Toronto IES Presentation
April 15, 2015

Solid-State Lighting:
What is New in Research?

N. Narendran, Ph.D.,
Director of Research
Lighting Research Center
Troy, New York

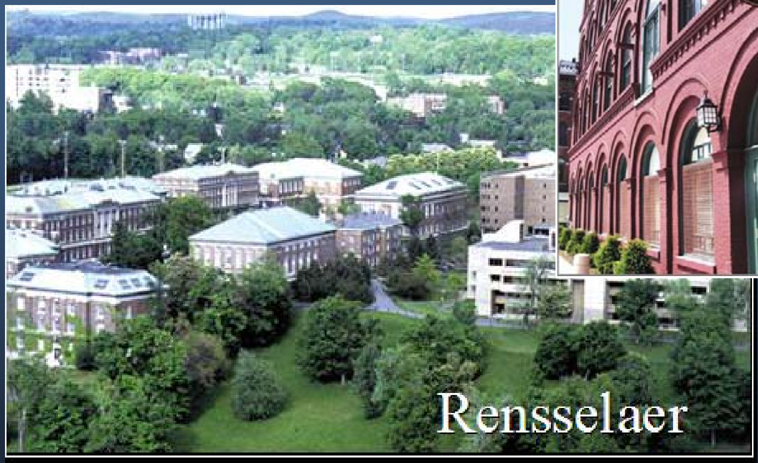
Lighting Research Center

www.lrc.rpi.edu/programs/solidstate

Rensselaer

Rensselaer's Lighting Research Center

- Rensselaer Polytechnic Institute is the oldest engineering university in the US (established 1824).
  - LRC is the largest university-based center for lighting research and education.
  - Started in 1988
- LRC Mission:
  - Advancing the effective use of light and creating a positive legacy for society and the environment



LRC Staff Expertise

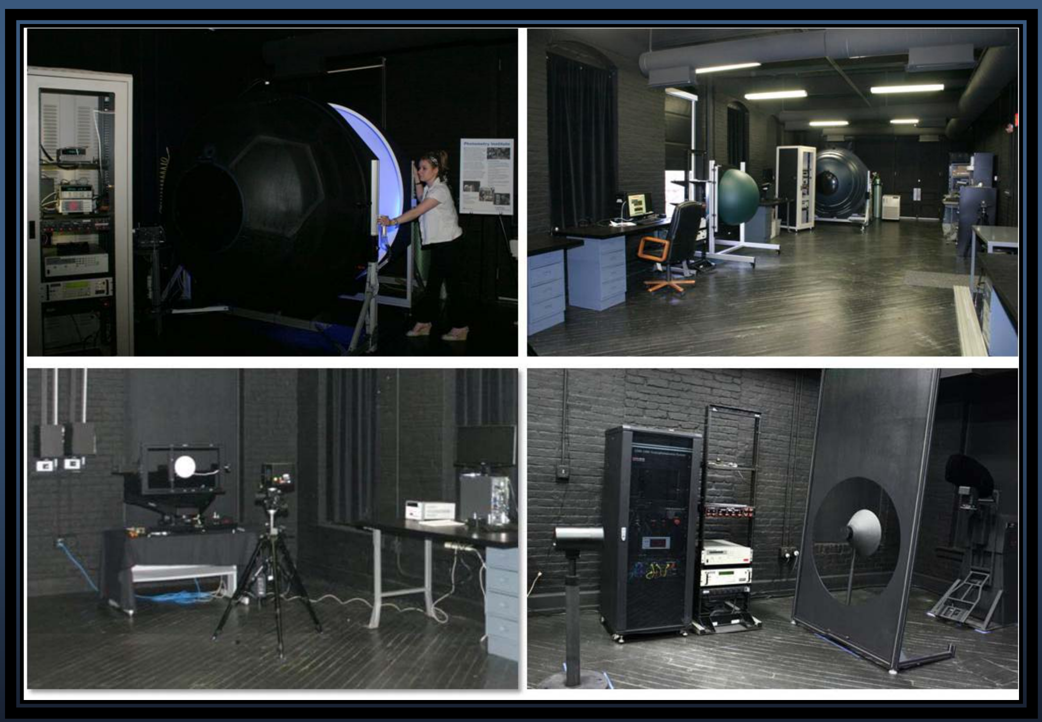
35 faculty and staff

- Engineering
  - Electrical
  - Mechanical
  - Optical
  - Materials
- Architecture
  - Lighting
- Science
  - Physics
  - Biology
  - Biophysics
- Humanities
  - Psychology

Research: Technology, Human factors, Design

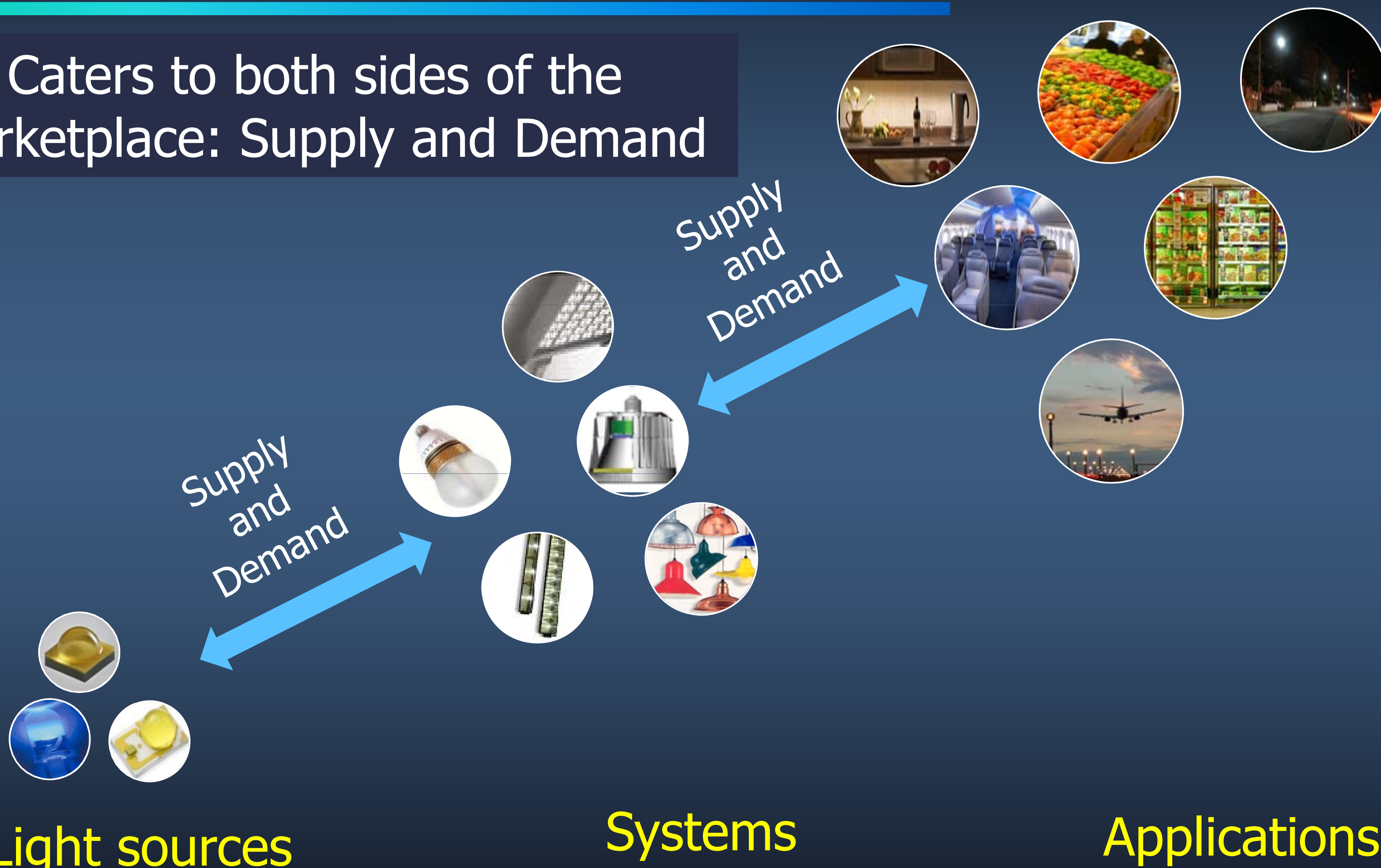
LRC Laboratory Facilities

- 30,000 square feet of research and testing space
- NVLAP accredited testing facility
  - NIST traceable measurements



