Windows & Comfort Science

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Comfort Science?
ASHRAE Standard 55-2010 Comfort Model

Model: PMV Only

Environmental Conditions:
- Air Temperature: 70.0°F
- MRT: 70.0°F (Linked with air)
- Air Speed: 19.7 fpm
- Relative humidity: 30%

Activity:
- Seated, quiet
- Metabolic rate: 1.0 met

Clothing:
- Clothing level: 0.91 clo

Results:
- PMV: -0.88
- PPD: 21%

Compliance:
- Does not comply with Standard 55-2010

Condition: Slightly cool
Comfort Acronyms

1. **MRT**: Mean Radiant Temperature
   - Sums thermal radiation in all directions

2. **PMV**: Predicted Mean Vote
   - Too Cold, Too Hot, “Just Right”

3. **PPD**: Predicted Percent Dissatisfied
   - Statistical representation of group response
Building Comparison

Building A

= Code Windows
= Code Furnace
= Code Air-Conditioning

$1000 HVAC costs
Are they Really Equal?

**Building A**
- Code Windows
- Code Furnace
- Code Air-Conditioning

$1000 HVAC costs

**Building B**
- < Code Windows
- > Code Furnace
- > Code Air-Conditioner

$1000 HVAC costs
Cold Night – Can the furnace compensate?
Window MRT Caution!

(Mean Radiant Temperature)

• Proper evaluation needs to consider the effects of window size-to-room and occupant proximity to windows

• EnergyPlus comfort evaluations put the occupant in the center of the room
Hot Day/Direct Sun – Picture shows IR, not solar
Solar Caution!

Full season comfort analysis of windows needs to:

• Predict PMV offset from short wave infrared

• Account for MRT shift due to space overheating
Efficient Windows Collaborative

![Probability of Discomfort Chart]

- **Single Clear**
  - Due to sunlight: 60%
  - Due to hot glass: 40%

- **Double Clear**
  - Due to sunlight: 80%
  - Due to hot glass: 20%

- **Double Tint**
  - Due to sunlight: 40%
  - Due to hot glass: 60%

- **Double Low-E with Argon Gas**
  - Due to sunlight: 20%
  - Due to hot glass: 80%
Window Performance for Human Thermal Comfort

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ABSTRACT

A model has been developed for predicting the effect of windows on thermal comfort. Within the constraints of the two-zone ASHRAE comfort model, this model predicts the comfort impact of windows. The calculation embedded separate analysis for long-wave (thermal infrared) radiation, induced drafts, and solar load effects. Results demonstrate that long-wave exchange between people and their surroundings dominates under no-solar conditions; that direct solar load (if present) has a major influence on occupant perceptions of comfort, and that for most residential-size windows, draft effects exist but are generally small.

Generally, windows are not the key element affecting the comfort of a building’s occupants. However, under more extreme conditions, where a window is very hot or cold and the occupant is very close to the window, they become most influential. Furthermore, it is believed that current methods may under-predict discomfort.

We discuss potential refinements to the model that might address these discrepancies by accounting for interactions in radiant temperature. In the near term, the model could be used to create a simplified “window comfort index.” To accompany the index, we envision educational material that would educate designers and consumers on the comfort implications of glazing selection.

KEYWORDS

window, glazing, thermal comfort
Introduction

Cardinal Glass owns and operates four research houses in Ft. Wayne, IN that have been employed in Building America field testing since 2005. The four houses are intended to be identical with the exception of window glass and site orientation. Two of the houses are oriented East-West, and two are oriented North-South. The window glass in one house is fixed, while the glass in the remaining three houses can be easily changed to accommodate different research objectives. The house plan is representative of a 40% energy savings house compared to the Building America Benchmark. Specifications and energy analysis for the house plan have been described in previous Building America test reports. The IBACOS team has recently employed one of the houses for long-term Building America field testing to evaluate the effects of heating system configuration on thermal comfort.

