULB OR SATURATION TEMP.
52 Btu/lb Enthalpy
80°F Wet Bulb Temperature
14.5 cu ft/lb SPECIFIC VOLUME
35 Btu/lb Enthalpy
71°F Wet Bulb Temperature
80%
60% Relative Humidity
40%
20%
80°F DRY BULB TEMPERATURE
DRY BULB TEMPERATURE, °F
SPECIFIC VOLUME, cu ft/lb Dry Air
HUMIDITY RATIO, POUNDS MOISTURE PER POUND DRY AIR
40%
0.006
0.002
32°F
70°F
105°F

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 → 0.00232
  - ➢ **At 70°F, x_B = 0.00232 yields 15% RH**
  - ➢ Minimum RH is reached within 24 hours

http://www.humidity-calculator.com/index.php

Degradation of Humidity Ratio



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

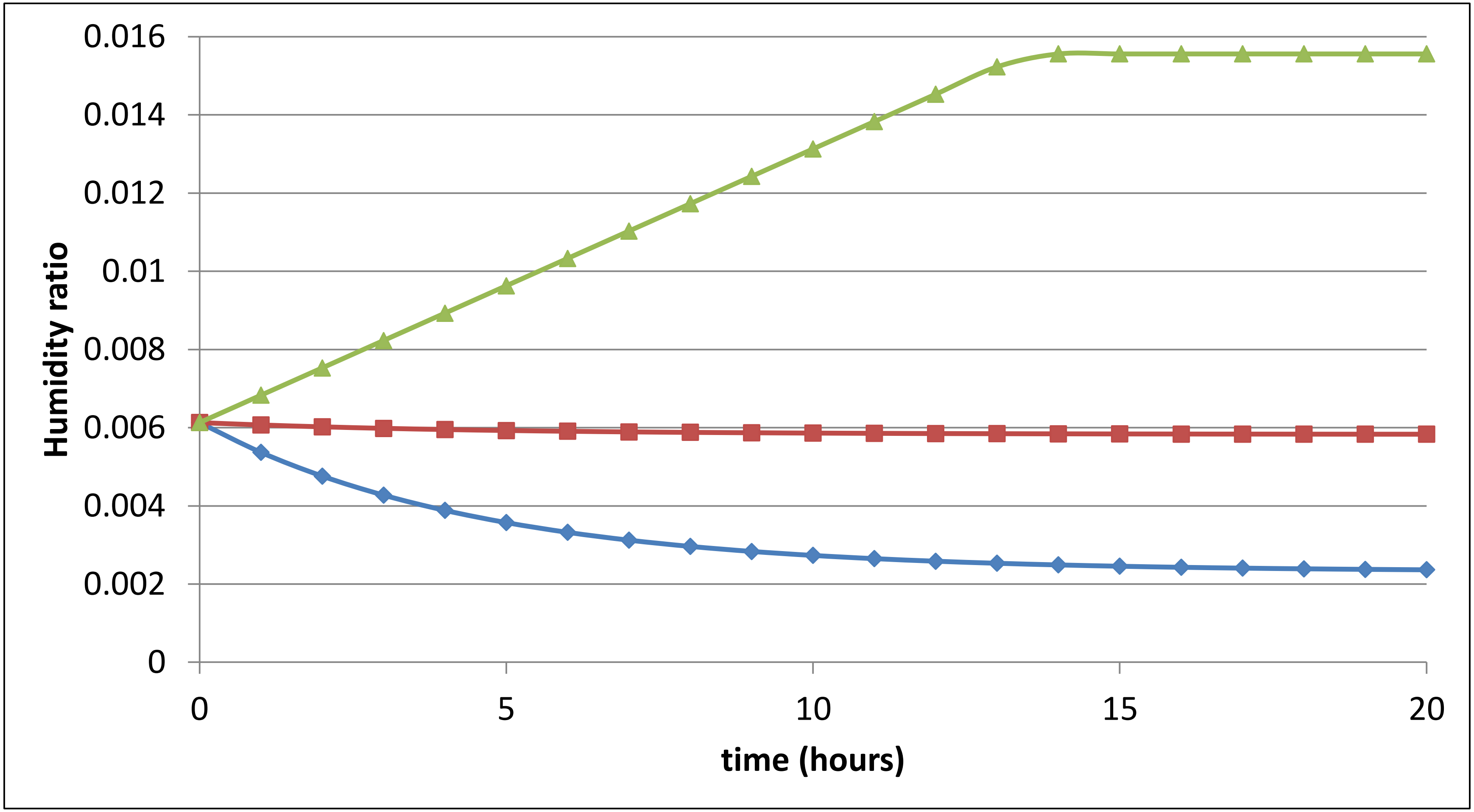
Activity	Gallons (liters) per week
Cooking	1.7 (6.3)
Dishwashing	0.8 (3.2)
Bathing/ Showering	0.6 (2.4)
Clothes washing	0.5 (1.8)
Normal respiration and skin evaporation from 4 occupants	10 (38)