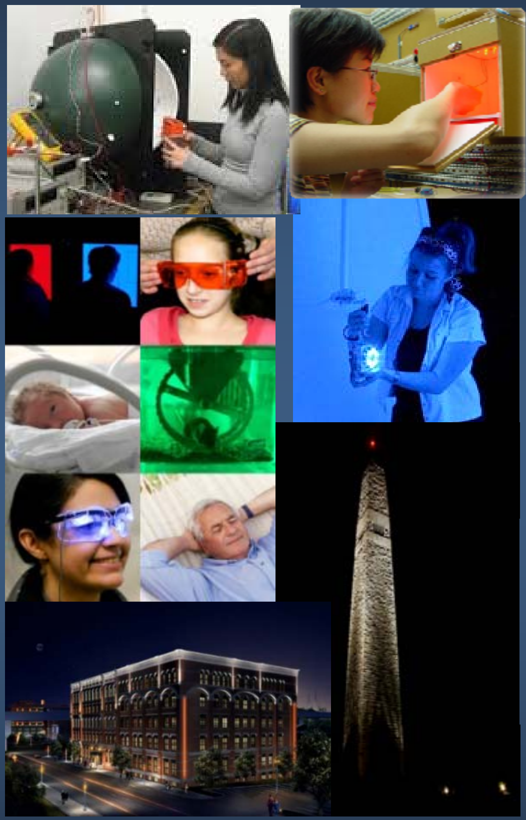
LRC's Solid State Lighting Program

Caters to both sides of the marketplace: Supply and Demand



M.S. and Ph.D. in Lighting

- Multidisciplinary
  - Technology
    - Light sources, luminaires, controls
    - Optics, photometry, colorimetry
  - Human Factors
    - Vision / psychology / physiology
  - Lighting Design
  - Leadership and Entrepreneurship



Finally students gain valuable experience with their thesis, enabling them to be the future leaders in the industry

Industry collaboration

ASSIST

Alliance for Solid-State Illumination Systems and Technologies

- Established: In 2002. A collaboration among researchers, manufacturers, and government organizations.
- Mission: To enable the broad adoption of solid-state lighting by providing factual information based on applied research and by visualizing future applications.
- Activities: Research, demonstration, education, industry networking and standards support

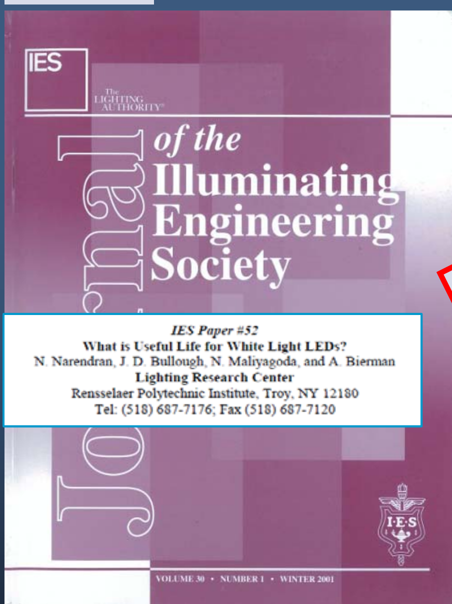
www.lrc.rpi.edu/assist

Dissemination of research results

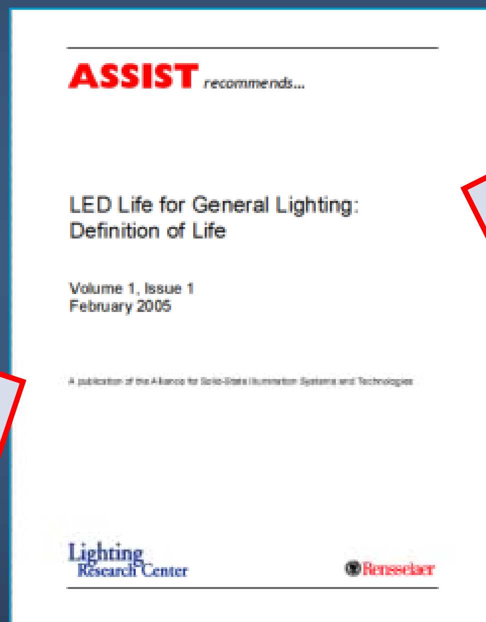
- "ASSIST recommends" publications
  - Goal: To provide formal recommendations about issues important for the reliable performance of LED lighting and its comparison to other technologies
    - Recommendations for testing and evaluating LED lighting & systems
    - Application guides and recommendations for using LED light fixtures in applications
  - Free download: http://www.lrc.rpi.edu/programs/solidstate/assist/recommends.asp

LED life definition and testing

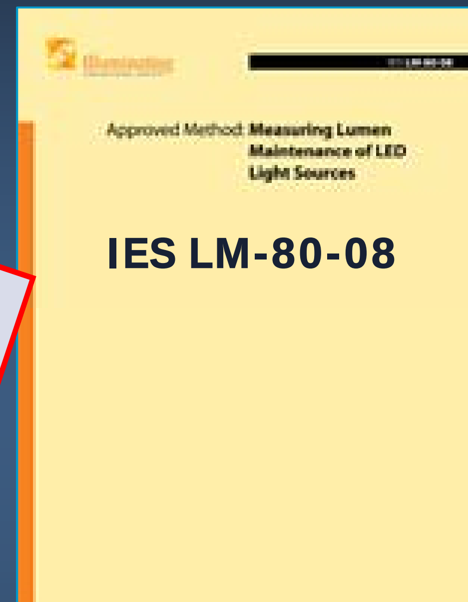
2000



2003-05



2008



ASSIST *recommends*

ASSIST *recommends*
Outdoor Lighting Luminaires

ASSIST *recommends*
Directional Luminaires

ASSIST *recommends*
Color Guide for Retail Lighting

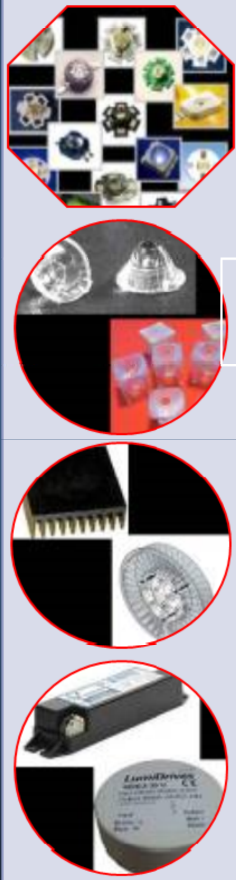
ASSIST *recommends*
LED Light Engines

ASSIST *recommends*
Freezer Case Lighting Luminaires

ASSIST *recommends*
Under-cabinet Lighting Luminaires

Outreach Education - LED Lighting Institute, since 2001

LED technology overview



LED

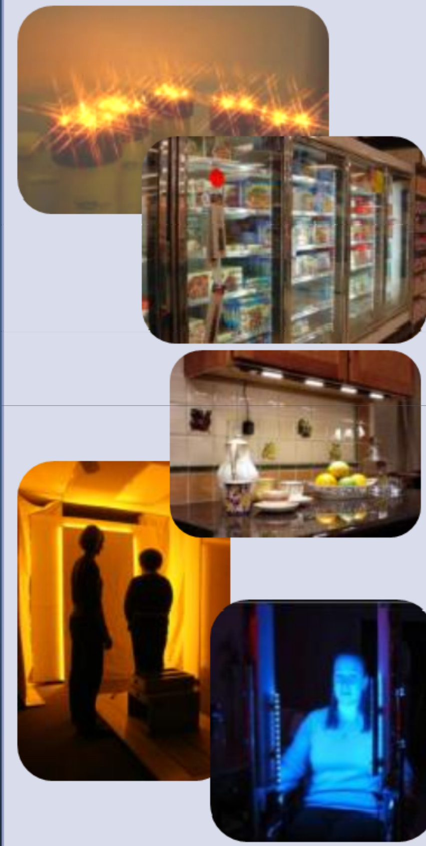
Optical & Photometry

Thermal

Electrical

Labs, demos, and hands-on sessions

Applications and Research Updates



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Topics

1. Color metric
2. Parking lot lighting
3. LED system life prediction

4. New building infrastructure (if time permits)

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Alliance for Solid-State Illumination Systems and Technologies

Class A Color Classification for Light Sources Used in General Illumination

Mark Rea, PhD and Jean Paul Freyssinier, MS

Lighting Research Center

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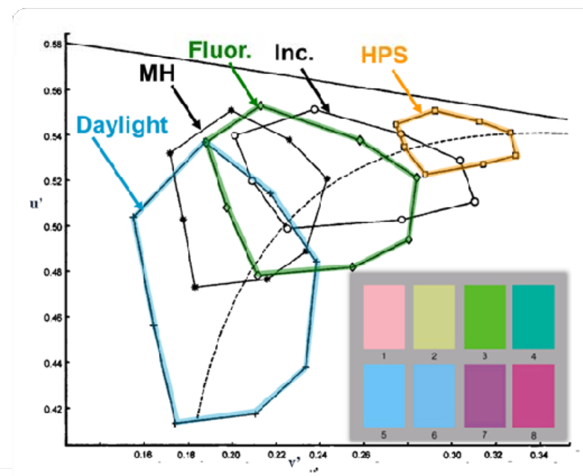
Introduction

- Color rendering (CRI) and the color of illumination (CCT) are two key factors that support architectural lighting (e.g., retail lighting).
  - However, CRI and CCT are not perfectly predictive of people's assessments of illumination from a light source.