The purpose of this field test was to explore potential applications of NREL’s newly acquired thermal comfort monitoring system and to provide comparison measurements for IBACOS’ thermal comfort monitoring. NREL’s thermal comfort monitoring system is comprised of five transducers and a data logger (Figure 1). The transducers provide measurements for plane radiant temperature asymmetry, air velocity, dew point, air temperature, and operative temperature. Thermal comfort was evaluated using ASHRAE Standard 55-2004 as a guideline. Evaluations focused on general comfort indices such as predicted mean vote (PMV) and predicted percent dissatisfaction (PPD) as well as local discomfort sources such as radiant temperature asymmetry and draft. PMV and PPD were calculated using an activity level and a clothing insulation value representative of a full-time occupant in a winter garment ensemble. Specific research objectives included the following questions:

Comfort Basics
PMV: 7 Point Comfort Scale

-3  Cold  -2  Cool  -1  Slightly Cool  0  Neutral  +1  Slightly Warm  +2  Warm  +3  Hot
PMV Research

The PMV model was developed by Fanger in the 1970s and is the standard method used to evaluate comfort in buildings.
PPD - Predicted Percent Dissatisfied

(what happens when engineer’s define the terminology)

Working with PPD:

• Higher Absolute Value is worser
• Lower Absolute Value is more better
Fig. 16  Predicted Percentage of Dissatisfied (PPD) as Function of Predicted Mean Vote (PMV)
Comfort Analysis from Std55

There are six primary factors that must be addressed when defining conditions for thermal comfort. A number of other, secondary factors affect comfort in some circumstances. The six primary factors are listed below. Complete descriptions of these factors are presented in Section 5.4 and Normative Appendices A and B.

1. Metabolic rate
2. Clothing insulation
3. Air temperature
4. Radiant temperature
5. Air speed
6. Humidity

Window MRT analysis requires:

- Window size
- Person position relative to window
- Window surface temperature
Metabolic Rate

- **Walking (2 mph)**: Metabolic rate 2.0 met
- **Standing, relaxed**: Metabolic rate 1.2 met
- **Seated, quiet**: Metabolic rate 1.0 met
- **Sleeping**: Metabolic rate 0.8 met
- **RIP**: Metabolic rate 0.1 met
Clothing Insulation

- Clothing level: 2.00 clo
- Clothing level: 1.00 clo
- Clothing level: 0.50 clo
- Clothing level: 0.10 clo
“Standard” Conditions

1. Activity Level

2. Adaptive Clothing
3. Surrogate for Air Temperature
4. Simple MRT Analysis

When applying this Graphic per Section 5.2.1.1, the following limitations apply:

- Applies to Operative Temperature only – cannot be applied based on dry bulb temperature alone. See Appendix C for acceptable approximations.
- Applies only when requirements of Sections 5.2.3 through 5.2.5.2 are met.

For other compliance paths, see Section 5.2.1.2 for the Computer Model Method and Section 5.3 for the Optional Method for Naturally Conditioned Spaces.

For further compliance requirements, see Sections 6 and 7.

(a)

- Operative Temperature (°F) (½ Dry bulb + ½ MRT for still air)
- No lower humidity recommendation for graphical method: See Section 5.2.2
- Comfort zone moves left with:
  - Higher clothing
  - Higher metabolic rate
  - Higher radiant temperature
  - See Section 5.2.1.2

- Comfort zone moves right with:
  - Lower clothing
  - Lower metabolic rate
  - Lower radiant temperature
  - See Section 5.2.1.2

- Apply Section 5.2.3 to determine cooling effect of elevated air speed
4. Complex MRT Analysis

B. VERTICAL RECTANGLE (ABOVE OR BELOW CENTER OF PERSON)
4. Window MRT Analysis

![Graph showing the relationship between Roomside Glass Temperature and MRT for different window sizes and distances.]

- Red line: Large Window @ 6' Away
- Blue line: Small Window @ 3' Away
- Green line: Large Window @ 3' Away

Legend:
- Large Window @ 6' Away
- Small Window @ 3' Away
- Large Window @ 3' Away
4a. Solar Comfort Issues

- Hot Glass (MRT)
- Direct Gain
Fig. 16  Predicted Percentage of Dissatisfied (PPD) as Function of Predicted Mean Vote (PMV)
5. Air Speed
   • Typically low speed for light sedentary activity

6. Humidity
   • Low humidity has no effect on thermal comfort
   • Summer humidity matters
Qualitative Window Comfort Summary

www.efficientwindows.org

1. Set temperature and/or solar gain limits for cold winter night and hot summer day
EWC Cold Limit = 52°F Glass

Source: Lawrence Berkeley National Laboratory (Lyons and Arasteh).
EWC “Hot” Analysis

