CH 15 THERMAL ENVELOPE

HEAT GAIN

1. DIRECT
2. HOT DAY
3. HOT AIR
4. HOT WATER
5. LIGHTS
6. APPLIANCES
7. PEOPLE
8. VENTILATION
9. COOLED AIR
10. HOT MOISTURE
11. COOLED OUT CRACKS
12. INFILTRATION HEAT INFILTRATION

HEAT GAIN THROUGH WALLS AND ROOFS

\[ H.G. = \left( \frac{\text{AREA}}{\text{WALLS + ROOFS}} \right) \times \left( \frac{1}{R \text{\, RESISTANCE OF WALL/ROOF}} \right) \times \left( \text{DETD} \right) \]

WHERE: \( \text{DETD} = f(\Delta T, \text{MASS OF BUILDING}, \text{ALBEDO}) \)

REFLECTANCE OF BOTH VISIBLE AND IR EMISSION

<table>
<thead>
<tr>
<th>WALLS</th>
<th>WHITE PAINT</th>
<th>10-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOFS</td>
<td>HIGHLY REFLECTIVE ROOF</td>
<td>50-70</td>
</tr>
<tr>
<td></td>
<td>BLACK ROOF</td>
<td>5-20</td>
</tr>
</tbody>
</table>

RESEARCH EXAMPLE SHOWN:

HVAC AND AIR CONDITIONING LOAD DOWN 20% IF AVERAGE ALBEDO OF WALL + ROOF CHANGED FROM 30 TO 90

JT Wunderlich PhD
H.G. through windows = (Area of windows) \times (SHGF) \times (SHGC)

\[ H.G. = f(Latitude, \text{ Window Orientation}, \text{ Season}, \text{ Time of Day}) \]

\[ \theta = f(Q = f(\text{ Glazing Types, Trees, Shading Strategies, etc.})) \]

- See CH9 "Passive Cooling"

Example: Double-glazed 4 ft x 5 ft window, 90% glass on wall facing south in building located at 40° North latitude. Time is 11:00 AM on March 21.

Using tables from reference books (course text, ASHRAE "Fundamentals", AIA Standards)

Find:

\[ SHGF = 197 \frac{BTU/HR}{FT^2} \]

\[ SHGC = 0.73 \]

Glass area = \( (4 \text{ ft} \times 5 \text{ ft}) \times 0.80 = 16 \text{ ft}^2 \)

\[ H.G. = (16 \text{ ft}^2) \times (197 \frac{BTU/HR}{FT^2}) \times (0.73) \]

\[ = 2301 \frac{BTU}{HR} \]

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Heat Loss

\[ H.L. = \text{Area} \times \left( \frac{1}{R_{\text{total}}} \right) \times (\Delta T) \]

\[ R = \sum \text{All } R\text{'s for all materials in a section} \]

Example Wall Section A-A:

- \( R = 0.7 \) Indoor Vapor Barriers (Plastic)
- \( R = 0.45 \) 1/2" Gypsum Board ("Drywall," "Sheetrock")
- \( R = 1.0 \) 3/8" Airspace (Non-insulation!)
- \( R = 2.5 \) 1/2" Rigid Board Insulation (Polyisocyanurate)
- \( R = 0.6 \) 1/2" Plywood Siding
- \( R = 0.2 \) Outdoor Air Film ("Tyvek")
- \( R = 0.5 \) Wood Siding

\[ R_T = 5.95 \]

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WE CAN GREATLY IMPROVE THIS $R_T$ FROM 5.95 BY FILLING 3/2" AIR GAP. (EVEN THOUGH AIR IN INSULATION IS OFTEN A CRITICAL COMPONENT OF IT'S THERMAL RESISTANCE)

<table>
<thead>
<tr>
<th>R per Inch</th>
<th>Insulation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1.5</td>
<td>Straw (maybe use in Africa)</td>
</tr>
<tr>
<td>~2.5</td>
<td>Blown fiberglass or wool</td>
</tr>
<tr>
<td>~3.5</td>
<td>Fiberglass batty (in rolls-&gt; staple it)</td>
</tr>
<tr>
<td>~4.5</td>
<td>Expanding foam (polystyrene)</td>
</tr>
</tbody>
</table>

So we could improve our $R_T$ from 5.95 by $(1.5 \times 3.5'' = 5.25)$ to $(4.5 \times 3.5'' = 15.75)$.

If we want more, make thicker walls.