Color rendering study

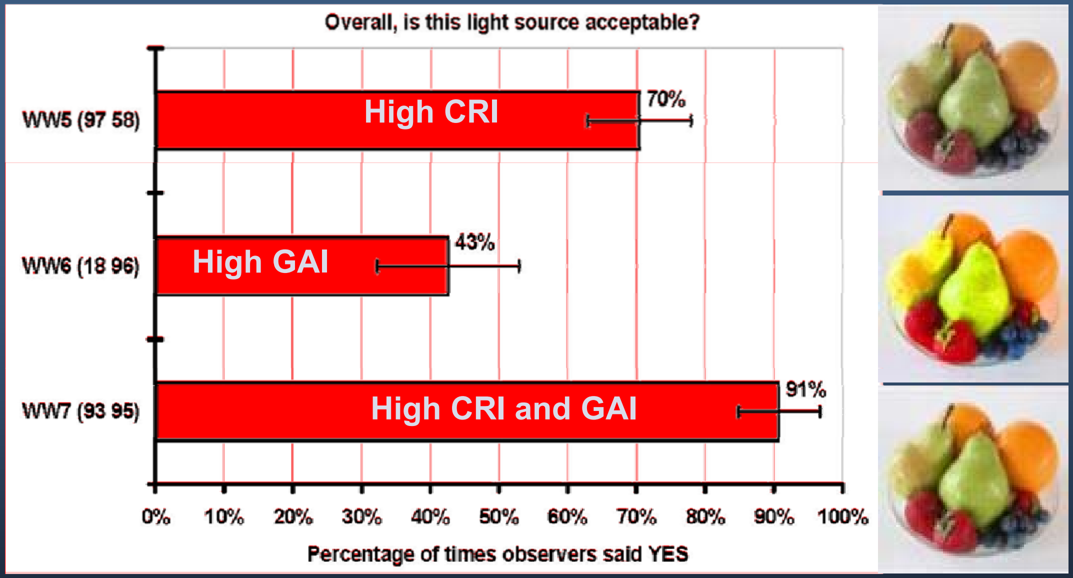
- The goal of the study was to examine correlations of subjective and objective evaluations to CRI and GAI
- In general, the larger the gamut area, the more saturated the color samples are and the easier it is to discriminate between them.

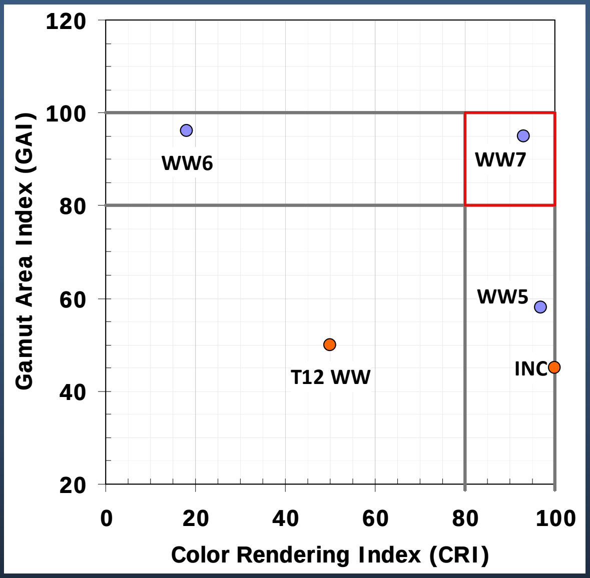


Adapted from *Human Factors in Lighting* - 2nd Edition
Boyce, P. R. 2003. London; New York: Taylor & Francis.

Color rendering study results

- Two metric approach can characterize color rendering much better than a single metric.
  - Good color rendering by a light source depends on providing an optimum amount of color saturation (but without distortion; e.g., objects look like under daylight.)





•Rea, M.S. and J.P. Freyssinier-Nova. 2008. Color rendering: A tale of two metrics. *Color Research and Application* 33(3): 192-202.
•Rea, M.S., and J.P. Freyssinier. 2010. Color rendering: Beyond pride and prejudice." *Color Research and Application* 35 (6): 401-409.

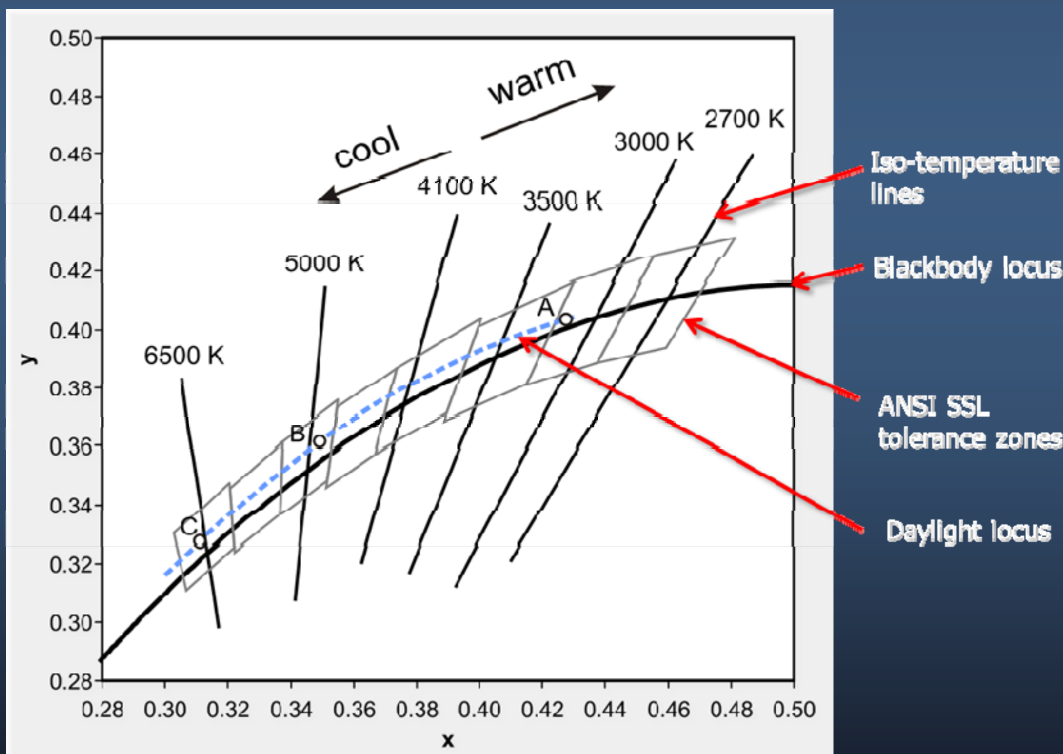
The two-metric strategy

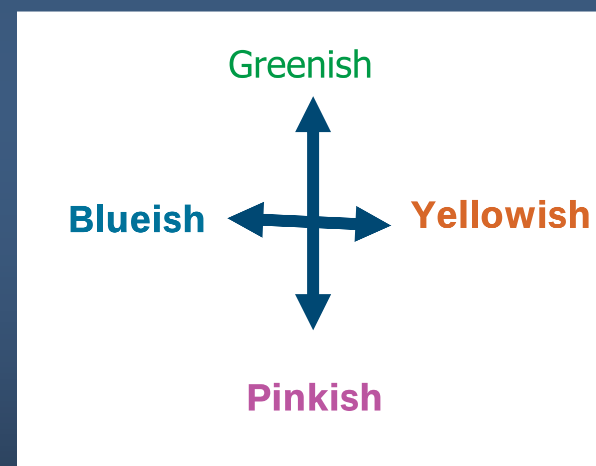
- CRI plus GAI approach
  - Is practical, predictive, and validated by human factors studies.
  - Does not require additional measurements to report CRI and GAI values

Color Appearance of Illumination

Light source color appearance

- Correlated color temperature is the most used metric to specify light source color appearance
  - Based on light source chromaticity





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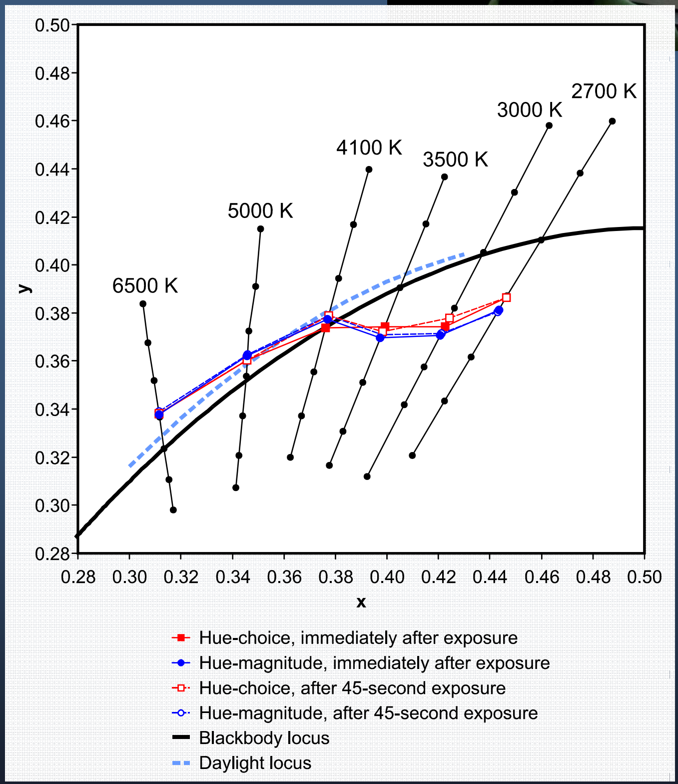
Color appearance study