Source: Lawrence Berkeley National Laboratory (Lyons and Arasteh).
Qualitative Window Comfort Analysis

www.efficientwindows.org

1. Set temperature and/or solar gain limits for cold winter night and hot summer day
2. Sum hours above/below comfort limits and present high-to-low ranking
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Quantitative Window Comfort Analysis

1. Use Std55 baseline conditions (clothes, activity)
2. Set thermostat to code baseline
3. Assume moderate size window (30 sq.ft.) and occupant @ 3’ away
4. Set PPD limits at 10% above space w/o window
Winter Comfort w/o Windows
Window MRT Limit ~ 68°F
Quantitative Window Comfort Analysis

1. Use Std55 baseline conditions (clothes, activity)
2. Set thermostat to code baseline
3. Assume moderate size window (30 sq.ft.) and occupant @ 3’ away
4. Set PPD limits at 10% above space w/o window
5. Analyze window response vs. TMY3 weather data
6. Sum hours of discomfort for:
   • Winter Night
   • Summer Day
   • Swing Season (no heat or cool; space temp drifts)
## MINNEAPOLIS, MN

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### Double Pane Glass

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### Hours of Discomfort

- **SummerDay**
- **SwingSeason**
- **WinterDay**
- **WinterNight**
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MINNEAPOLIS, MN

### Hours of Discomfort

#### Double Pane Glass

- **No Low-E**
  - **SummerDay**: 1500
  - **SwingSeason**: 700
  - **WinterDay**: 500
  - **WinterNight**: 200

- **High Solar**
  - **SummerDay**: 750
  - **SwingSeason**: 350
  - **WinterDay**: 150
  - **WinterNight**: 70

- **Med Solar**
  - **SummerDay**: 450
  - **SwingSeason**: 200
  - **WinterDay**: 100
  - **WinterNight**: 40

- **Low Solar**
  - **SummerDay**: 300
  - **SwingSeason**: 100
  - **WinterDay**: 50
  - **WinterNight**: 20
## Low E Type

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## MINNEAPOLIS, MN

### Hours of Discomfort

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</tbody>
</table>

### Double Pane Glass

<table>
<thead>
<tr>
<th>Double Pane Glass</th>
<th>No Low-E</th>
<th>High Solar</th>
<th>Med Solar</th>
<th>Low Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.47</td>
<td>0.33</td>
<td>0.32</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>0.57</td>
<td>0.52</td>
<td>0.32</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>44°F</td>
<td>55°F</td>
<td>56°F</td>
<td>56°F</td>
</tr>
</tbody>
</table>

### Triple Pane

<table>
<thead>
<tr>
<th>Triple Pane</th>
<th>No Low-E</th>
<th>High Solar</th>
<th>Med Solar</th>
<th>Low Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Solar</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Med Solar</td>
<td>0.42</td>
<td>0.29</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Low Solar</td>
<td>61°F</td>
<td>61°F</td>
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</tbody>
</table>
## SAN ANTONIO, TX

<table>
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<tr>
<td>Window SHGC</td>
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<tr>
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### Hours of Discomfort

- **Summer Day**
- **Swing Season**
- **Winter Day**
- **Winter Night**

**Double Pane Glass**

- **No Low-E**
- **High Solar**
- **Med Solar**
- **Low Solar**

**Triple Pane**

- **High Solar**
- **Med Solar**
- **Low Solar**

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*Graph showing hours of discomfort for different window types and conditions.*
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**MINNEAPOLIS, MN**

Double Pane Glass

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<td>Hours of Discomfort</td>
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<td>Summer Day</td>
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Triple Pane

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**Double Pane Glass**

**Triple Pane**
## KANSAS CITY, MO

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### Hours of Discomfort

- **Double Pane Glass**
  - No Low-E
  - High Solar
  - Med Solar
  - Low Solar

- **Triple Pane**
  - High Solar
  - Med Solar
  - Low Solar

---

The bar chart above illustrates the hours of discomfort for various types of windows in Kansas City, MO. The chart differentiates between Summer Day, Swing Season, Winter Day, and Winter Night conditions.
Comfort Corollary w/Equip Sizing

Design to the worst case conditions and you’ll provide the best thermal satisfaction

(don’t forget about overheat!)
Thermostat Roulette

Are you betting on the equipment or the envelope?