Estimate Rate of Change of %RH

- 14 gallons per week → 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



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

http://www.yourhome.gov.au/technical/fs49.html

Thermal Mass vs. Insulation

	Styrofoam	Concrete
Specific Heat Capacity ($Btu/lb_m.°F$)	0.3	0.2
Density (lb/ft^3)	2	150
Heat Conductivity (κ) (Btu/ft.hr.°F)	0.02	0.5
Reflectivity (Albedo)	0.7	0.4

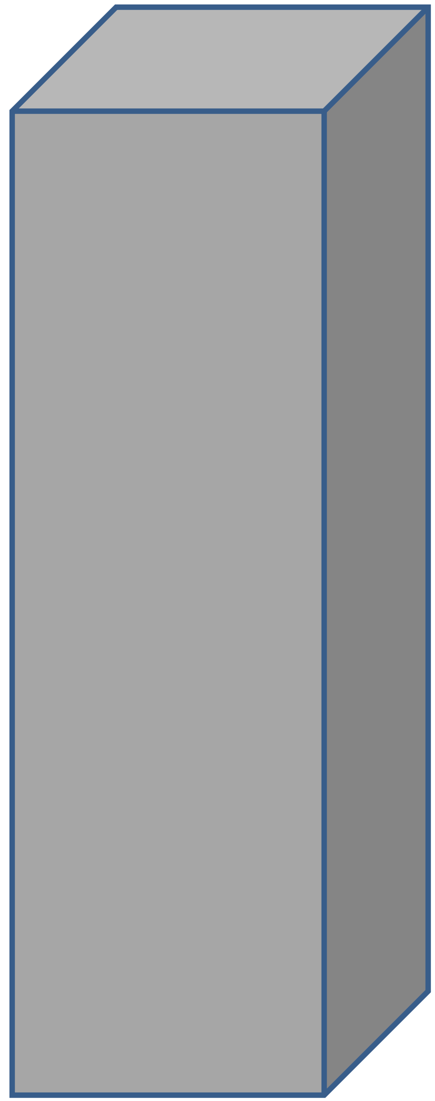
Thermal Mass of a Solid Wall

