Illuminating the Lighting Landscape

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Connected Lighting and the Future of Intelligent Buildings

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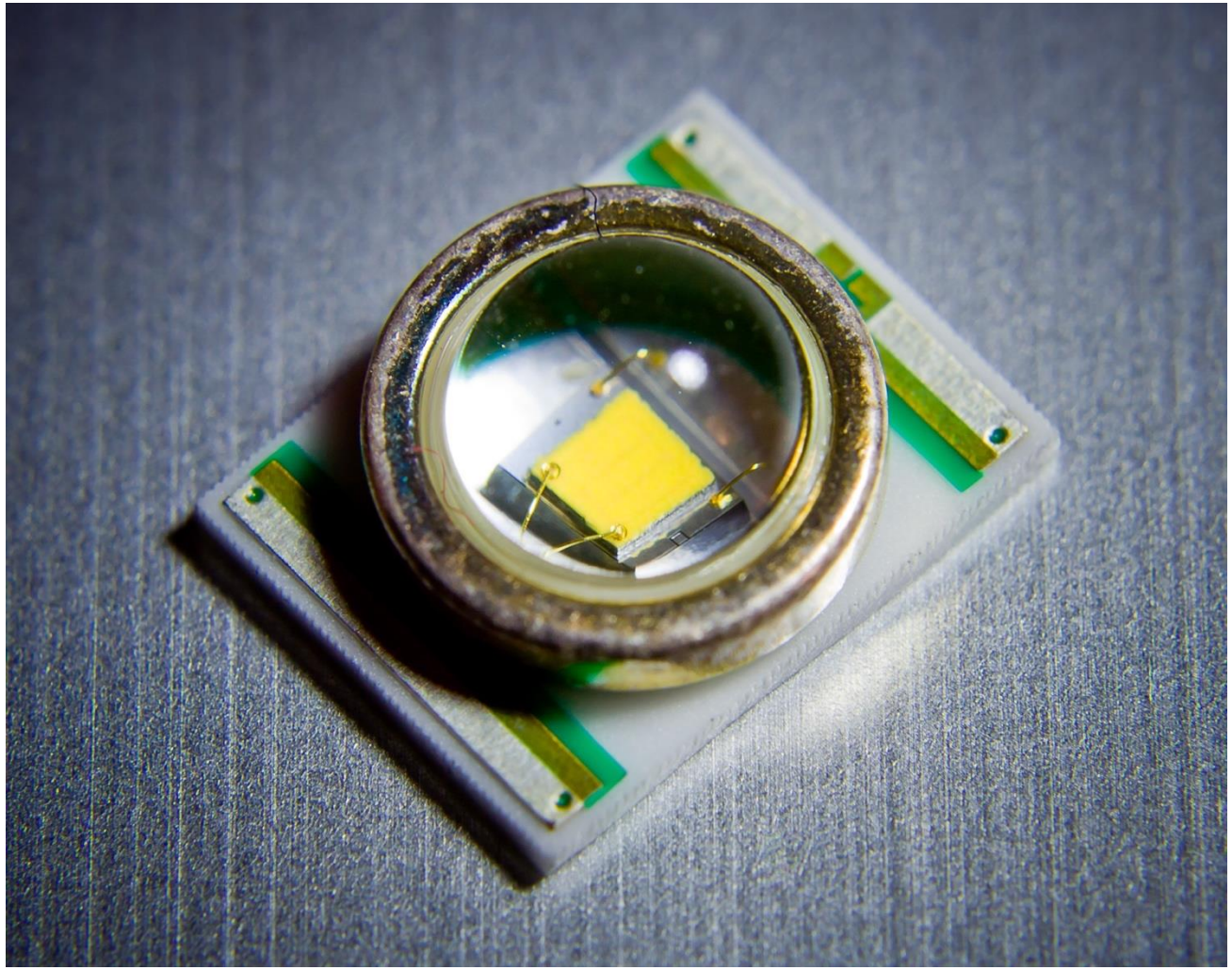
Connected Lighting and the Future of Intelligent Buildings

- What exactly *is* Connected Lighting?
- A Brief Survey of Applications
- Why Should the Energy Industry Care?
- Issues to Keep an Eye On

What Exactly *Is* Connected Lighting?

The LED Revolution is Over

- Device price/performance curves are flattening
- Fixtures are becoming commoditized
- LED products represent well over 50% of sales for all major lighting companies



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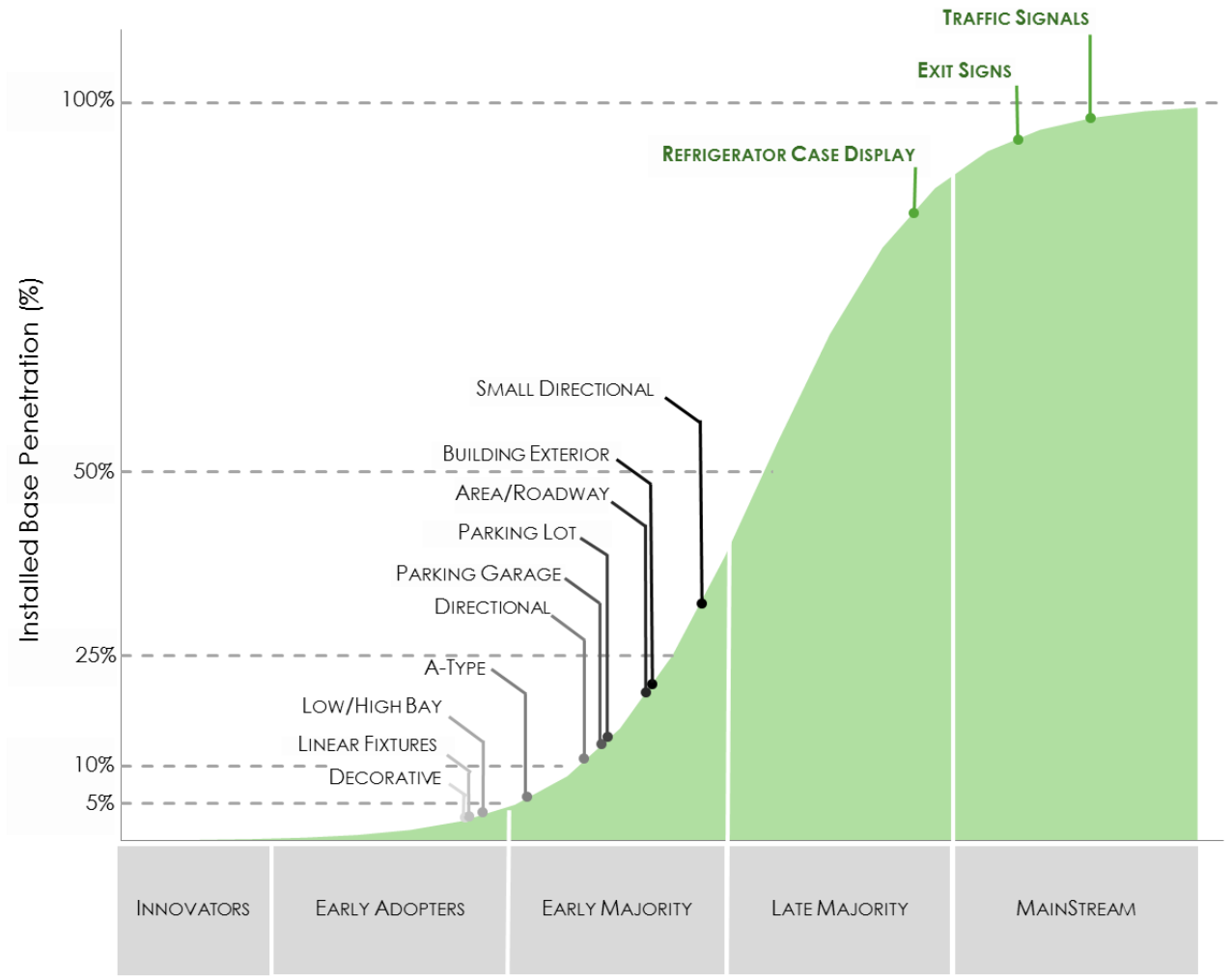
And Yet…

- Vast majority of the installed base still runs on legacy lighting
- Slowest adopters are some of the largest electricity users
- Tremendous opportunity remains as the installed base converts



Source: Department of Energy Solid-State Lighting R&D Plan, June 2016

Connected Lighting
is the New Big Thing

"SSL is creating an opportunity for a whole new lighting system paradigm…The convergence of SSL, low-cost sensors, smartphones and apps, and the Internet of Things (IoT) is expected to facilitate new lighting functionality and an unprecedented exchange of data among lighting and other building systems, the Internet and other devices (e.g., mobile phones)."