In some places in U.S., building codes now require $R_T$ for exterior walls to be so high that everyone is switching from "2 x 4" studs (1/2" x 3 1/2" actual) to "2 x 6" studs (1/2" x 5 1/2" actual).

So with this 5/2" air gap, we could improve our $R_T$ by $(1.5 \times 5.5'' = 8.25)$ to $(4.5 \times 5.5'' = 24.75)$.

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FROM TABLE 15.6A (P471)

RECOMMENDED MIN RT

<table>
<thead>
<tr>
<th>Location</th>
<th>Roof</th>
<th>Walls</th>
<th>Basement or Slab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast, PA.</td>
<td>50</td>
<td>20</td>
<td>2.6</td>
</tr>
<tr>
<td>Phoenix, AZ.</td>
<td>50</td>
<td>20</td>
<td>1.7</td>
</tr>
<tr>
<td>Miami, FL.</td>
<td>40</td>
<td>14</td>
<td>1.7</td>
</tr>
</tbody>
</table>

GOTO: http://energycode.pnl.gov/energy/code_regs

RADIANT BARRIER

- Can add to RT by 3 to 11
- Metal foil (typically aluminum)

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Wall</th>
<th>Ceiling in Winter (Keep in Heat)</th>
<th>Summer (Out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GLASS ("GLAZING")

<table>
<thead>
<tr>
<th>RT</th>
<th>Single Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Glass block (averaged thickness)</td>
</tr>
<tr>
<td>2.5</td>
<td>&quot;Double-pane&quot; with low E coating</td>
</tr>
<tr>
<td>3</td>
<td>&quot;Triple&quot;</td>
</tr>
<tr>
<td>4</td>
<td>&quot;Quadruple&quot;</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

TRANSLUCENT PANELS (10 to 50% light transmission)

RT = 7 to 20

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DRAPES

Governing Equations and Required Input:

\[ \text{Heat flux} = \frac{\text{heat loss rate}}{\text{area}} = \frac{q}{A} = U \Delta T = \frac{\Delta T}{R} \]

Where \( U \) is the thermal conductance which is the inverse of the more widely known thermal resistance or R-value. The R-value is calculated as \( R = \frac{l}{k} \) where \( l \) is the thickness of the material and \( k \) is the thermal conductivity.

The thermal resistances for the window with and without drapes are:

Without drape: \[ R_{\text{total}} = R_{\text{air film}} + R_{\text{window}} + R_{\text{air film}} \]

With drapes: \[ R_{\text{total}} = R_{\text{air film}} + R_{\text{drapes}} + R_{\text{gap}} + R_{\text{window}} + R_{\text{air film}} \]

Assumed values from ASHRAE Fundamentals (2001):

- Thickness of glass = 1/8 inch
- Curtain-window spacing = 3.5 inch
- Conductivity of glass = 0.81 BTU/(hr ft °F)
- Conductivity of drapes = 0.035 BTU/(hr ft °F)
- Thickness of drapes = 1/16 inch
- Thickness of insulated drapes = ½ inch

<table>
<thead>
<tr>
<th>Air Space/Gap</th>
<th>R-value (hr ft² °F/BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside vertical air film, ( R_{\text{air film}} )</td>
<td>0.68</td>
</tr>
<tr>
<td>Uninsulated drapes, ( R_{\text{drapes}} )</td>
<td>0.15</td>
</tr>
<tr>
<td>Insulated drapes, ( R_{\text{drapes}} )</td>
<td>1.2</td>
</tr>
<tr>
<td>3.5 inch vertical air gap, ( R_{\text{gap}} )</td>
<td>1.1</td>
</tr>
<tr>
<td>Single glazed window (wood or vinyl frame), ( R_{\text{window}} )</td>
<td>1.2</td>
</tr>
<tr>
<td>Double glazed window (wood or vinyl frame), ( R_{\text{window}} )</td>
<td>2.0</td>
</tr>
<tr>
<td>Outside vertical air film, ( R_{\text{air film}} )</td>
<td>0.25</td>
</tr>
</tbody>
</table>

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Using the analysis described above:

<table>
<thead>
<tr>
<th>Window/Drapes</th>
<th>Governing Equation</th>
<th>Overall R-value (hr ft² °F/BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-paned window</td>
<td>$R_{total} = R_{airfilm} + R_{window}$</td>
<td>$R_{total} = 0.68 + 1.2 + 0.25 = 2.13$</td>
</tr>
<tr>
<td>No drapes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-paned window</td>
<td>$R_{total} = R_{airfilm} + R_{window}$</td>
<td>$R_{total} = 0.68 + 2 + 0.25 = 2.93$</td>
</tr>
<tr>
<td>No drapes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-paned window</td>
<td>$R_{total} = R_{airfilm} + R_{drapes} + R_{gap}$</td>
<td>$R_{total} = 0.68 + 0.15 + 1.1 + 1.2 + 0.25 = 5.3$</td>
</tr>
<tr>
<td>Regular drapes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-paned window</td>
<td>$R_{total} = R_{airfilm} + R_{drapes} + R_{gap}$</td>
<td>$R_{total} = 0.68 + 0.15 + 1.1 + 2 + 0.25 = 4.43$</td>
</tr>
<tr>
<td>Regular drapes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-paned window</td>
<td>$R_{total} = R_{airfilm} + R_{drapes} + R_{gap}$</td>
<td>$R_{total} = 0.68 + 1.2 + 1.1 + 1.2 + 0.25 = 4.43$</td>
</tr>
<tr>
<td>Insulated drapes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-paned window</td>
<td>$R_{total} = R_{airfilm} + R_{drapes} + R_{gap}$</td>
<td>$R_{total} = 0.68 + 1.2 + 1.1 + 2 + 0.25 = 5.23$</td>
</tr>
<tr>
<td>Insulated drapes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For single glazed windows, adding drapes reduces heat loss by 37%. Adding the same drapes to double glazed windows reduces heat loss by 30%. Adding insulated drapes to a single glazed window reduces heat loss by 56% (48% for double glazed windows).

So, for single and double glazed windows, both claims are approximately true. The reduction in heat loss is smaller for double glazed windows than it is for single glazed windows.

However, This Answer Made Some Important Assumptions:

1. The air in the gap between the drapes is perfectly still. This is a bad approximation. Cool air trapped between the drape and the wall would fall to the floor. Warm air would enter the space from above the window, cool down, and fall. This process would create a convective loop that would serve to mix the air in the room better and also cause more heat to be lost to the outside. This mixing can actually cause greater heat loss than if there were no drapes.

2. Humidity controlled to prevent dew point condensation on windows. Drapes also come with vapor barriers.

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VENEZIAN BLINDS

- Simulate insulating effects as drapes (uninsulated)
- Trap air gap
- Also can reflect heat with special coatings
- May be easier to seal edges to prevent convection currents
- Can work well when combined with thermal drapes

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INfiltration Barriers

→ stop air flow in and out of building:

1. Weather-stripping in cracks:
   - A) Doors
   - B) Windows
   - C) Foundation sill plate
     (interface between foundation wall and floor structure for first floor)

2. Air-barrier ("building-wrap")
   → Ex) Tyvek
   → Woven Fabric

3. Air locks
   - A) Vestibule
   - B) Revolving door
MOISTURE CONTROL

- TO CONTROL ADVERSE THERMODYNAMICS
- " " BUILDING DAMAGE
  - MOULD
  - WOOD ROT

- CONTROL MOISTURE TRANSPORT:

  1. FLUID FLOW (IN BULK)
     - BUILDING WRAP
     - ROOFING
     - GUTTERS & SPOUTS
     - FLASHING AT JOINTS
     - CAULKING " "
     - CAPILLARY

     "WEEP-HOLES" FROM CAVITIES
     (BEHIND BRICK FAÇADES, ETC.)

  2. VAPOR

     - VIA VENTED AIR
       - MANAGE AIR EXCHANGES CAREFULLY

     - THROUGH WALLS & ROOF
       - USE VAPOR BARRIER
         - UNDER DRYWALL
         - PLASTIC
         - 4 mil

     BUT

     - BE CAREFUL NOT TO TRAP H2O

     - PROPER CONTROL OF
       - IMPACT MOISTURE
       - LEVELS
C. Use hydraulic buffer
  → Brick facades
  → Wood siding
  → They store moisture, so less to enter building

D. Consider non-porous insulation
  → Rigid boards
  → Expanding foam

E. Use active and passive ways for building to dry itself

F. Good drainage off and around building
VENTING

- VENT BASEMENTS
  - VENT ATTICS
    - RIDGE VENTS
    - SOFFIT VENTS
  - VENT BATHROOMS
  - VENT DRYERS

CONTROL AIR INFILTRATION

SEE LAST SECTION