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

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

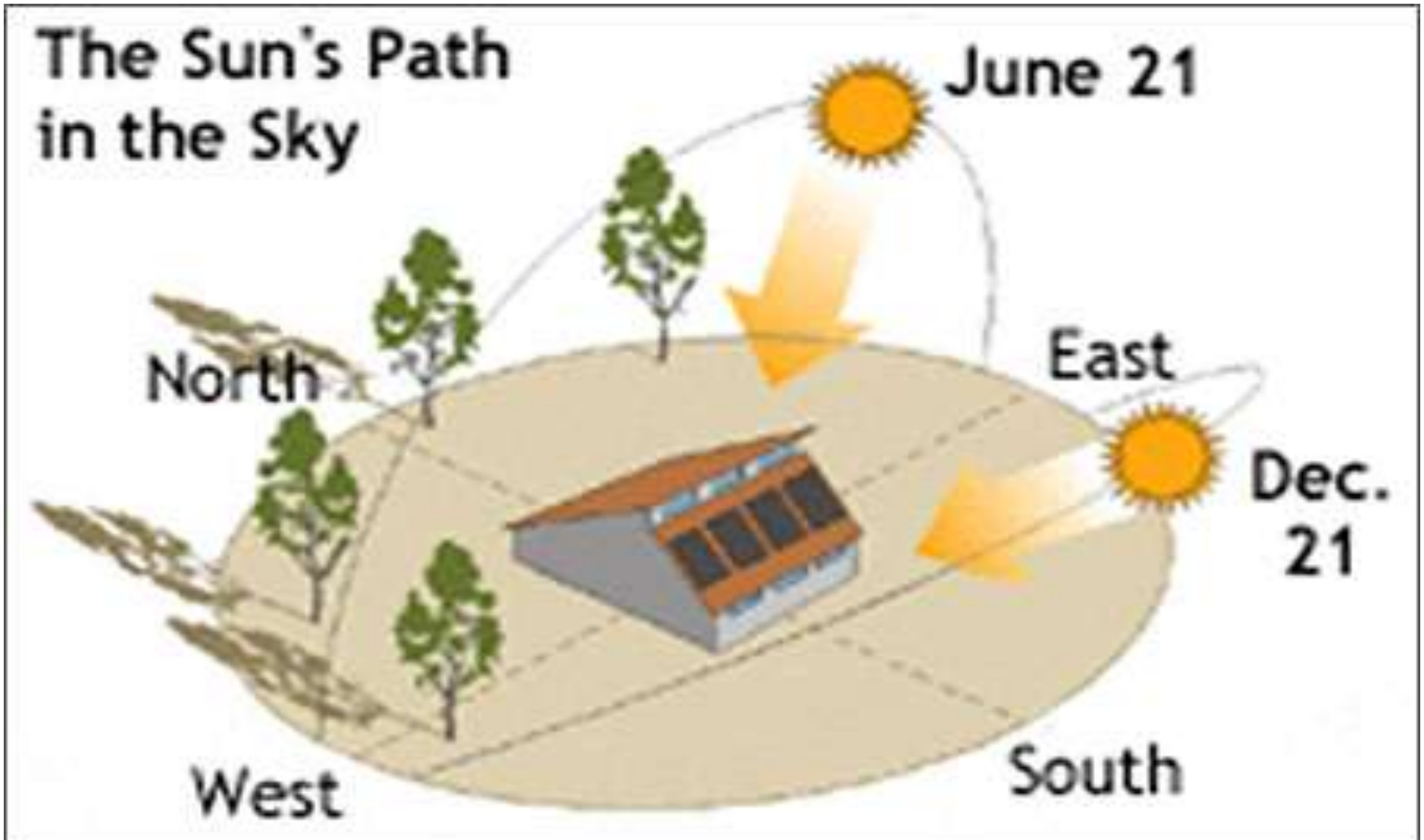
Styrofoam wall
270 lbs
4,000 Btu
550 Btu/hr

Indoors 70°F



Jan. Average Temp.
Outdoors 21°F

Solar Exposure



Solar Exposure Data

- 'Solar Radiation Data Manual for Buildings' – NREL, National Renewable Energy Laboratory
  - Solar Radiation
  - Climatic Conditions
  - Illuminance

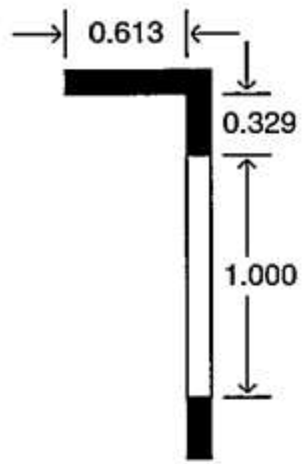
http://rredc.nrel.gov/solar/pubs/bluebook/