-U.S. Department of Energy

A Taxonomy of Connected Lighting

Type 1	• Digitally dimmable LED light sources • Networked fixture-by-fixture control
Type 2	• Distributed sensing integrated into fixtures • Software-adjustable rules with humans “in the loop”
Type 3	• Closed-loop autonomous control • Flexible, data driven behaviors

Why Now?

Key enabling technologies have improved at a rapid pace:

- LEDs and phosphors
- Microprocessors
- Sensors
- Networking chips
- Cloud computing and data storage

A Brief Survey of Applications

If every light over your head were intelligent –

carrying its own processor, sensors and a network connection –

what could we build?

Connected Lighting Application Categories

- Lighting Control
- Energy Management
- Environmental Monitoring
- Security
- Space Utilization
- Asset Tracking
- Location Services

Connected Industrial Lighting

Energy Management

Leverage facility-wide lighting networks to meter every electrical circuit

Asset Tracking

Determine the position of critical equipment and products in real time across hundreds of thousands of square feet

Connected Retail Lighting

Location Services

Provide shoppers with directions, product information and special offers while collecting info

Space Utilization

Map out high-traffic areas and place merchandise accordingly

Connected Office Lighting

Lighting Control

Give employees the ability to adjust lighting to meet their needs

Space Utilization

Identify underutilized real estate

Connected Health Care Lighting

Lighting Control

Make patients more comfortable to improve outcomes

Asset Tracking

Track the location of life-critical and costly equipment

Connected School Lighting

Lighting Control

Adapt spectrum to children's unique circadian rhythms

Security

Monitor locations of students, teachers, staff and visitors in real time

Connected Agricultural Lighting

Environmental Monitoring

Track temperature and humidity throughout large indoor farming facilities

Lighting Control

Tailor red-blue spectral mix to specific crops and growing cycles

Source: http://aerofarms.com/media/

Connected Outdoor Lighting

Environmental Monitoring

Measure critical variables across large urban landscapes

Security

Monitor traffic, disturbances, and large gatherings

Why Should the Energy Industry Care?

First, the Bad News

395 TWh
The 2030 Projected Electricity Savings from **Solid-State Lighting equals....**

=

1.8X
2030 Projected Wind Power Electricity Generation

OR

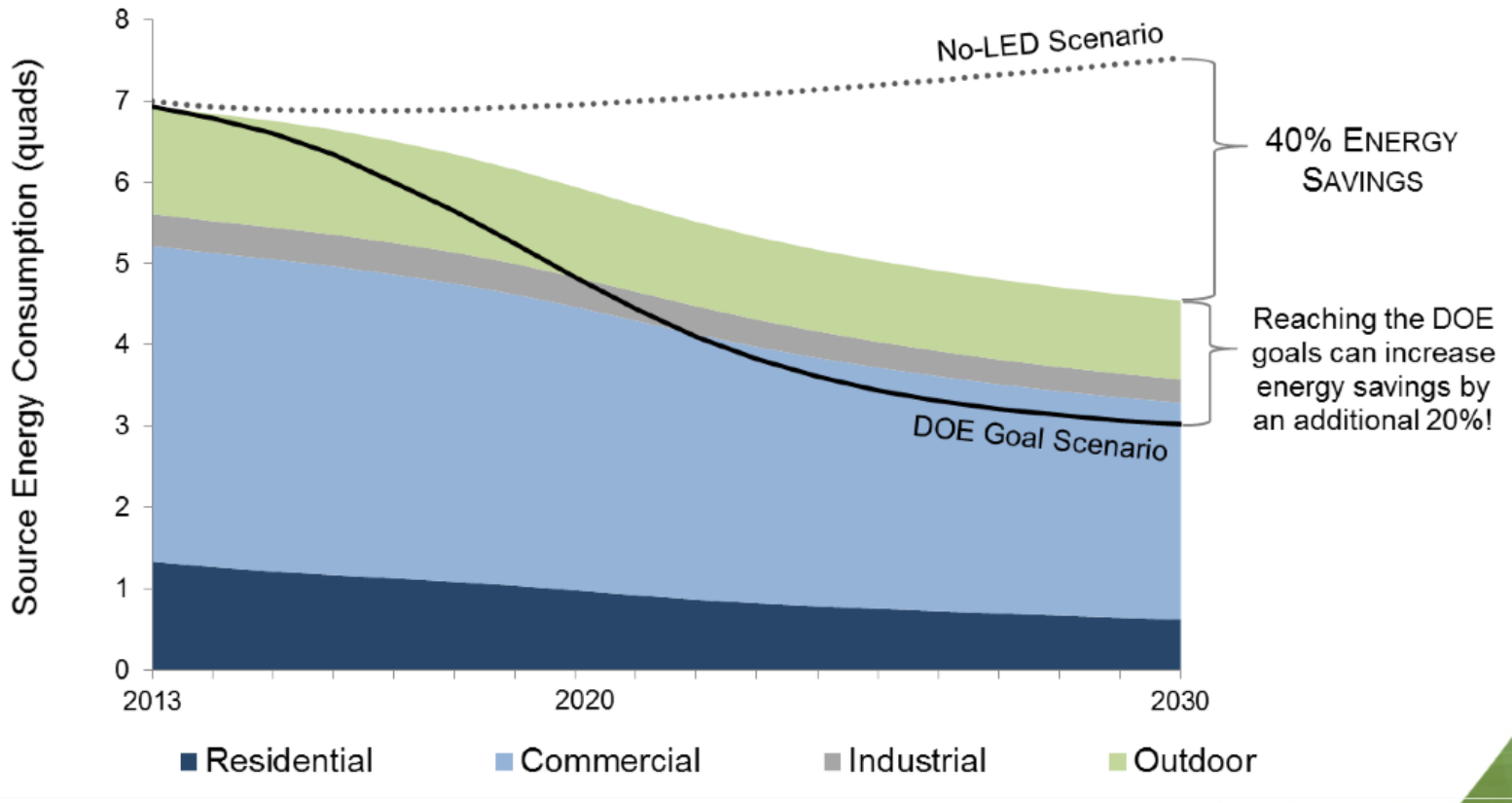
20X
2030 Projected Solar Power Electricity Generation