- A laboratory psychophysical experiment was conducted to investigate the subjective target chromaticity of white illumination of different CCTs
- White points for CCTs 3500 K and lower are below the blackbody locus
- And above the blackbody locus for 4100 K and above



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Class A Lighting – for ease of communication

- CRI > 80 and 80 ≤ GAI ≤ 100
- On or near the "white body" locus
- Consistent chromaticities

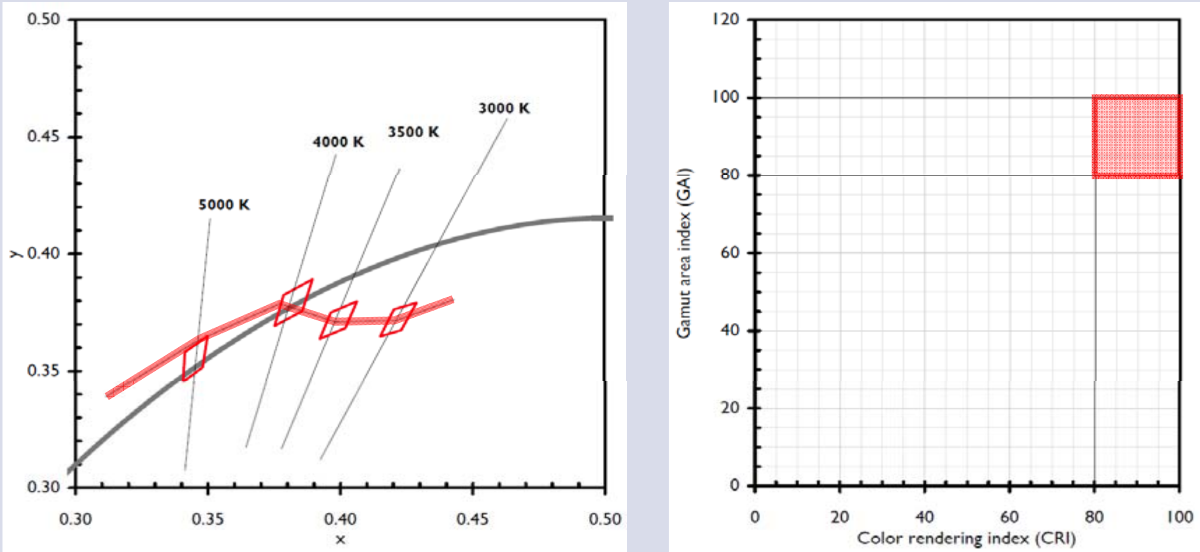

Figure 3. Class A target zones for "white" illumination (left panel) and good color rendering properties (CRI≥80 and 80≤GAI≤100; right panel).

Parking lot lighting

The benefits of uniform illuminance in parking lots

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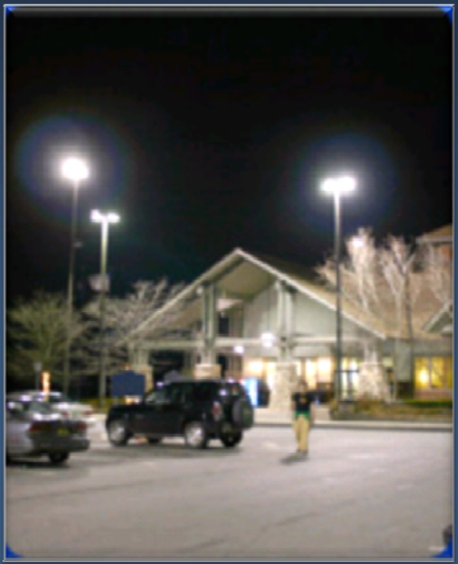
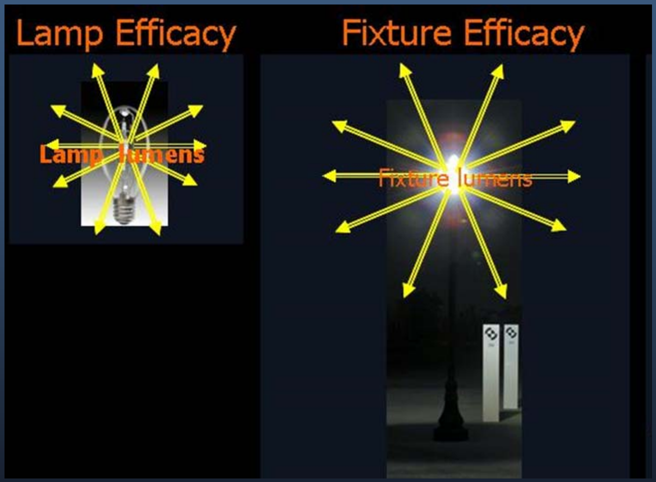
Introduction

- The purpose of parking lot lighting is to satisfy visibility requirements while providing a sense of safety and security, comfort, and aesthetic appeal.
  - Other considerations
    - Economy and Environment





- **Myth:** Highly efficacious light sources or luminaires guarantee energy efficient applications.

Luminaire System Application Efficacy (LSAE)

- 2009 ASSIST recommends - LSAE to evaluate parking lot luminaires based on application efficacy, which considers
  - Only the flux on the target that met the IES RP-20-98 criteria for minimum light level (2 lx) and uniformity ratio (20:1; max:min)
    - LSAE = useful luminous flux ÷ luminaire power

LSAE has a good correlation with a parking lot's lighting power density.

This metric used the requirements of RP-20-98 because at the time there was no evidence to use a different uniformity criterion.

*For basic illumination in this example

Lighting transformation

- Transformation from HID to LED
  - potential to save energy and reduce maintenance cost.
- Commonly, LED luminaires are built to match beam distributions of traditional HID luminaires
  - To maintain similar light levels and distribution
- LED luminaires can efficiently direct light to where it is needed
  - Can achieve highly uniform illuminance on parking lot surface.

Is there a benefit to uniform illuminance?

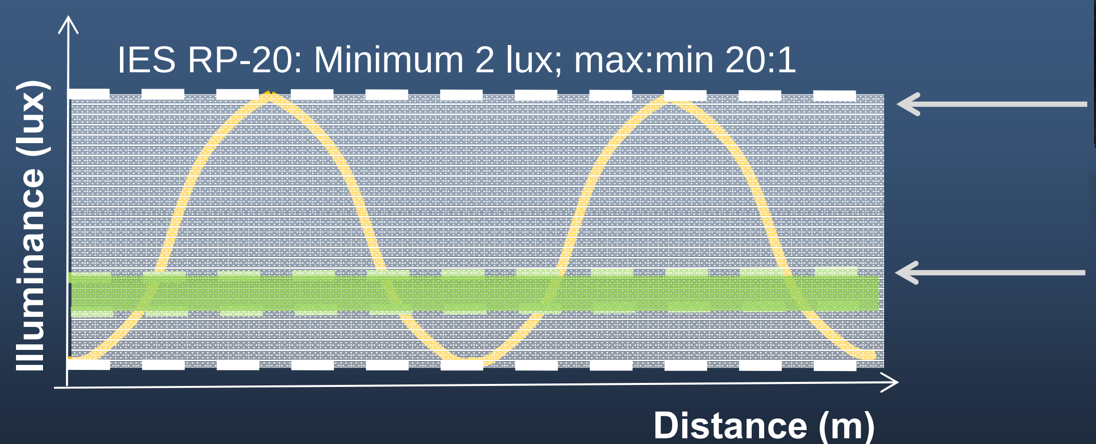
Knowledge gap: There weren't any past studies that have shown the benefits of uniform illuminance in parking lots.