Albany, NY

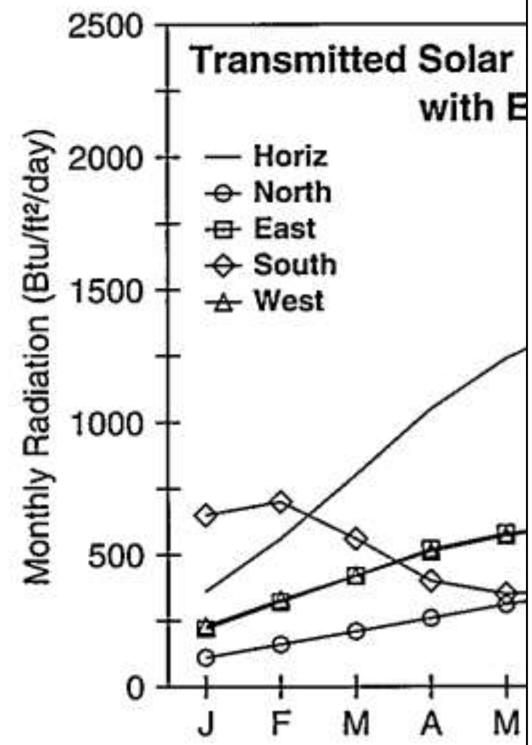
WBAN NO. 14735

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%

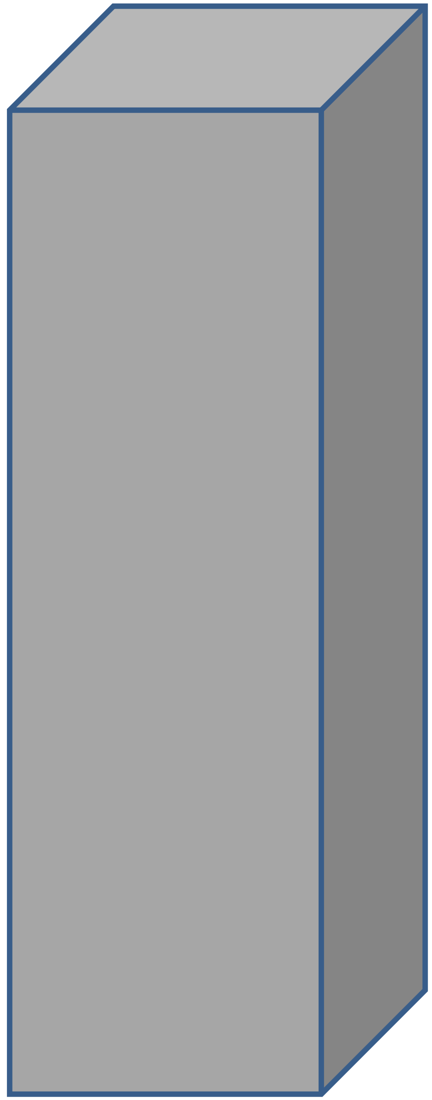
Orientation		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Horizontal	Global	560	830	1140	1470	1720	1890	1900	1630	1290
	Std.Dev.	56	75	85	115	148	136	102	83	101
	Minimum	370	610	900	1220	1430	1600	1610	1320	900
	Maximum	670	1050	1280	1700	2030	2170	2090	1820	1450
	Diffuse	330	460	590	730	850	910	880	770	610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