OR

Annual Electricity Consumption of
36 Million
U.S. Homes

OR

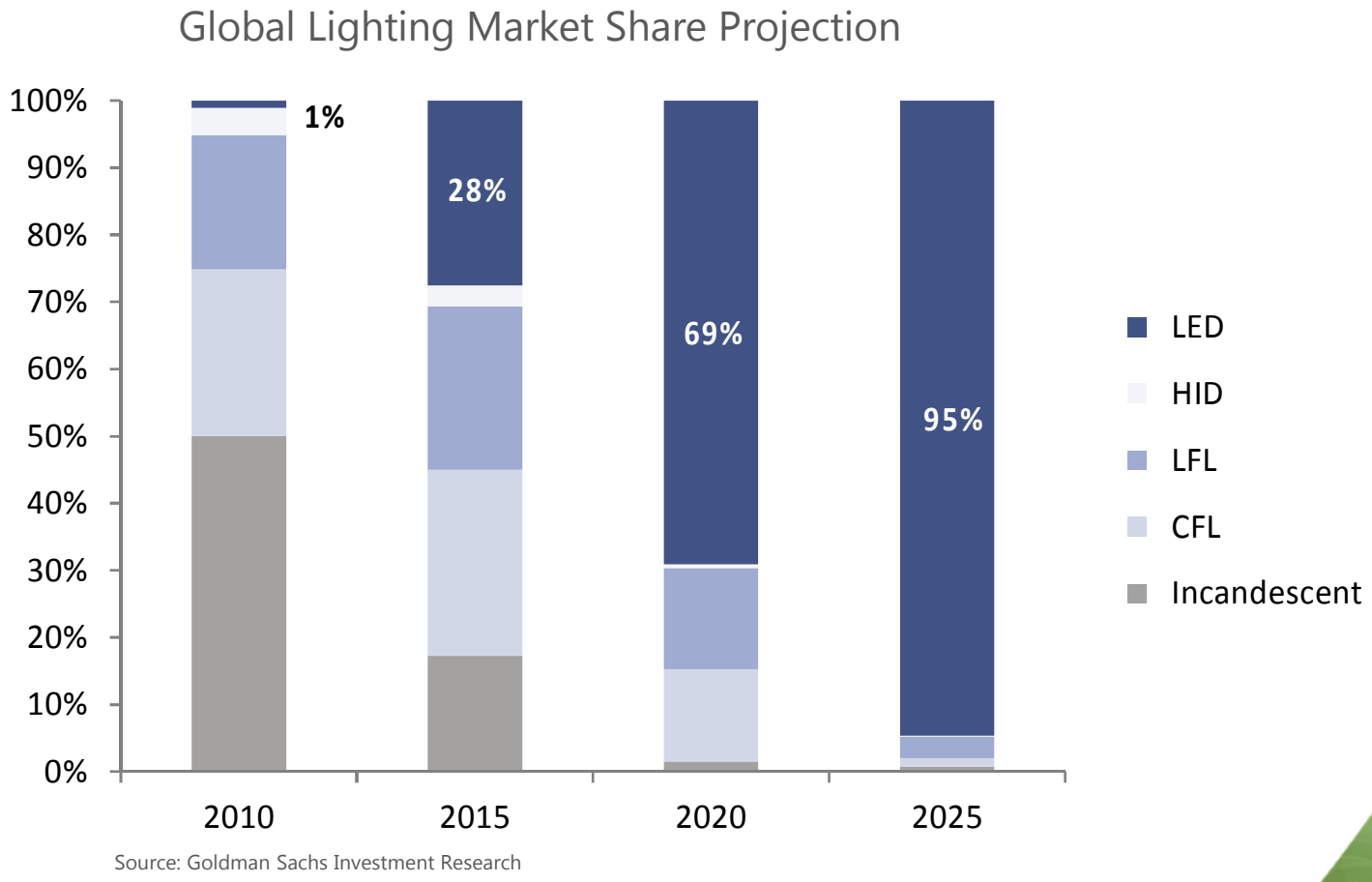
$40 Billion (US)
in Electricity Costs



Source: Department of Energy Solid-State Lighting R&D Plan, June 2016

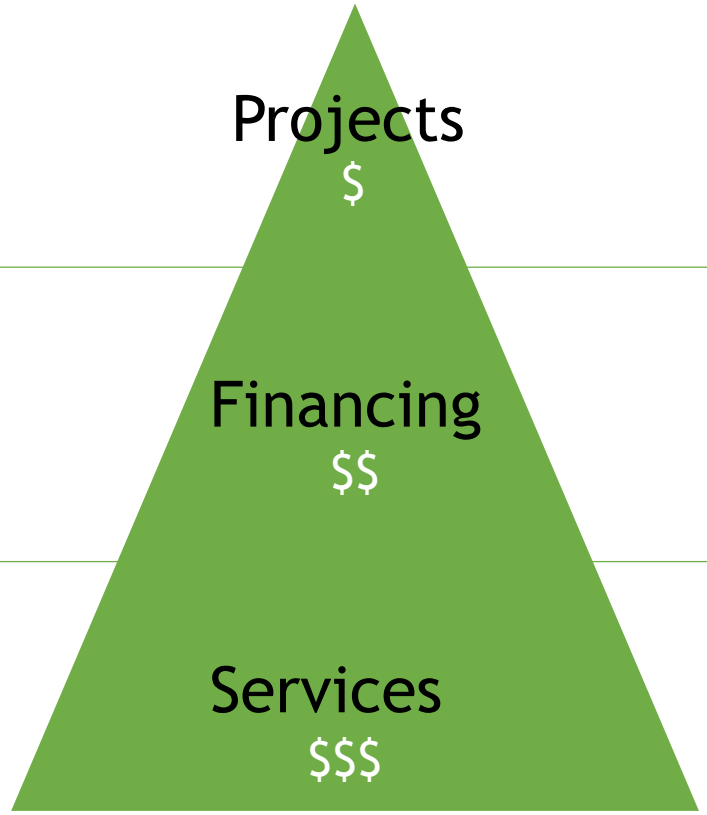
Massive Opportunity Ahead

- Every light fixture and lamp socket across the globe is in play
- Energy savings provide hard dollar payback
- Connected lighting features provide additional recurring revenue streams



Source: Goldman Sachs Investment Research

Three Ways To Make Money



Design and implement lighting retrofits

Provide upfront capital against ongoing energy savings

Monetize data via compelling applications

A Few Names To Keep an Eye On

Lighting

PHILIPS

AcuityBrands

enlighted

CREE

GE

Building Systems

Schneider Electric

Honeywell

EATON

Johnson Controls

SIEMENS

Technology

CISCO

SAMSUNG

QUALCOMM

ECHELON

intel

We Have Issues

Privacy and Data Security

- What personal information do these systems collect?
- How is it anonymized?
- Who owns the data?
- How are the systems and their data secured?

Target Investigates Breach Involving Credit Card Data

By NICOLE PERLROTH DECEMBER 18, 2013 6:40 PM 40

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UPDATED | ***Target confirmed Thursday morning that data was stolen from 40 million shoppers.***

SAN FRANCISCO — Target is investigating a security breach involving stolen credit card and debit card information for millions of its customers, according to one person involved in the investigation.

The breach, which was first reported Wednesday by Brian Krebs, a security blogger, began the day after Thanksgiving, and may be continuing, according to the person involved in the investigation, who spoke only on condition of anonymity.

Heat System Called Door to Target for Hackers

By NICOLE PERLROTH FEB. 5, 2014

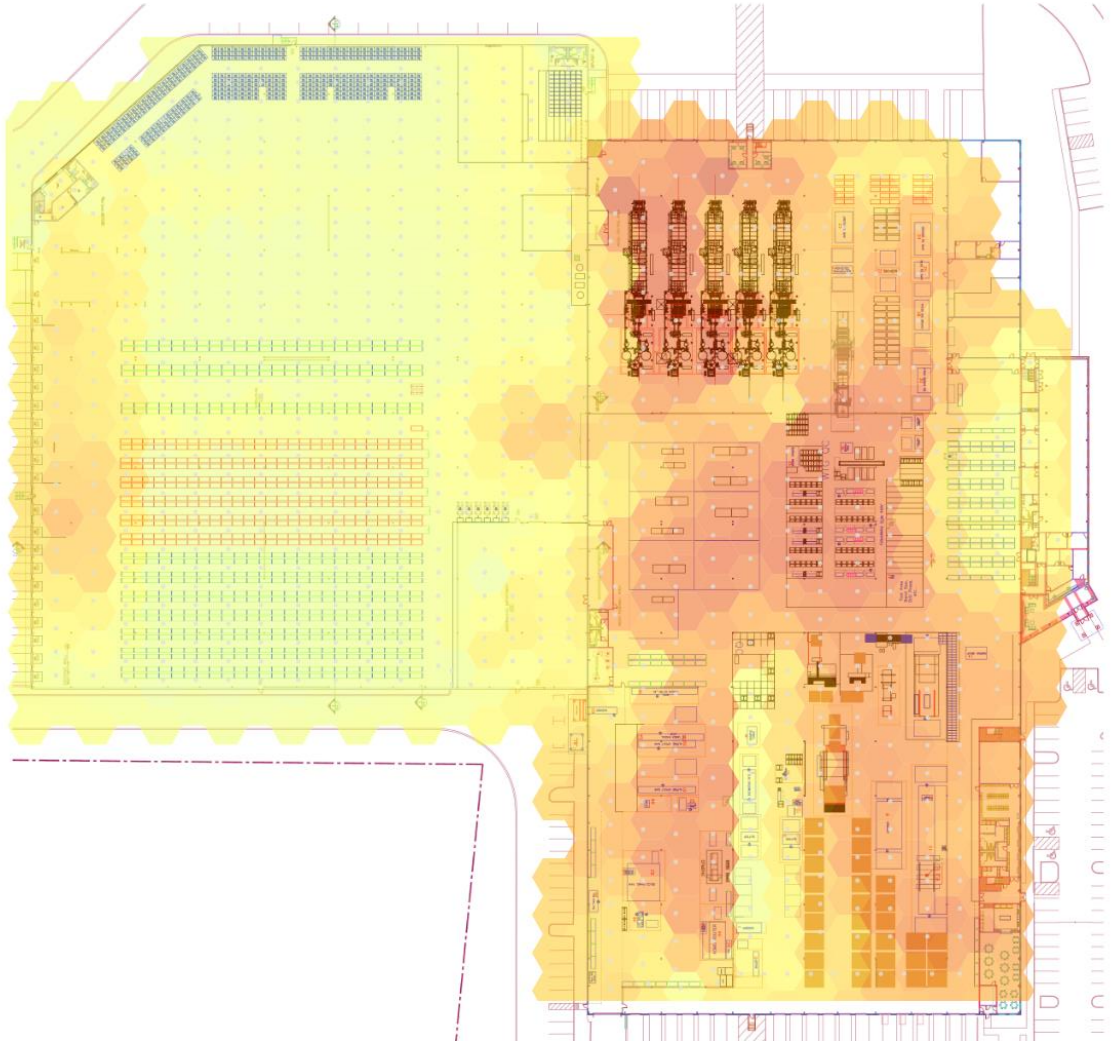
SAN FRANCISCO — Investigators say they believe they have identified the entry point through which hackers got into Target's systems, zeroing in on the remote access granted through the retailer's computerized heating and cooling software, according to two people briefed on the inquiry.