Studies

- We performed a three-part study.
  - Part 1: Human factors study
    - To understand if uniform lighting can improve visibility and perception of safety and security
    - To determine the minimum light level required to achieve highest user satisfaction under uniform and non-uniform lighting conditions
  - Part 2: Optical ray tracing analysis
    - To understand how much uniformity is achievable with LED fixtures
  - Part 3: LSAE Analysis
    - To estimate the potential for energy savings from systems that provide uniform lighting

Study objectives

- To understand if uniform lighting can improve
  - Visibility, perception of safety and security, and energy demand
- To determine minimum light level requirements
  - when the illuminance is more uniform



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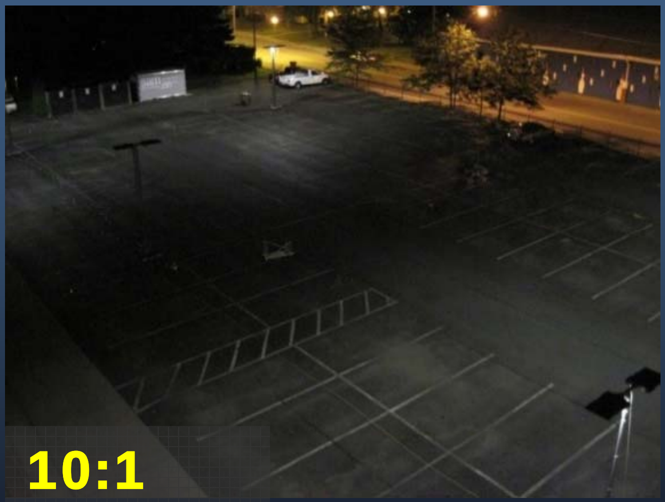
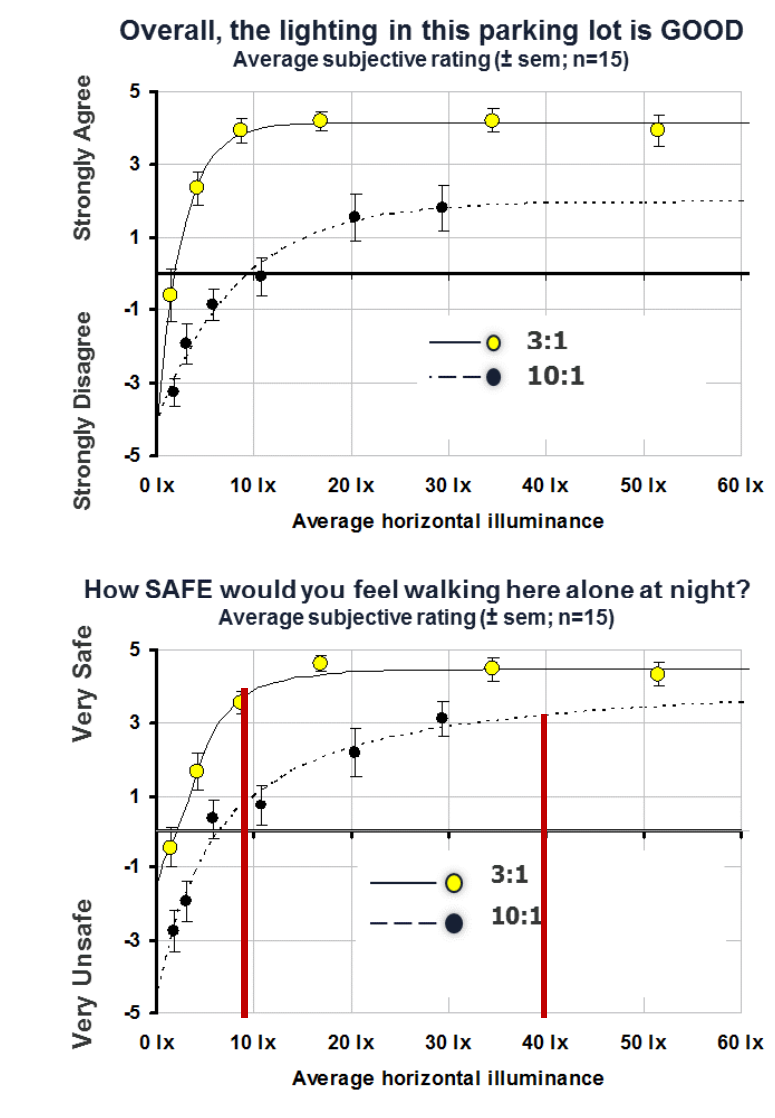
Field study

- Field evaluation
  - RPI campus parking lot
  - Two levels of uniformity,
    - 3:1 Uniform; 10:1 Non-Uniform
  - Six nominal light levels from 2 lx to 60 lx
- Gathered subjective impressions from 43 participants
  - about perceptions of brightness, visibility, safety, glare, uniformity, and well the parking lot is lighted



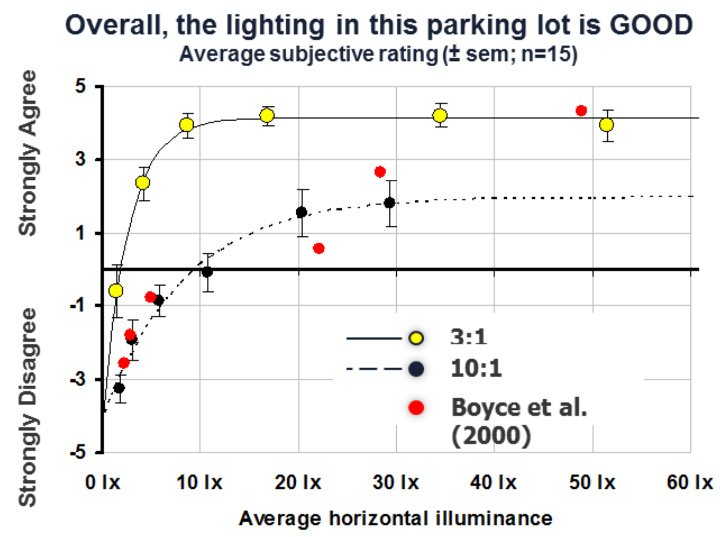
Results

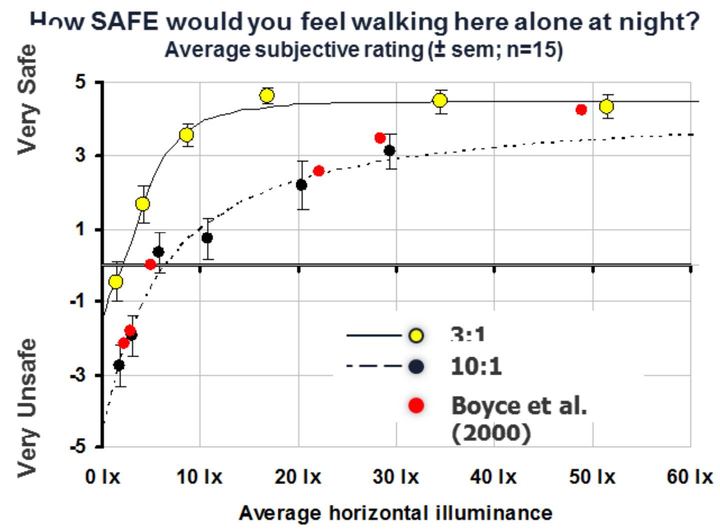
- When the illumination is
  - Uniform: perceptions of how good the lighting is and how safe people feel reach high ratings at much lower light levels
  - Non-uniform: subjective ratings are not as high even for increased illuminance



Results

- When the illumination is
  - Uniform: perceptions of how good the lighting is and how safe people feel reach high ratings at much lower light levels
  - Non-uniform: subjective ratings are not as high even for increased illuminance
  - Consistent with Boyce et al. (2000)





Results summary

- The perceptions of good lighting and safety reach high ratings at
  - >9 lux: for **Uniform**; 3:1 ratio
    - Maximum rating ~ +4
  - >40 lux: for **Non-uniform**; 10:1 ratio
    - Maximum rating ~ +2