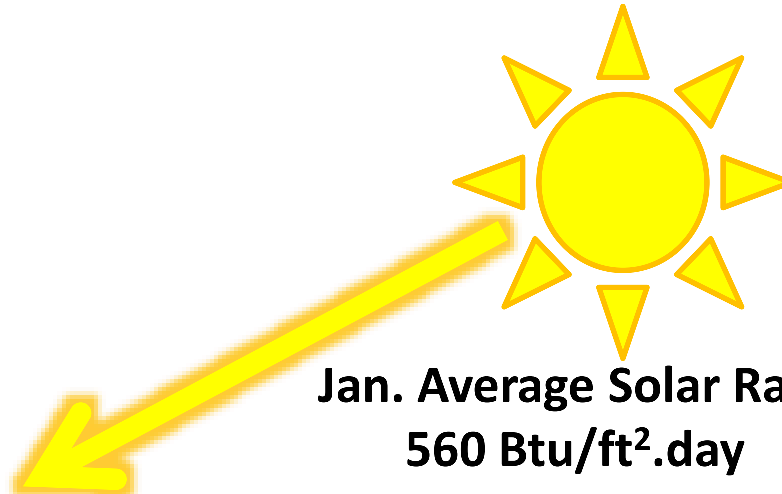
Solar Heat Gain of a South Wall

Area = 270 ft²
Volume = 135 ft³

Concrete wall 20,000 lbs 200,000 Btu

Indoors 70°F





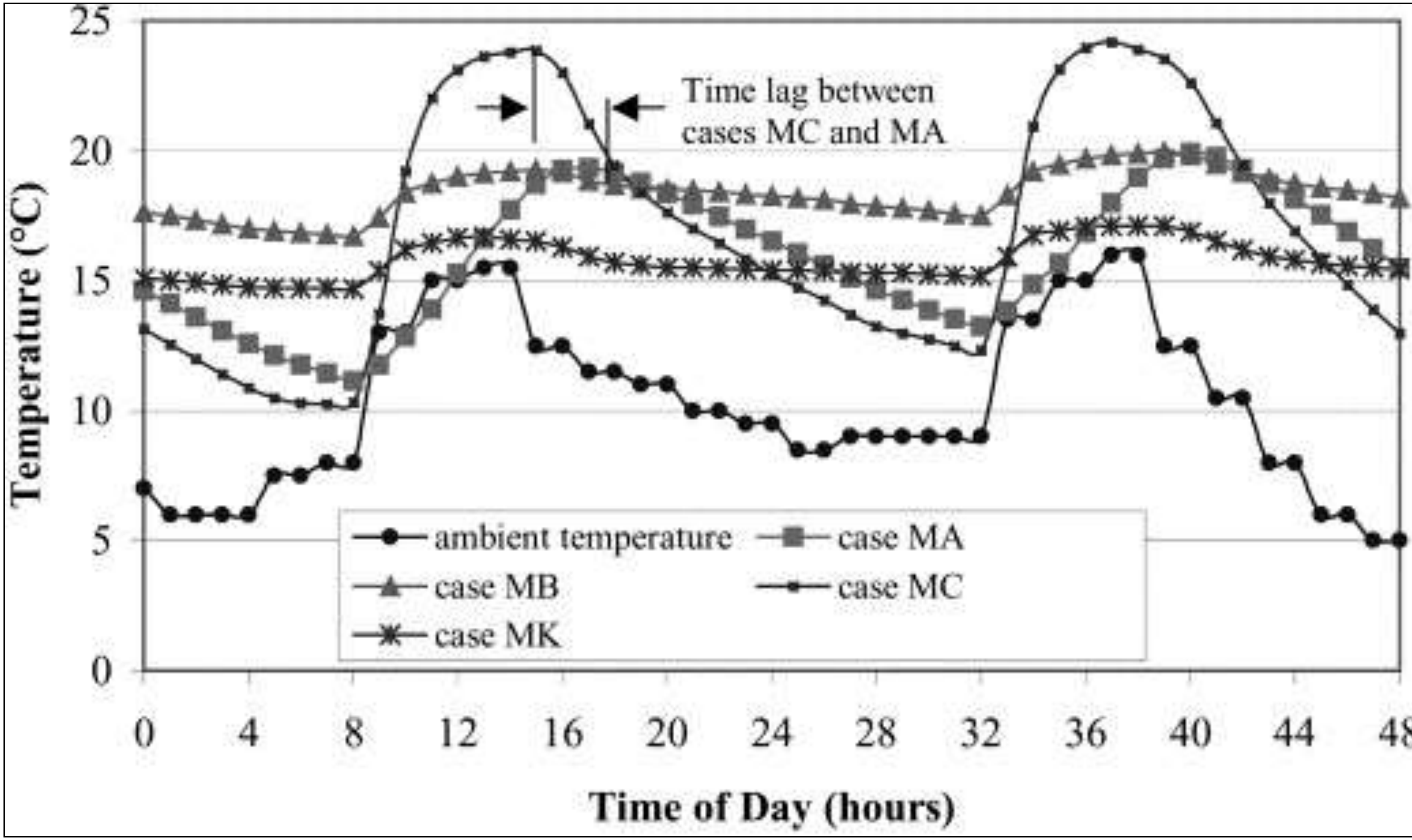
Jan. Average Solar Rad.
560 Btu/ft².day

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



Measures used to lower building energy consumption and their cost effectiveness. G.A Floridesa, S.A Tassoub, S.A Kalogiroua, L.C Wrobel. *Applied Energy* 73:299-328.