The latest revelation highlights the reality that a large company is actually a sprawling network of interconnected vendors, and that weak security at any one vendor can lead to a breach that costs hundreds of millions of dollars.

Source: New York Times

Scalability

- What works for a conference room doesn't work for an entire building
- What works for a single building doesn't work for a campus
- What works for a campus doesn't work for a global real estate portfolio



Interoperability

- Customers want things to “just work”, and don’t care how it gets done
- Lighting companies have a history of not playing well together
- Will this time be different?
- What will be the role of standards bodies?
- Will de facto standards carry the day?

Emerging Standards

DESIGNLIGHTS CONSORTIUM

NETWORKED LIGHTING CONTROL SYSTEM SPECIFICATION V1.0

Table 1 provides a Summary of "Required" and "Reported" System Capabilities.

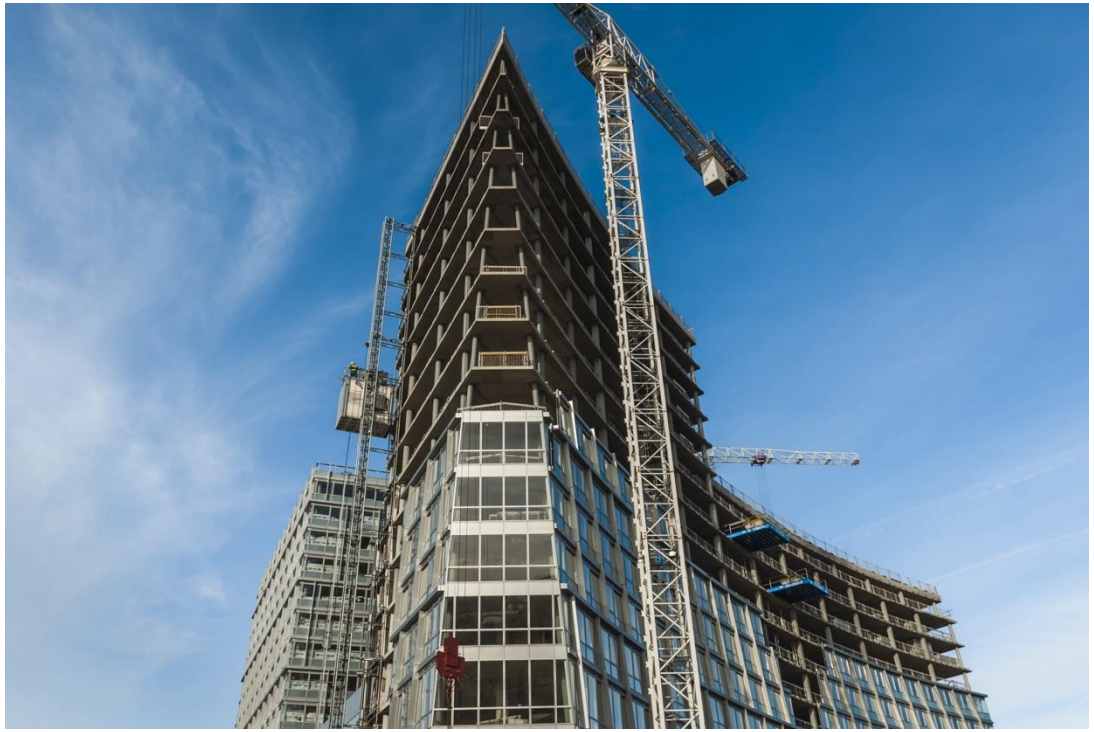
Table 1

v2.0 Draft

'Required' System Capabilities	'Reported' System Capabilities	'Required' Interior System Capabilities	'Reported' Interior System Capabilities
• *Networking of Luminaires and Devices*	• *Type of User Interface*	• *Networking of Luminaires and Devices*	• *Type of User Interface*
• *Occupancy Sensing*	• *Luminaire-Level Control (non-integrated)*	• *Occupancy Sensing*	• *Luminaire-Level Control (non-integrated)*
• *Daylight Harvesting*	• *Luminaire Level Control (integrated)*	• *Daylight Harvesting / Photocell Control*	• *Luminaire Level Control (integrated)*
• *High End Trim*	• *Localized Processing / Distributed Intelligence*	• *Task Tuning / High End Trim*	• *Personal Control*
• *Zoning*	• *Scheduling*	• *Zoning*	• *Load Shedding (DR)*
• *Luminaire and Device Addressability*	• *Personal Control*	• *Luminaire and Device Addressability*	• *Plug Load Control*
• *Continuous Dimming*	• *Load Shedding (DR)*	• *Continuous Dimming*	• *BMS/EMS/HVAC Integration*
	• *Plug Load Control*	• *Localized Processing / Distributed Intelligence*	• *Device Monitoring / Remote Diagnostics*
	• *BMS/EMS/HVAC Integration*	• *Scheduling*	• *Operational and Standby-Power*
	• *Energy Monitoring*	• *Energy Monitoring*	• *Emergency Lighting*
	• *Device Monitoring / Remote Diagnostics*	• *[DC & PoE only] Wiring & Power Supplies*	• *Inrush Current*
	• *Operational and Standby-Power*		• *Security*
			• *Interoperability / API*
			• *Color Changing / Tuning*
			• *Commissioning Party*

