What is Dimming?

Project Update
Daniel Marcus
Kathryn Sweater
N. Narendran
Edward Bear
Jean Paul Freyssinier
Please Note...

• The information contained in this presentation is preliminary and still under investigation. Please do not circulate.

• Once the research is finalized, we will submit reports or documents and provide an electronic copy to you.
Introduction

• No formal definition of dimming
  – Universally understood as the ability of a light source to change in light output between fully on and a minimum value
    – Incandescent lamps: dim to zero
    – Linear fluorescent lamps: could dim to 1%
• Dimming modes: continuous or step
  – Purpose of dimming: ambiance, energy savings

• Objective: Identify parameters that create a precise definition of dimming
Background

• LRC research focused on
  – Evaluating dimmers/lamps under NEMA SSL-6
    • Electrical characteristics
    • Dimming profile
    • Flicker
  – Conducting human factors research to understand consumer requirements
Literature review

• IES Lighting Handbook (2000) identifies the following issues with dimming
  – Dimming is contextual: absolute light levels, color shift
    • Conference room: reading vs. audiovisual presentation
    • Color shift may be desirable in hospitality applications
      – May be desirable and expected from incandescent lamps
      – Not desirable from fluorescent lamps
  – No flicker
  – No audible sound
## Literature Review

### Dimming Characteristics Identified in NEMA SSL-6

<table>
<thead>
<tr>
<th>Human Factors</th>
<th>Photometric</th>
<th>Electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimming profile</td>
<td>Maximum light output</td>
<td>Inrush current</td>
</tr>
<tr>
<td>Dead travel</td>
<td>Minimum light output</td>
<td>RMS current</td>
</tr>
<tr>
<td>Monotonic dimming</td>
<td>Color shift</td>
<td>Voltage ring up</td>
</tr>
<tr>
<td>Audible noise</td>
<td>Light level turn on compared to set light level</td>
<td>Current ring up</td>
</tr>
<tr>
<td></td>
<td>Flicker</td>
<td>Pop on phase angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turn on time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turn off voltage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current crest factor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Efficiency</td>
</tr>
</tbody>
</table>
Study Focus
Selected Parameters to Define Dimming

1. Minimum light level
2. Dimming profile
   2.1. Dimming curve
   2.2. Dead travel
   2.3. Monotonic dimming
3. Flicker
4. Audible noise
5. Maximum light level
1. Minimum Light Level
Experimental Design

• Reading task
  – “Please let me know when the light level reaches the minimum acceptable level where you can still search for names and numbers in the white pages.”

• Ambiance setting task
  – “Please let me know when the light level reaches the minimum acceptable level that you would dim to make the room relaxing and comfortable.”
1. Minimum Light Level

Results

![Graphs showing minimum acceptable light levels for different tasks under various illuminance levels, including visual and ambient tasks with absolute and relative light levels.]
1. Minimum Light Level
CFL samples

- 19 (53%) combinations dim below 50%
- 13 (36%) combinations dim below 25%
- 10 (28%) combinations dim below 10%
1. Minimum Light Level

LED samples

<table>
<thead>
<tr>
<th>Lamp</th>
<th>LED A</th>
<th>LED B</th>
<th>LED C</th>
<th>LED D</th>
<th>LED E</th>
<th>LED F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimmer 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimmer 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimmer 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimmer 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimmer 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimmer 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 22 (61%) combinations dim below 50%
- 19 (53%) combinations dim below 25%
- 17 (47%) combinations dim below 10%
2.1. Dimming Curve
Experimental Design

- Subjects were asked if the light level of each presentation matched their expectations of the light level (in percent) as stated by the experimenter.
2.1. Dimming Curve

Results

Experiments verified the square law curve for brightness perception (n=15)
2.1. Dimming Curve Results

Dimming Profiles for Subject Evaluation

Average Subject Ratings (n=15)

*Curves 1 and 2, while based upon the NEMA boundary curves, are not actually the NEMA curves
2.1. Dimming Curve

Measured dimming curves of 5 LED/dimmer combinations

Dimmer Travel vs. Light Output
LEDs on Dimmer 2

- Power Law
- LED A
- LED B
- LED C
- LED D
- LED E
- Incandescent Lamp

User Perception (Dimmer Travel, %)
Measured Light Output (%)
2.1. Dimming Curve

Measured dimming curves of 3 CFL/dimmer combinations
2.1 Dead Travel

Dead travel occurs when the actuator of the dimmer changes value while the light output does not.

