MIT Media Lab

Energy efficient control of polychromatic solid-state lighting using a sensor network

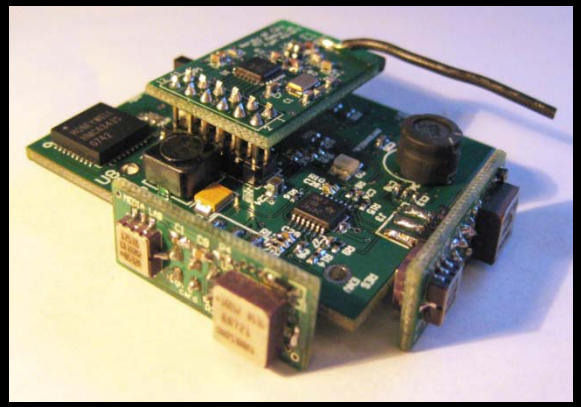
Matt Aldrich, MIT Media Lab, PhD Candidate
Nan Zhao, RTWH Aachen, Visiting Student
Prof. Joseph Paradiso, MIT Media Lab
www.media.edu/resenv/lighting/

Tenth International Conference on Solid State Lighting (2010)
Session 2, Alternative Design

INTRODUCTION

- MIT Media Lab
  - 25 years of multidisciplinary research: organized as 23 unique research groups, each with special research interest.
- Responsive Environments Group
  - Led by Prof. Joseph Paradiso

Feldmeier, Personalized HVAC

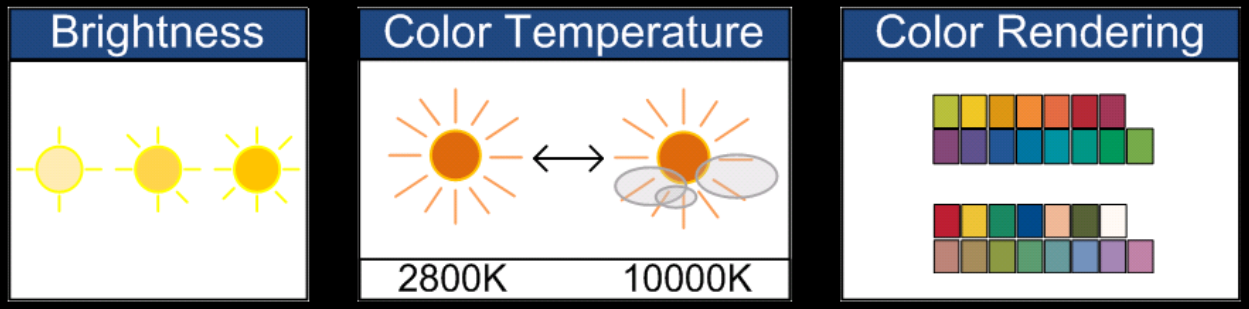


Lapinski, Sportsemble

Malinowski, Cargonet

ADAPTIVE LIGHTING

- Precise control of emitted spectrum using LEDs presents new opportunities
- Reduce network energy consumption using dimming, modulated spectra
- Unify lighting preferences with intuitive control



LED Control Opportunities

Adapted from: E Fred Schubert *et al* 2006 *Rep. Prog. Phys.* **69** 3069

BACKGROUND

- Spectral control of active-emitters
  - Muthu et al. - Control and Mixing of RGB Emitters (2002)
  - Žukauskas – Boundary search optimization of efficacy \ CRI (2002)
  - Ashdown – Neural Network control of RGB System (2004)
  - Ackermann et al. – Feedback and control of 4 colors (2006)
  - Dowling & Kolsky – Control of 22 unique wavelengths (2009)

- Lighting Network Control
  - Crisp and Hunt – Personal control, occupancy, and ambient light (1978)
  - Singhvi et al. – Optimal dimming and prediction of lighting control (2005)
  - Wen et al. – Wireless network based lighting and control (2006)
  - Park et al. – Intelligent light control for entertainment and media (2007)

SSL: BROAD CONTROL POTENTIAL

ENERGY RESEARCH, VOL. 2, 343–374 (1978)

LIGHTING CONTROLS: THEIR CURRENT USE AND POSSIBLE IMPROVEMENT*

D. R. G. HUNT AND V. H. C. CRISP

Building Research Establishment, Building Research Station, Garston, Watford WD2 7JR, England