Obsolescence

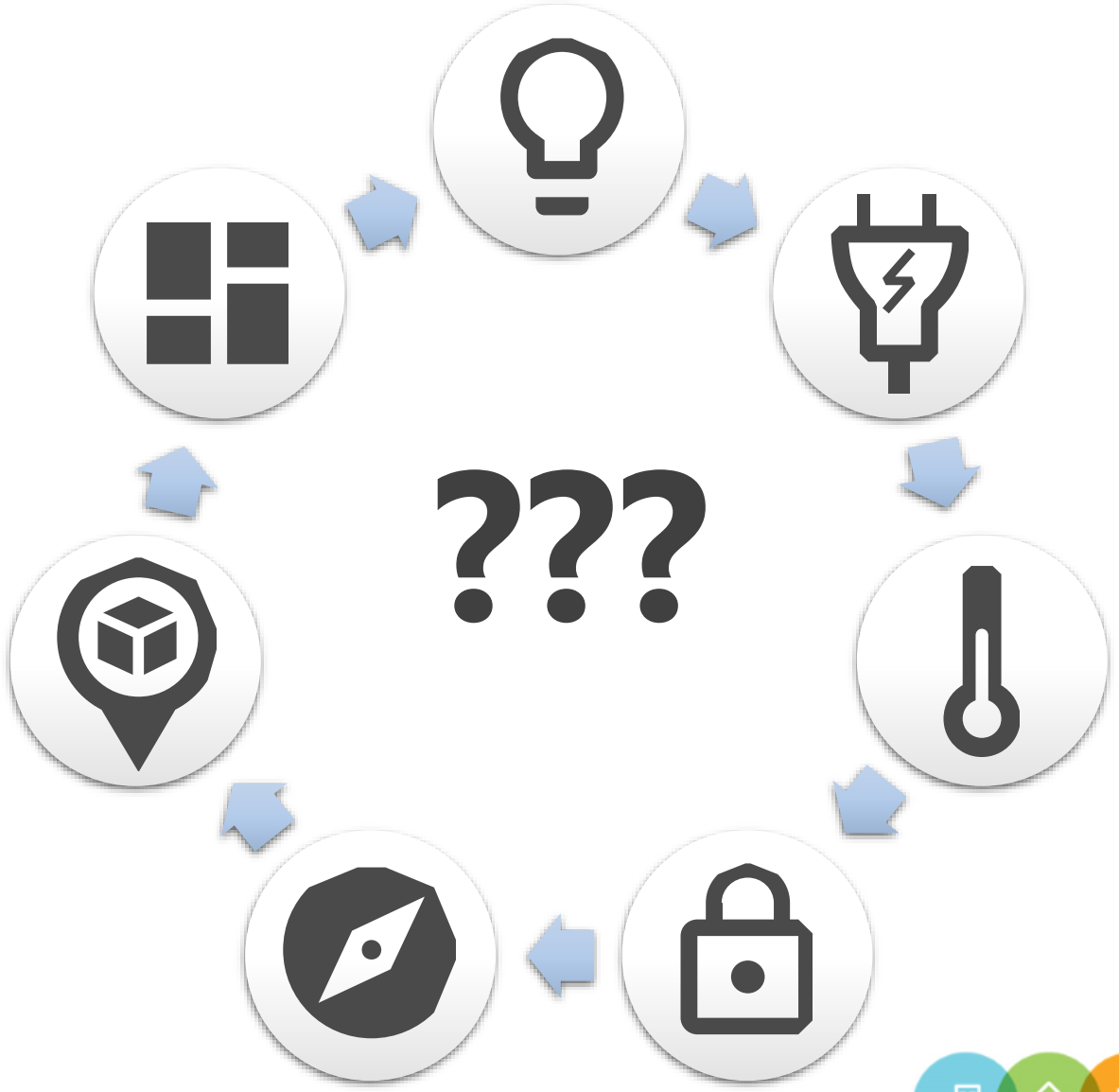
Building systems
Average life span: 10 to 20 years



Tech hardware
Average life span: 21 months

Apps vs. Platforms

- Likely not to be a single killer application that fits every building type
- Platforms, not applications, may end up being the big winners
- Who owns the platform?



Thank you!

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Emerging Technologies Summit

MAKING THE CONNECTION:
From Energy Efficiency Innovation to Delivery

April 19 – 21, 2017

Solid-State Lighting: Where We Are and Where We're Going

Dr. John W. Curran,
President, LED Transformations, LLC

On behalf of the U.S. Department of Energy
and the National Energy Technology Laboratory

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Course Description

This presentation will provide a view of the current state of solid-state lighting: where it is currently; where it is headed in the future and some of the obstacles to be overcome in order to achieve the energy and economic advantages promised including the often overlooked economics of people.

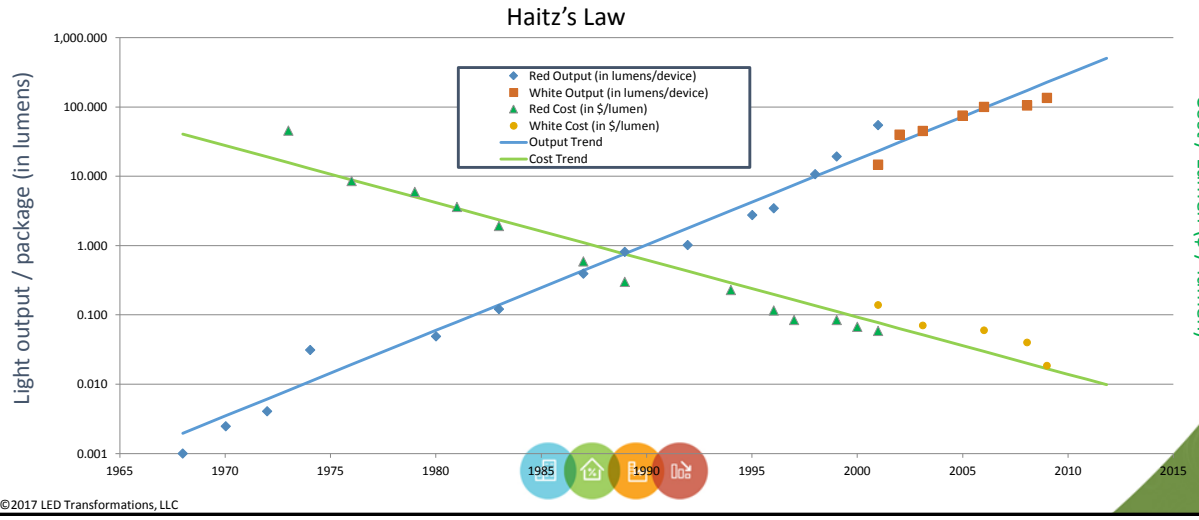
Learning Objectives

1) Understand the current performance levels of solid-state lighting
2) Examine how minimizing complexities will improve the chances of successful field applications
3) Evaluate the full impact of LED product selection when calculating overall project savings, including effect on building occupants
4) Determine what can be learned from LED standards

LED Devices

Semi-Conductor Heritage – Improved performance and lower cost

Technological Push – Higher output and lower cost

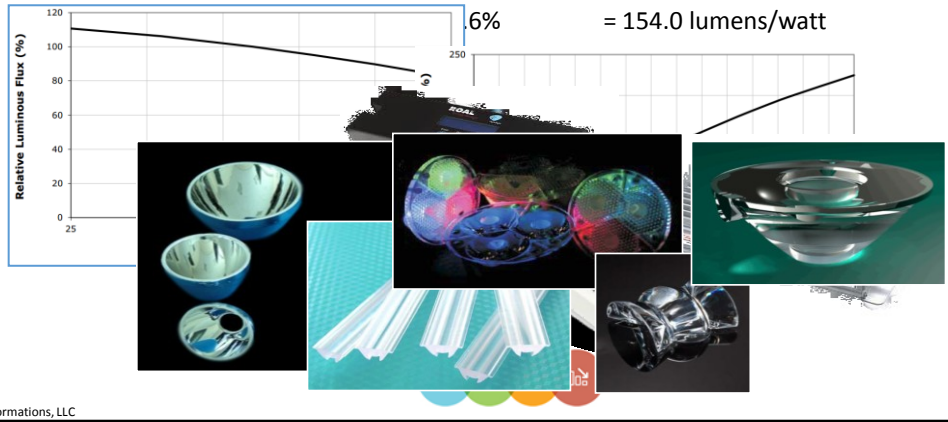


LED Devices

Luminaire Efficacy – Where the losses come from

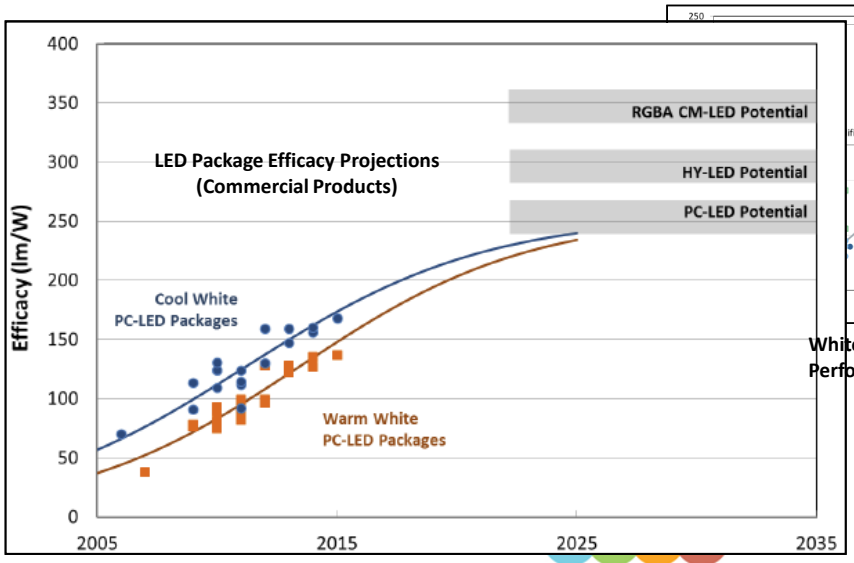
Output of the LEDs is only the starting point