![Graph showing dimmer travel](image-url)
2.1 Dead Travel

- Dimming profiles with various levels of dead travel were assessed by subjects.
- None
- Top of Profile
  - 5%, 10%, 20%, 30%
- Middle of Profile
  - 5%, 10%, 20%, 30%
- Bottom of Profile
  - 10%, 20%, 30%
2.1 Dead Travel

- Dimming profiles with various levels of dead travel were assessed by subjects.

- None
- Top of Profile
  - 5%, 10%, 20%, 30%
- Middle of Profile
  - 5%, 10%, 20%, 30%
- Bottom of Profile
  - 10%, 20%, 30%
2.1 Dead Travel Results

"Did you notice dead travel in the dimming profile?"

Subjects Responding 'Yes' (%)

Percent Dead Travel

- Top of Profile
- Middle of Profile
- Bottom of Profile

CONFIDENTIAL – Do Not Distribute – PRELIMINARY
© 2012 Rensselaer Polytechnic Institute. All rights reserved.
2.1 Dead Travel Results

“How distracting was the dead travel?”

- **Top of Profile**
- **Middle of Profile**
- **Bottom of Profile**

![Bar chart showing distraction levels for different profiles and percent dead travel.](image)
2.2 Monotonic Dimming

Clear tolerance levels are needed for ‘non-monotonic dimming’
2.2 Monotonic Dimming

Clear tolerance levels are needed for ‘non-monotonic dimming’
3. Flicker

- Detection and acceptability of stroboscopic effects (above 100 Hz) can now be modeled (Bullough et al. 2012)
- What’s needed:
  - A method to distinguish between high frequency and low frequency light output signals
  - A model to evaluate frequencies below 100 Hz
  - Limits on ‘acceptable’ perceivable flicker
Rated Acceptability of Stroboscopic Effects: Was it acceptable?

Bullough et al. (2012 in press)
http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp

Bullough et al. (2012 in press)
4. Audible Noise

• Specific methodology required
  – NEMA SSL-6 uses dBA with no test procedure requirements

• Methodology standards (examples):
  – ISO 532:1975
  – ISO 7779:2010
5. Maximum Light Level

- A dimmer/lamp combination should have a light output within X% of the lamp’s output when operated without a dimmer.

$$\text{max}(\%) = \frac{\phi_{\text{dim(max)}}}{\phi_{\text{AC}}}$$

**Maximum Light Output Relative to Lamp on 120VAC**

![Graph showing maximum light output relative to lamp on 120VAC for various lamps and dimmer settings.](image)
ASSIST Recommends Draft Definition of Dimming

1. Minimum light level
   - 10% of maximum light level

2. Dimming profile
   - Within a defined tolerance of initial profile (Figure 1)
   - No more than 10% dead dimmer travel anywhere in dimming profile
   - Monotonic dimming, within a defined tolerance of inverse change in intensity over a dimmer travel period < 10% of dimming profile (Figure 2)

![Noticable Variation in Brightness](Figure 1)

![Noticable Variation in Brightness](Figure 2)
3. Flicker
   – No flicker below 100 Hz; < 25% flicker above 100 Hz.

4. Audible Noise
   – Maximum limit to be determined for audible noise; update methodology.

5. Maximum light level
   – No less than 90% of maximum when operated on constant AC voltage
Acknowledgments

3M  AcuityBrands  amerlux  BRIDGELUX
CIRRUS LOGIC  COOPER  CREE  DOW CORNING
FAA  GE Lighting Solutions  ITRI  INTEMATIX
LG Electronics  LG Innotek  LightingScience  LITEON
nysarda  OSRAM SYLVANIA  OSRAM  PHILIPS
nysarda  Sylwania  TOSHIBA  posco LED
SEUL  SHARP  TOSHIBA  U.S. EPA
U.S. EPA

© 2012 Rensselaer Polytechnic Institute. All rights reserved.
Questions/Discussion