Replacing RP-20-14 recommendations from

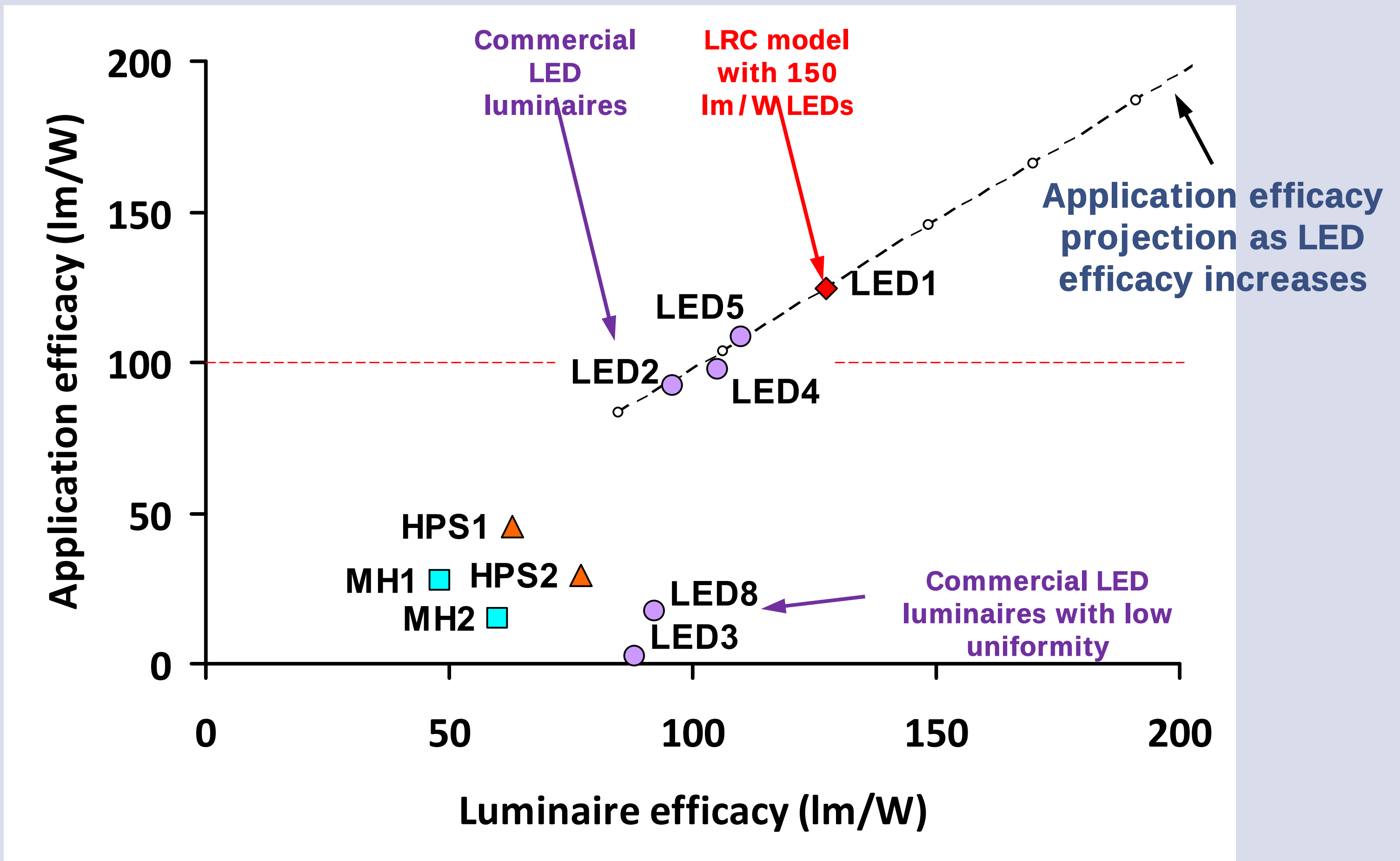
- Minimum light level of 5 lux
- Uniformity ratio (max/min) of 15:1 (max: 75 lx)

to

- Minimum light level of 4.5 lx
- Uniformity ratio of 3:1 (max: 13.5 lx)
- Average light level of 9 lux

will yield better illuminated parking lots.

LSAE comparisons



Conclusions

- In parking lots, for equal average illuminance and uniform lighting provides
  - higher ratings of perceived safety and security
  - Up to 75% energy savings
- Smaller light sources have an optical advantage over larger size sources
  - for creating uniform beam distributions.
- LSAE is a more useful metric than light source or luminaire efficacy

Development of a Predictive Life Test Method for LED lighting systems

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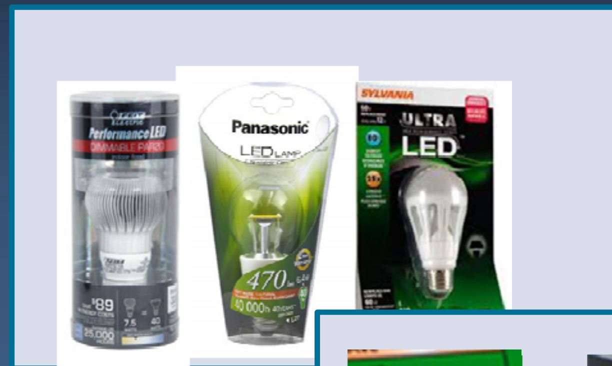
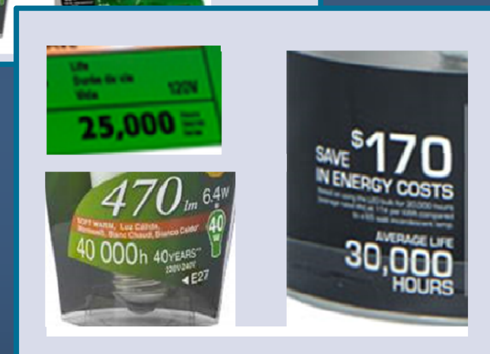
Background

- Why LED system life?
  - How often to change the light bulb
  - Life-cycle cost analysis





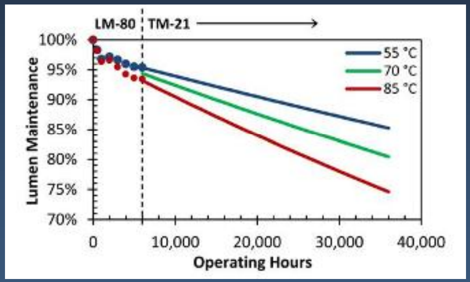
- Users buying a lighting product expect it to perform and last the same in all applications

Applications

www.destinationlighting.com/

Background

- LED system life
  - Presently, LED lighting product life is rated based on LED lumen maintenance (LM80/TM21)
- A lighting system has many components.
  - Failure of any component can cause system failure
- Therefore, the whole system has to be tested to obtain a reasonable life estimate.



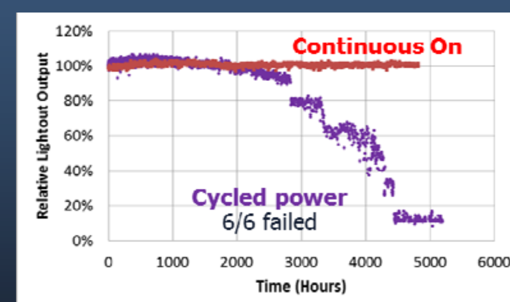
Background

- IESNA LM 84-14 standard:
  - First attempt towards developing a system life test method
  - Test method is based on continuous operation
- In applications the lighting systems are turned on and off
  - Typical use pattern:
    - A - Office: 12 hrs on, 12 hrs off
    - B - Home: 4 hrs on, 4 hrs off
- LRC studies have shown that power cycling causes component/system failure

A

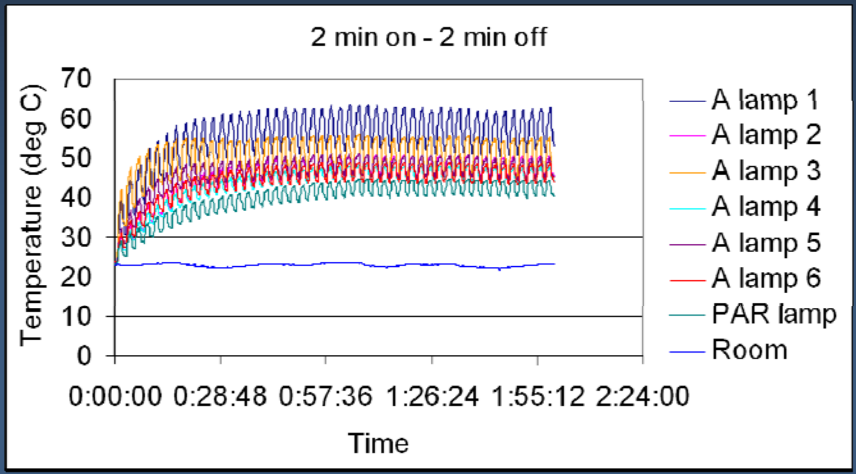
B

- community.lighting.philips.com/
- www.ledsource.com/products/residential



Background

- Some standards have very fast cycling of LED products to test for failures.
  - Very small delta T
  - May not cause damage



- Generally there are two types of failures:
  - Parametric
    - Lumen depreciation or color shift
  - Catastrophic
    - Ceases to produce light

Study Goal

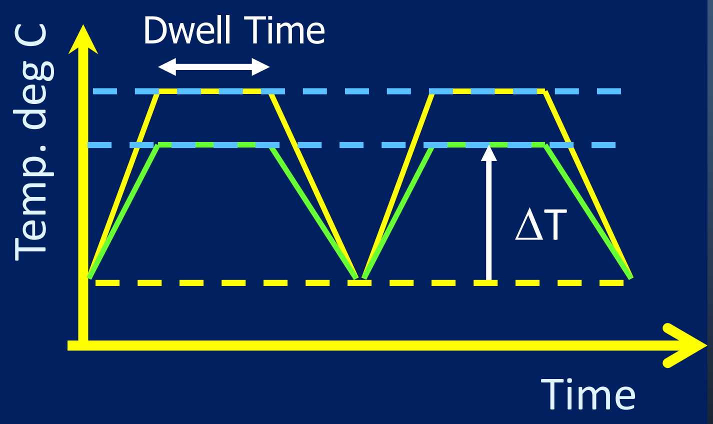
- To develop an accelerated test method that can predict failure of an LED system based on factors such as
    - Environment temperature (Tpin)
    - On-off cycling