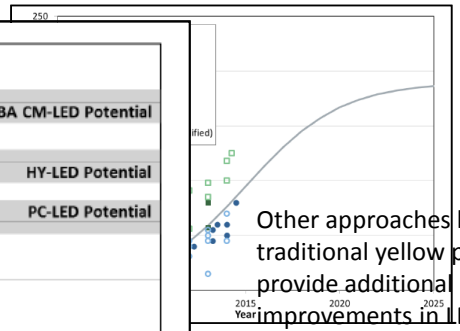
LED efficacy (@ 25^{O}C & 350 mA)		= 200 lumens/watt
Temperature Loss (@85^{O}C)	87.9%	= 175.8 lumens/watt
	6%	= 154.0 lumens/watt



LED Devices

SSL Efficacy Roadmap – Where are we and where are we going





White Light OLED Panel Performance Projections

Other approaches besides the traditional yellow phosphor provide additional improvements in LED device efficacy

LED Devices

SSL Efficacy Roadmap – Where are we and where are we going

Projected LED Improvements					
	2015	2018	2020	2025	Goal
Driver Efficiency	88%	91%	93%	95%	7%
Package Efficacy (lum/W)	137	175	208	237	255
Thermal Efficiency Droop	88%	91%	93%	95%	7%
Fixture/Optical Efficiency	90%	92%	94%	95%	5%
Overall Luminaire Efficacy (lum/W)	95	133	169	203	218

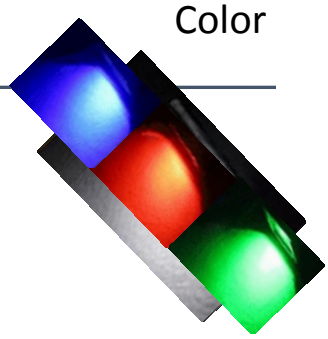
Projected OLED Improvements					
	2015	2017	2020	2025	Goal
Driver Efficiency	85%	85%	85%	90%	95%
Panel Efficacy[1] (lum/W)	60	100	125	160	190
Device to Luminaire Efficiency	85%	85%	85%	85%	86%
Optical Efficiency	100%	100%	100%	90%[a]	90%[a]
Overall Luminaire Efficacy[1] (lum/W)	51	85	106	130	162

[a]Possible use of beam shaping optics

Source: DOE Solid-State Lighting R&D Plan, 2016

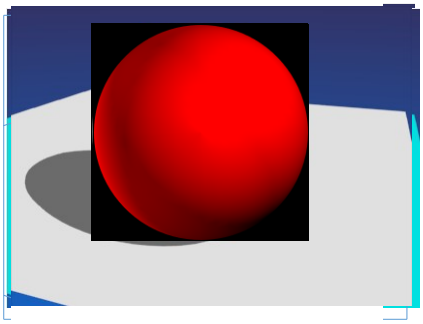
Color

An Experiment – What color is the ball?



Without light objects have **NO Color**

en

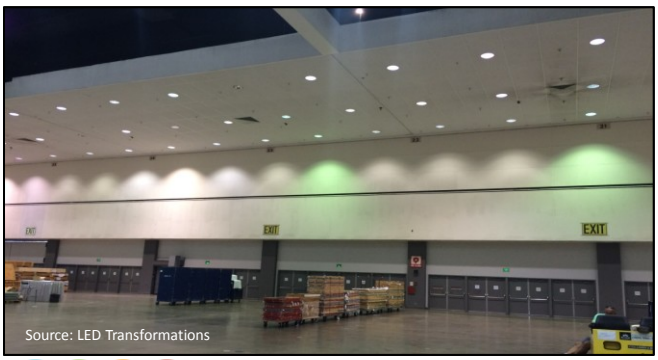


Color

Color Consistency – Can be extremely important over lifetime

Color changes occur due to binning which occurs during LED production as well as color shift due to phosphor/die changes over time

- Variation unit to unit
- Purchase to purchase
- Shift during lifetime



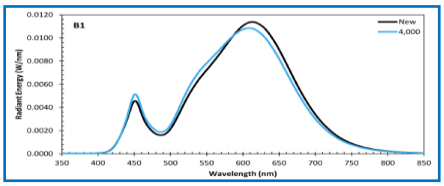
Source: LED Transformations

Color

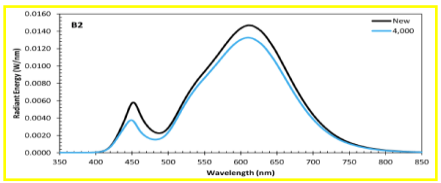
Field Issue – Color shifts can change in many directions

Results of DOE CALiPER testing from 2008 to 2010 shows color shifts after 6000 hours of operation (black) and 12,000 hours (brown)

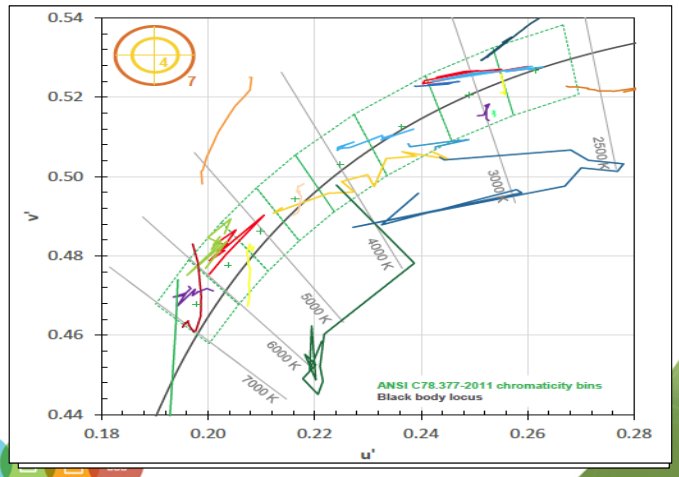
Source: Michael Royer, PNNL



Shift to blue



Shift to yellow



Color

Standards – Rules for LED lighting

- **LM-79-08** *Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products*
- **LM-80-15** *Approved Method for Measuring Luminous Flux and Color Maintenance of LED Packages, Arrays and Modules*
- **TM-21-11** *Projecting Long Term Lumen Maintenance of LED Light Sources*
- **TM-30-15** *IES Method for Evaluating Light Source Color Rendition*
- **ANSI C78.377-2015** *Specifications for the Chromaticity of Solid-State Lighting (SSL) Products*
- **LM-84-14** *Measuring Luminous Flux and Color Maintenance of LED Lamps, Light Engines and Luminaires*
- **TM-28-14** *Projecting Long-Term Luminous Flux Maintenance of LED Lamps and Luminaires*
- **LM-85-14** *Electrical and Photometric Measurements of High-Power LEDs*

Color

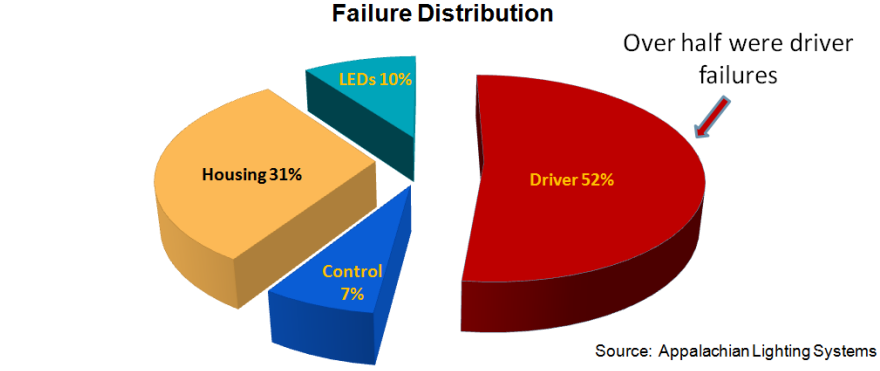
Color Shift – No testable standard to date

- TM-31 – There is a standard in the works which according to members of the committee will provide guidance on color shift similar to that provided by TM30 regarding lumen depreciation.
  - Status: still in committee
  - Expect to see it in 2018
  - Remains to be seen how well it handles color shift
- OLEDs – There are presently **no standards** for OLED devices although some work is going on in committees.