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)
  - $$\frac{heat\_loss(BTU)}{time(hr)} = \frac{T(°F)_{diff} * Area(ft^2)}{R\_value}$$
- Sensible heat (h_s)

$$h_s = 1.08(q.dt)$$

- Latent heat (h_l)

$$h_l = 4840(q.dw_{lb})$$

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

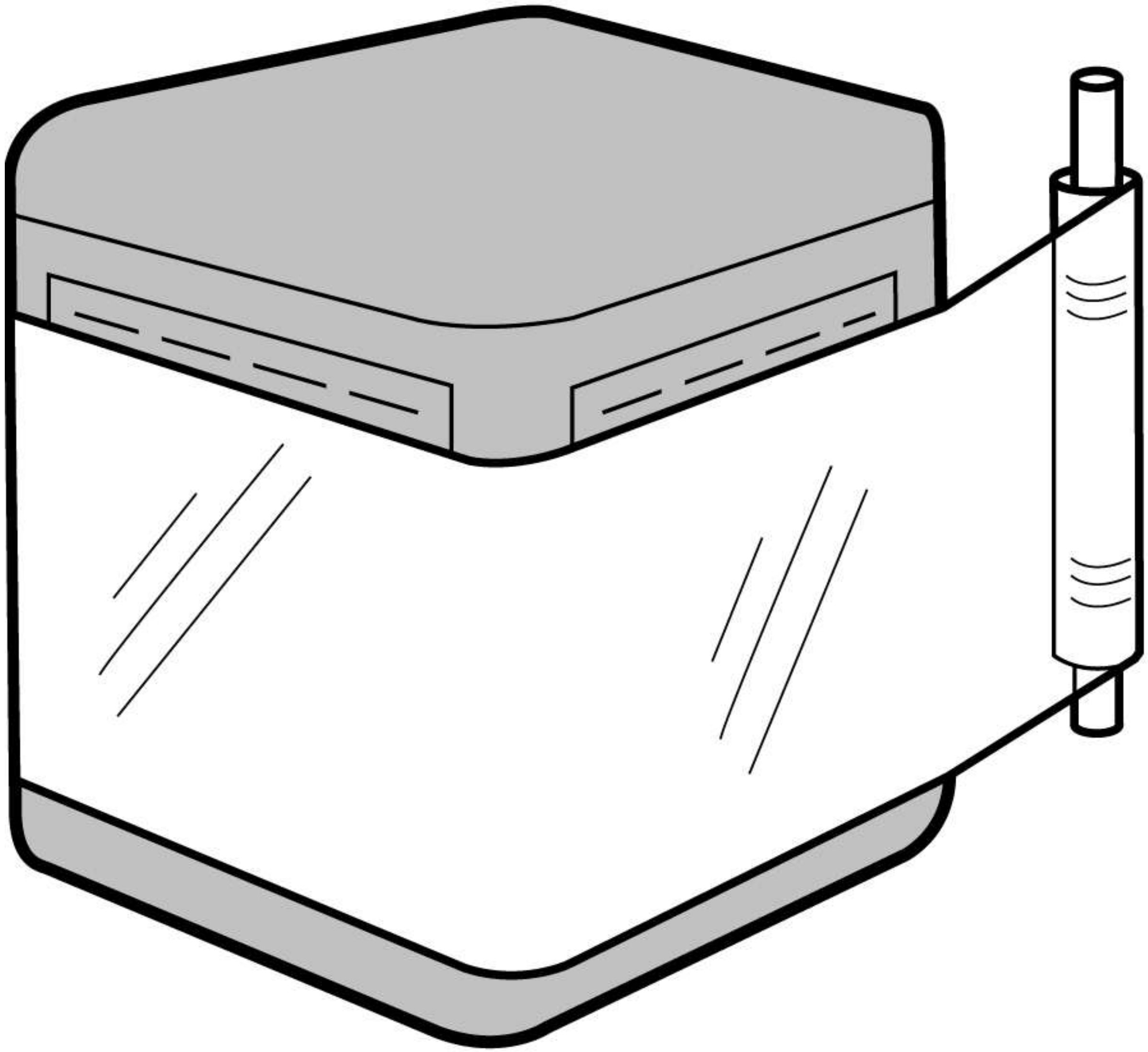
- Thermal Mass is the ability of a substance to hold heat energy (**§402.2.4 Mass walls**)
- High Thermal Mass comes from →
  - High Heat Capacity
  - High Density
  - Low Conductivity
  - Low Reflectivity (“Albedo”)
- Thermal Mass is NOT the same as Insulation

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
  - http://publicecodes.citation.com/st/ny/st/b1200v10/index.htm
- 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
  - http://rredc.nrel.gov/solar/pubs/bluebook/

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?