Study

- Objective: To understand the effect of different delta temperature and dwell times on LED lamp failure
  - Lamps used: 40W and 60W equivalent LED replacement lamp

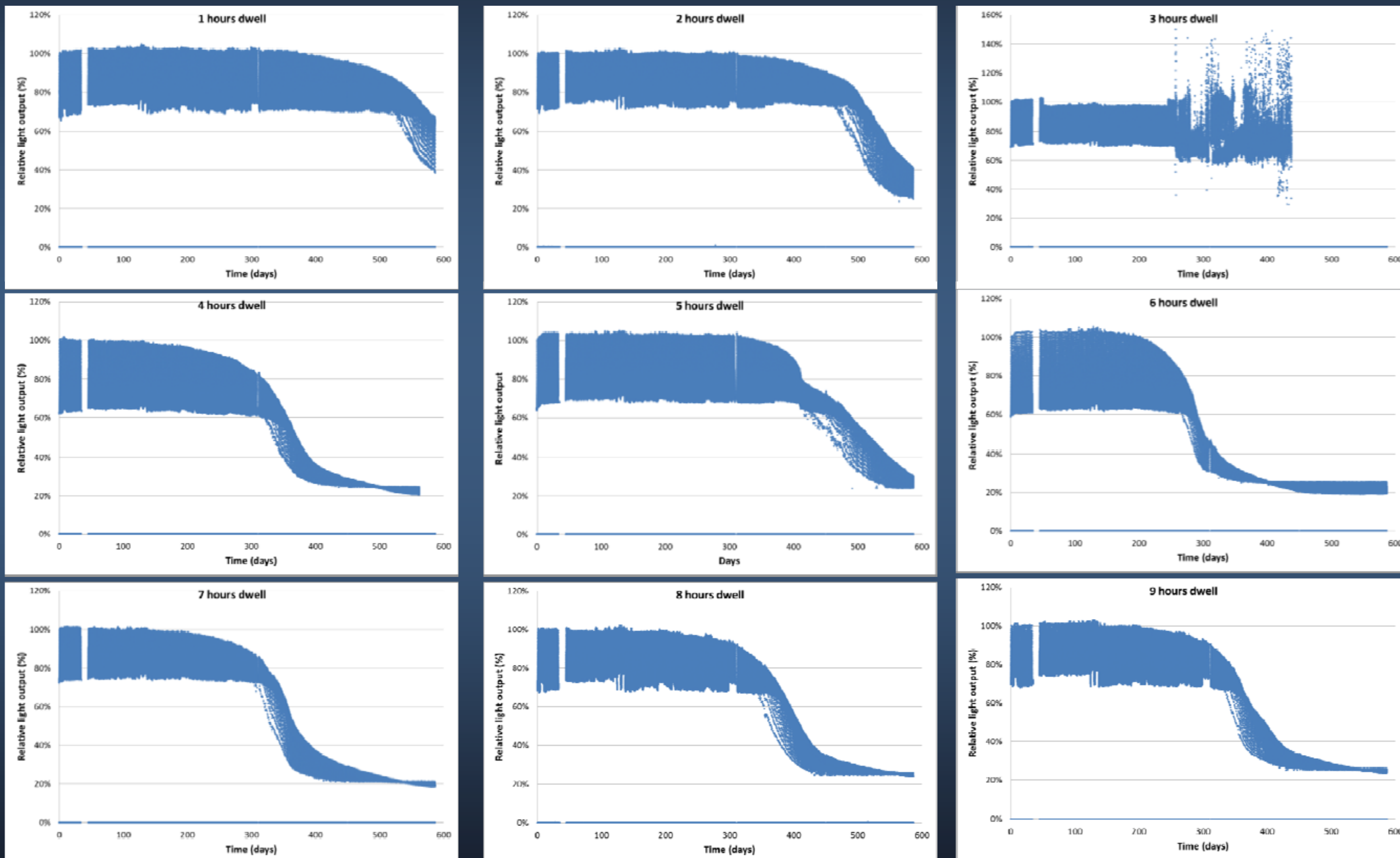
ΔT	60°C	70°C	80°C	90°C

Dwell Time	1, 2, 3, 4, 5, 7 hours



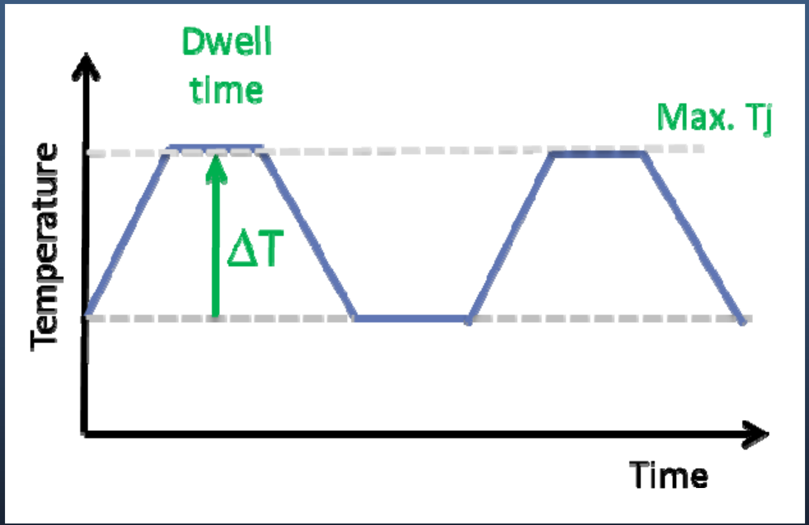
Results: 40W

Light output pattern

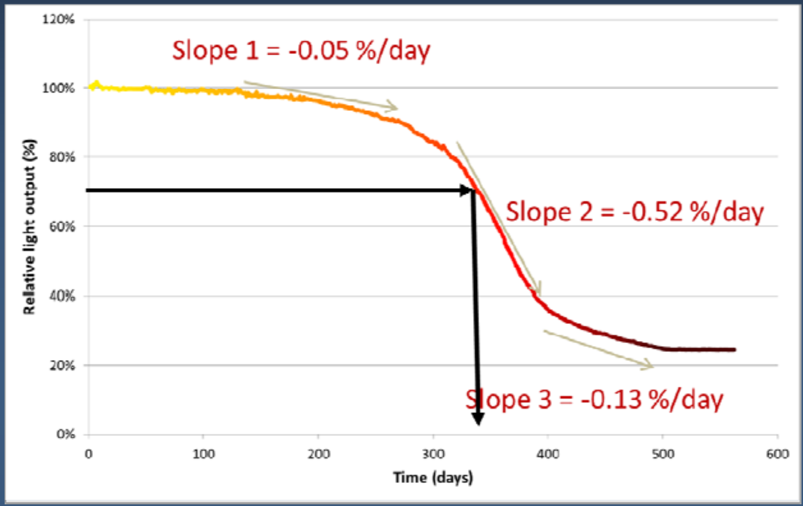


Results: 40W

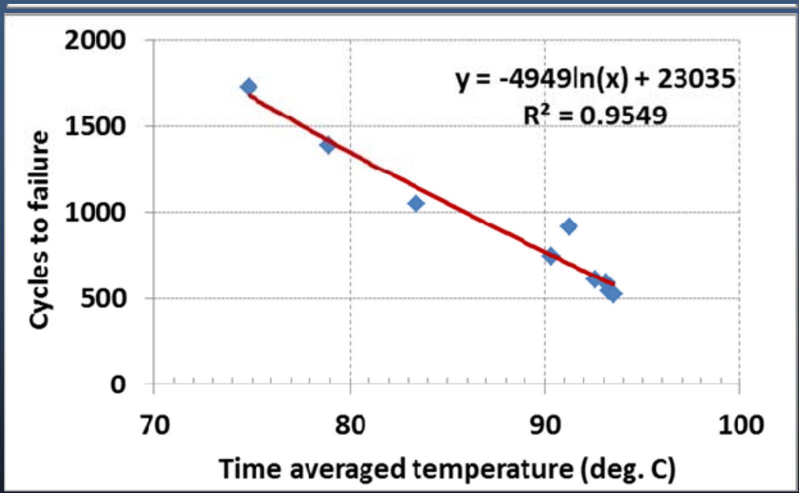
- Lumen deprecation, failure assumption:
  - 70% light level
- Cycles to failure
  - Correlated well with
    - time averaged temperature