Field Issues

Electronics/Driver – Reliability depends on the driver as well

In one study it was found that 90% of the luminaire failures were due to something other than the LEDs!



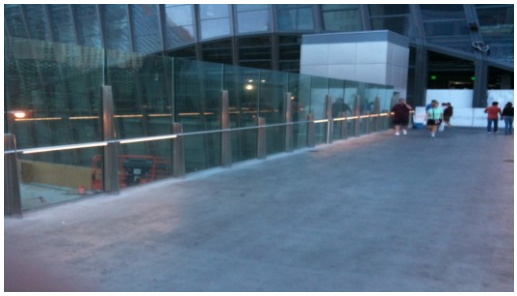
Total number of failures = 29 out of 5,400 units installed (0.54%)

Field Issues

Electronics/Driver – Reliability depends on the driver as well

Two examples of failures caused by the driver

Stop & Shop, Raritan, NJ – 6 weeks



City Center, Las Vegas – 5 months

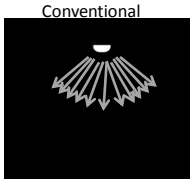
Not quite 50,000 hours!

Field Issues

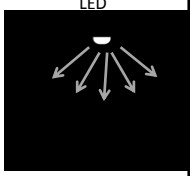
Glare Issues – Pushing the limits

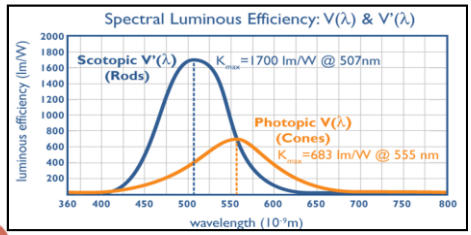
- Poor luminaire design
  - No optics; poor optics; no shielding
- Luminous intensity within solid angle
  - LEDs typically concentrate the light within narrow beams causing discomfort glare
- High contrast between fixture and background luminance
- Inappropriate output for height or direction of use
- Human eye response
  - As color temperature increases, the higher blue wavelength content of LEDs is perceived as "brighter" due to increased scotopic response in lower light environment

Conventional



LED





Field Issues

LED Performance – Be careful what you ask for; you might get it

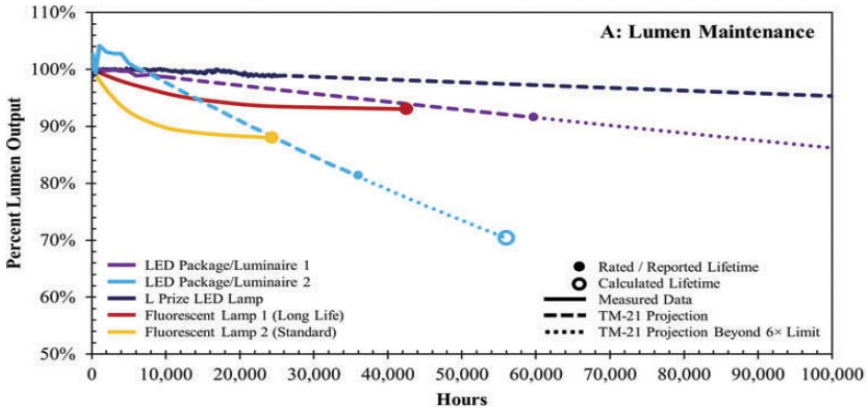
- There is much discussion on light trespass, light pollution, etc.
- The typical view is that light cut-off is desirable for many applications
- LEDs allow cut-offs that are not possible with other light sources
- Sometimes, that exact cut-off is not what people really want

Cut-off Extremes

Field Issues

Lumen Depreciation – Applied to LED sources

Five different light sources: 2 LED; 2 fluorescent; L Prize and their associated lumen depreciation rates



Source: M Royer, *Lumen Maintenance and Light Loss Factors: Consequences of Current Design Practices for LEDs*, LEUKOS, 12/13

Lighting Controls & Sensors

Controls – End user training

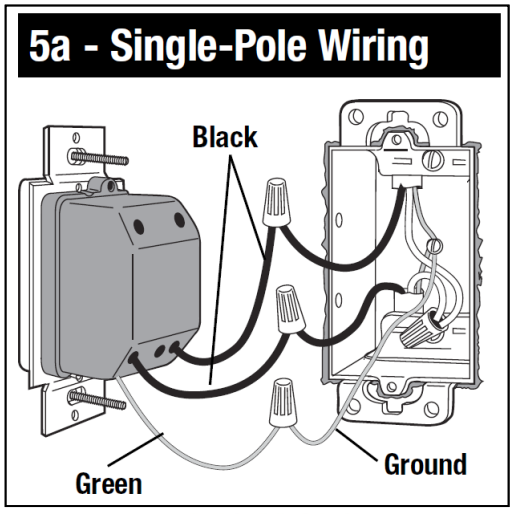
Intuitive

Not so Intuitive

Lighting Controls & Sensors

Installation Instructions – Wall dimmer

Straightforward

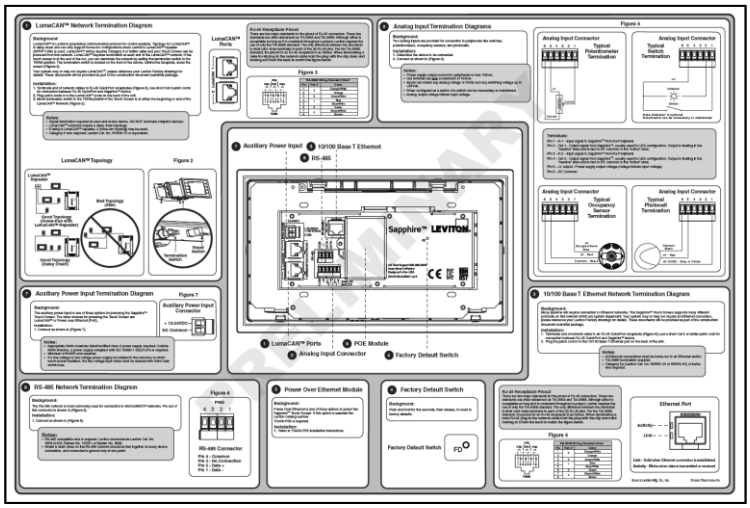


Source: Lutron

Lighting Controls & Sensors

Installation Instructions – Relatively simple control panel

Not so Straightforward



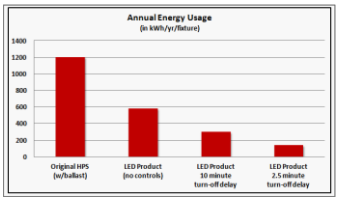
Source: Leviton

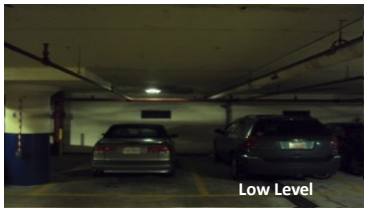
Lighting Controls & Sensors

Unexpected Problems – Energy savings have a number of elements

Energy savings will be a function of:

- Time delay until turn-off
  - Longer time delays decrease energy savings
  - Shorter time delays can increase the annoyance factor for facility occupants
- Low illumination setting
  - Decreasing the low level setting increases the potential energy savings
- Exogenous factors such as amount of vehicular and pedestrian traffic the sensor detects
  - Heavy traffic can negate the overall usefulness of an occupancy or motion sensor (e.g. it is on all the time)





Lighting Controls & Sensors

The Ideal Lighting Control System - Simple

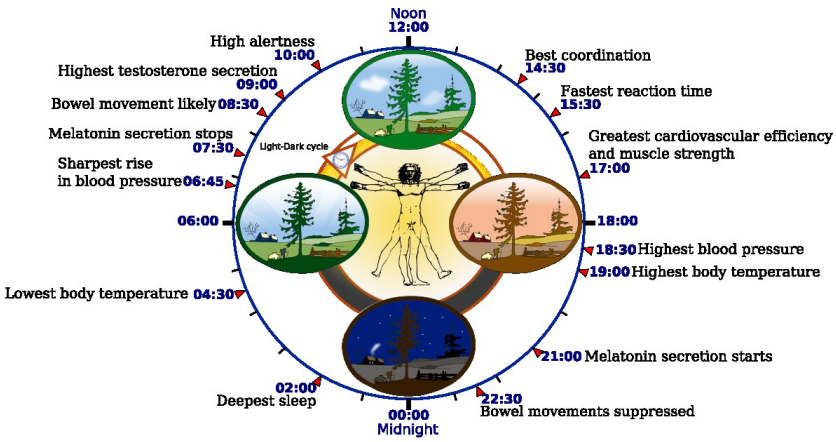
- Any complexity is hidden from user
- Ability to use right out of the box
- Intuitive and easy to use
  - Design and layout
  - Installation
  - End user
- Flexible and adapts to user
  - Self commissioning
  - Self optimizing
  - Easy to configure/reconfigure
  - Easy to maintain and repair, as necessary

Economics of People

Human Physiology – Circadian Cycle and its effect on the human body

"To every thing there is a season, and a time to every purpose under the heaven"

Sources: The Bible and The Byrds



Source: Wikipedia, YassineMrabet

Economics of People

Human Physiology – Circadian Cycle and its effect on the human body

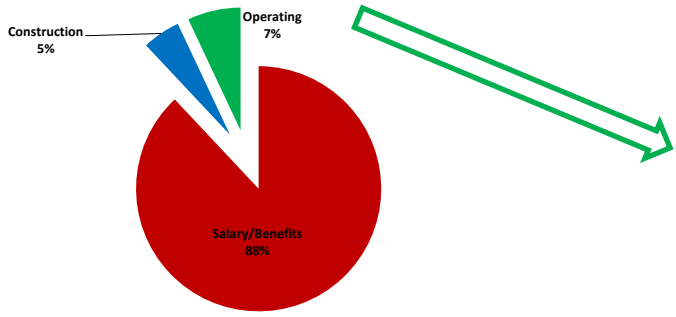
- Without light, the human body's circadian cycle runs slightly longer than 24 hours
- In order to stay in synchronization with the earth's 24 hour cycle, requires exposure to sunlight
- Alternatively, circadian rhythms can be synced to a natural 24 hour cycle by the use of light with a CCT of 6500^{O}K or greater at an intensity of 600 lux during the "daylight" period and 2700^{O}K at an intensity of 50 - 80 lux during "evening" hours
- Therefore the most healthy lighting system is one that mimics the natural daylight cycle
- This implies a lighting system that controls intensity and CCT of the light

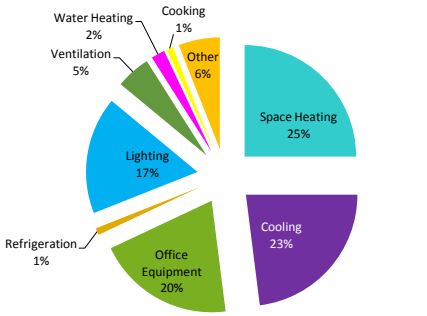
Source: *Light for Better Sleep*, Mariana G. Figueiro, LRC, November 2013

Economics of People

Lifecycle Operating Costs – For a typical office building

An often overlooked element - people





Data source: Graham Ive

Data source: E Source

A 50% reduction in energy usage due to lighting changes represents a 0.6% decrease in lifecycle operating costs, while a 1% decrease in office worker performance represents a 0.9% increase in lifecycle operating costs

Do the math!

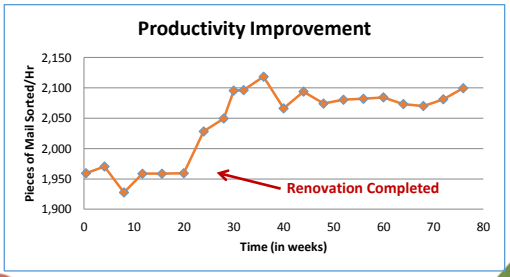
Economics of People

Lifecycle Operating Costs – An example

Reno Nevada Main Post Office

A $300,000 renovation in the facility's lighting system, produced a little over $50,000 annual savings ($22,400 in direct energy savings and 30,000 in reduced cost of maintenance)

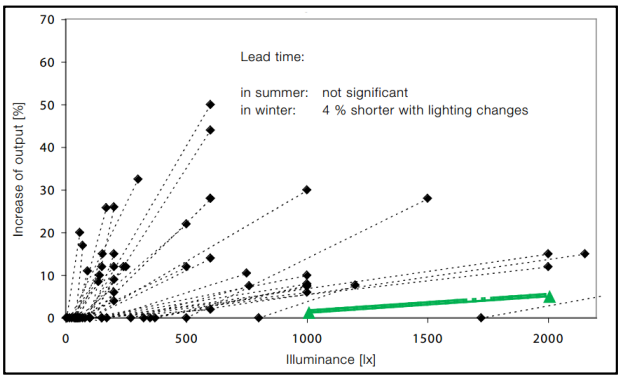
That same renovation resulted in major reductions in operator errors (to 0.1%) as well as a 6% improvement in employee productivity which was worth an additional **$400,000** annual savings



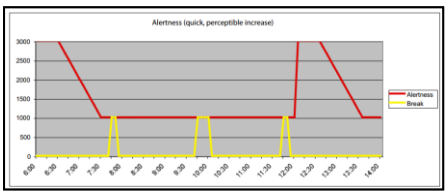
Economics of People

Electronics Assembly – Worker response to dynamic lighting levels

Dynamic change in lighting levels at a Flextronics assembly facility resulted in **4%** improvement in performance



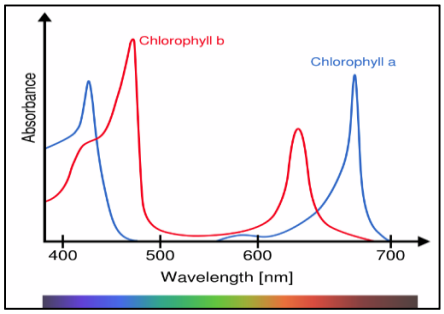
Source: *Effect of changing room light on the productivity of permanent morning shift workers at industrial workstations,* Markus Canazei and Dehoff, Zumtobel Lighting, 3/13



The study attributed the improvement to the reduced level of stress during work brought about by the dynamic lighting.

Economics of ~~People~~ Plants

Specialty Lighting – A horticulture example



Source: *Plant Physiology (3rd Edition)*, Taiz & Zeiger, 2002

Photosynthesis is a process where plants use light to strip a hydrogen atom from water and combine it with carbon from CO_2 to produce glucose. Chlorophyll is the most efficient pigment at performing this function

Using specific lighting spectral recopies, a nursery found improved plant stands, reduced crop time, and increased overall plant health.

Source: Philips Lighting

Final Thoughts

The Lighting World Is Changing – A revolution like never before

- LED technology has overtaken every other light source in terms of efficacy and longevity – that battle is over
- Now it is time to get back to designing quality lighting that takes issues such as glare, color and overall quality of light into consideration – that battle is just getting started
- Ahead is a whole new world where lighting combined with controls and sensors is used in new ways to improve health, wellbeing, productivity, communications, etc.
- Standards, as is often the case, lag the technology
- The landscape of the lighting marketplace is likely to change as new players and new skill sets become important
- What will never change – you get what you pay for!

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