Multiple degradation mechanisms

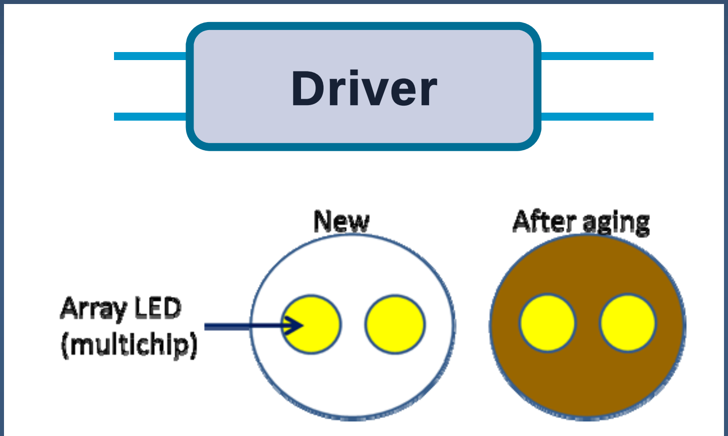


*4 hours dwell sample



Discussion: Failure Analysis

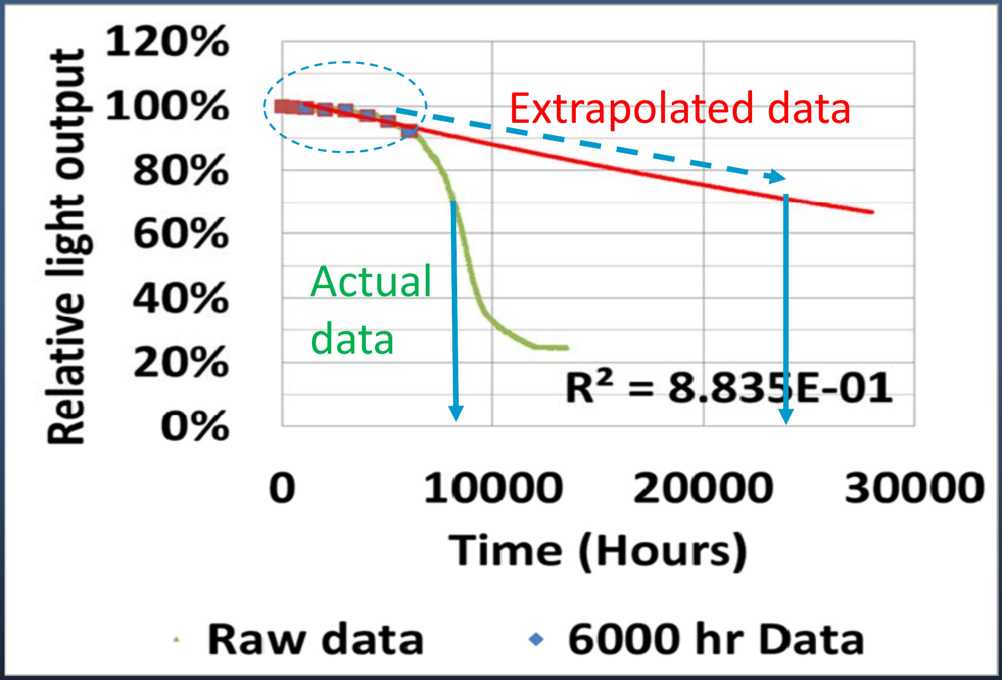
- Lumen depreciation was due to electrical and optical degradations
  - 40% light loss due to electrical
  - 13% light los due to optical



	New sample	D95 Aged sample	D95 aged sample with original current
Current (mA)	193	117	193
Light output	100%	47%	87%

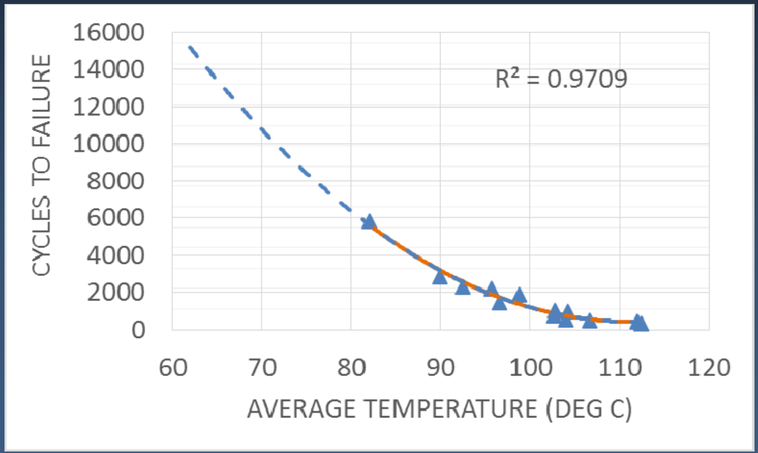
Discussion: Data Extrapolation

- Extrapolating the 6000 hr data can lead to erroneous results
  - Projected life = 25,000 hrs
  - Actual life = 8,000 hrs

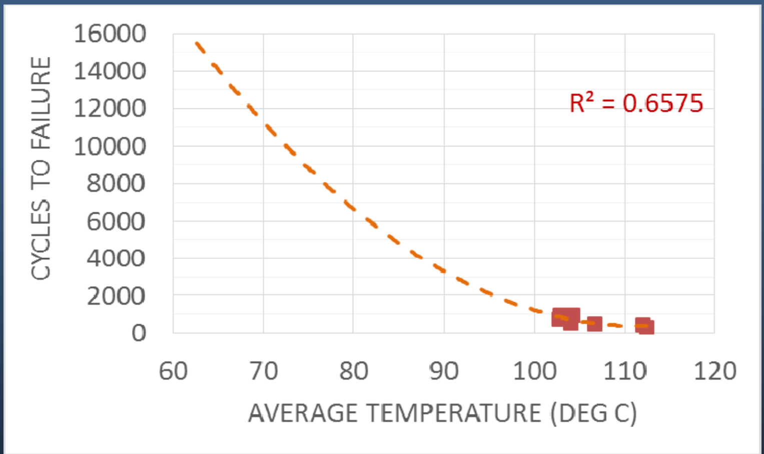


Results: 60W

- For the system tested, cycles to failure has a good correlation with time averaged temperature.
  - o Dominant failure mode: Solder joint failure



- It appears a 3000-hour test can be developed to project failure of an LED system.
  - o Based on factors such as environment temperature and on-off cycling



Final Remarks

- Failures can be parametric or catastrophic
- Life testing of LED systems must include on-off cycling
- In an LED system lumen depreciation can be due to several factors (Electrical and optical)
  - Simple function extrapolation for systems may lead to erroneous results
- Failure acceleration using delta T and dwell time looks promising in predicting the failure of LED systems under different operating conditions

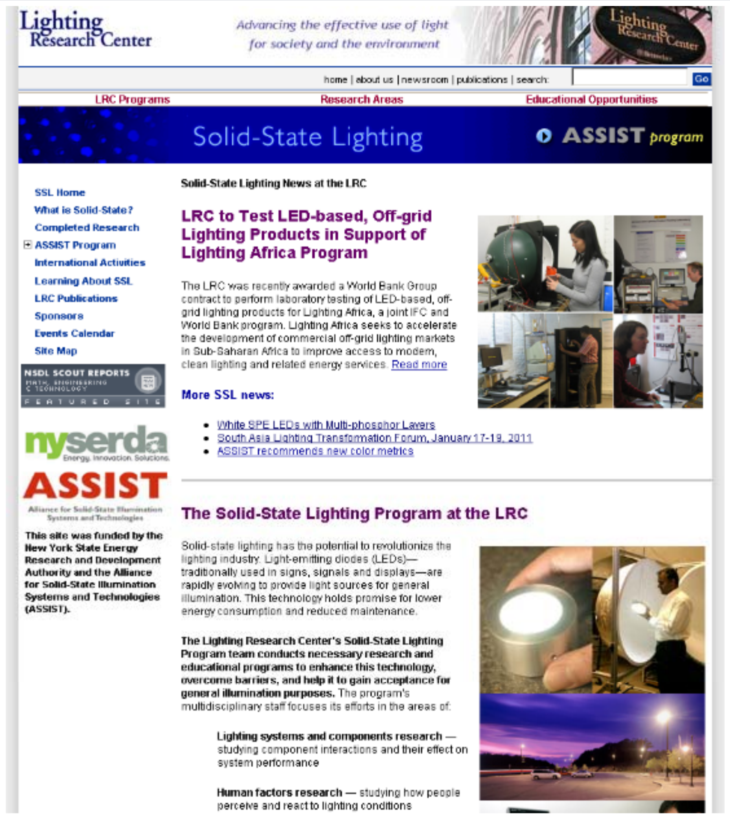
Future study

- Additional funding received from BPA, NYSERDA, and ASSIST is allowing us to:
  - Expand the ASSIST study to develop a cost effective, accelerated test method to project LED system life for any given environmental temperature and use pattern.
  - Include a wider range of LED luminaires, light engines, and integral lamps.
- A two-year study began in October 2014

Acknowledgments

- Toronto IES
- LRC partners and program sponsors
- LRC staff and students

Thank You



For more information, please visit
www.lrc.rpi.edu/programs/solidstate