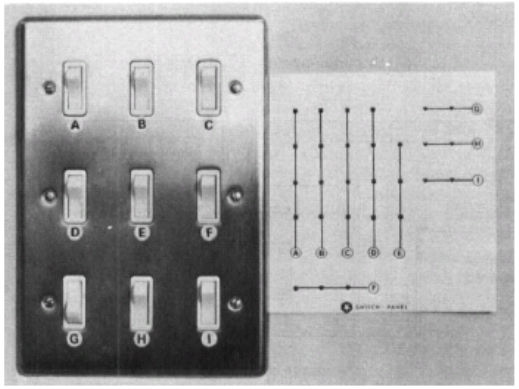


Figure 13. A simple, cheap method of labelling switches

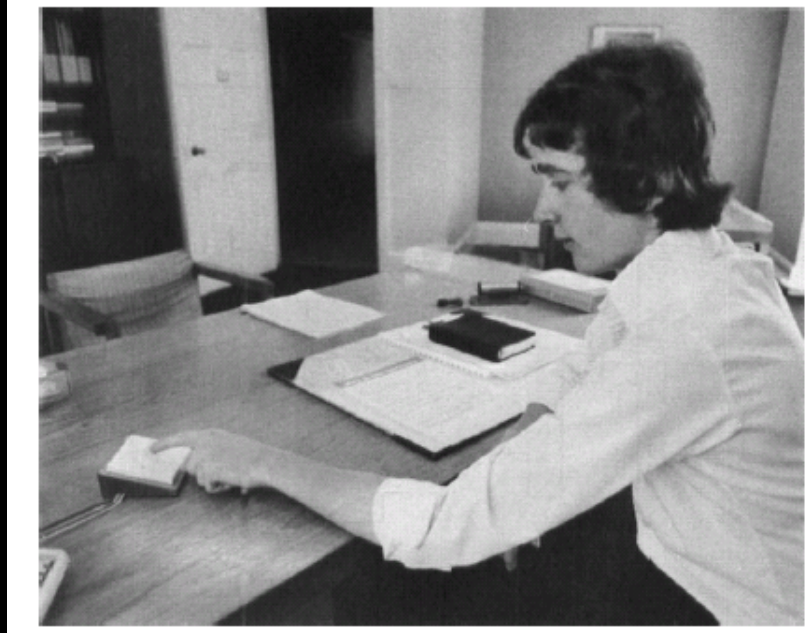
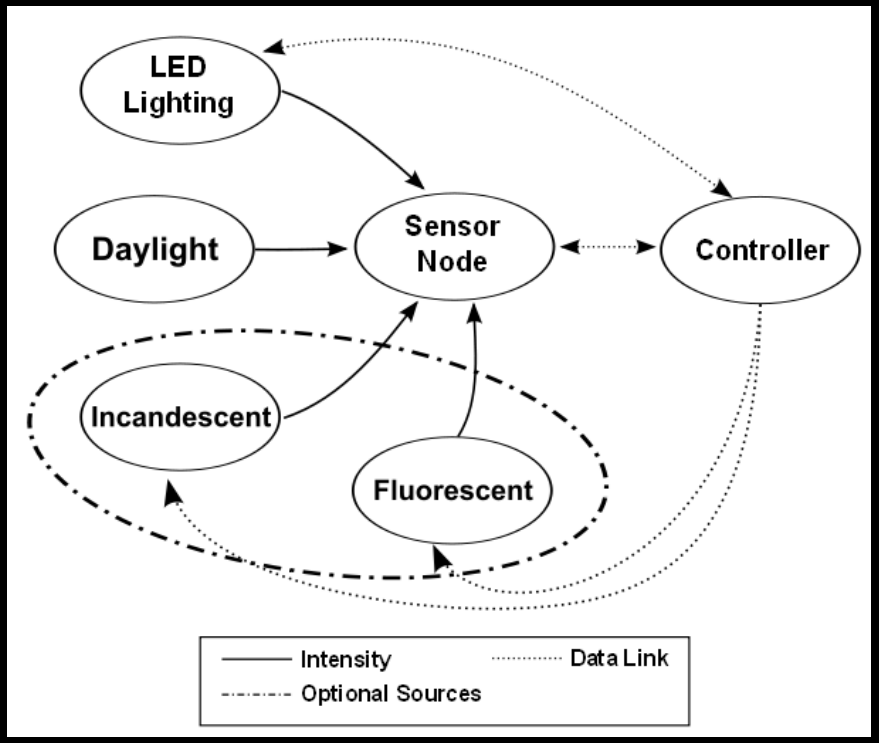


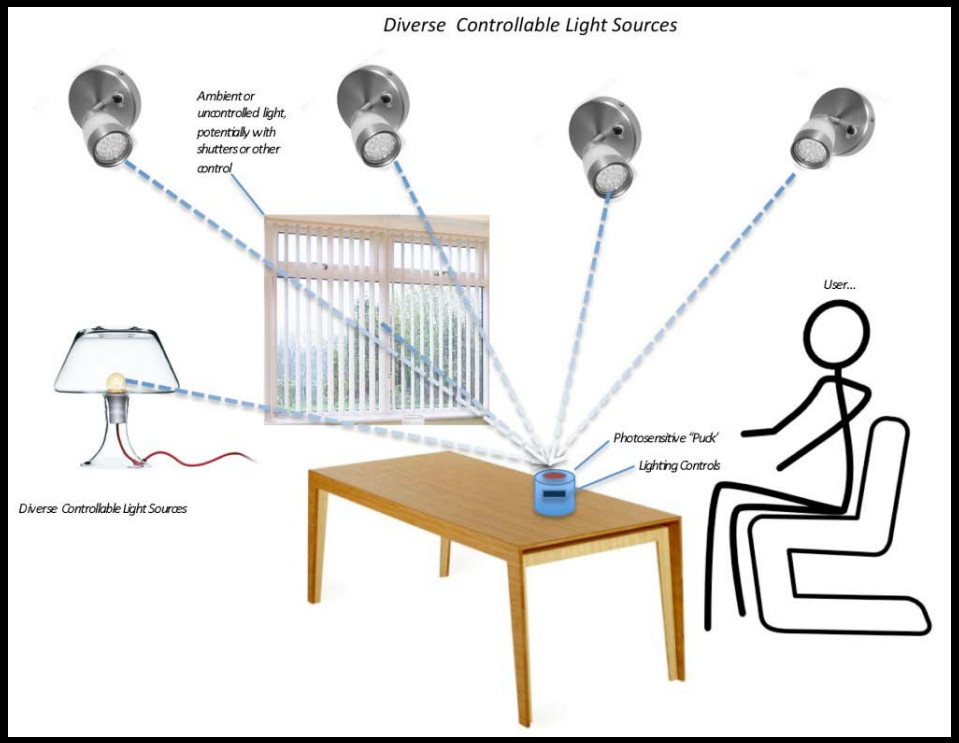
Figure 20. Low voltage switch for operating luminaires from desk

Zoning (left) and personal control (right) from Hunt & Crisp (1978).

Image of Lutron Grafik Eye (left) compact fluorescent dimming console (2010)

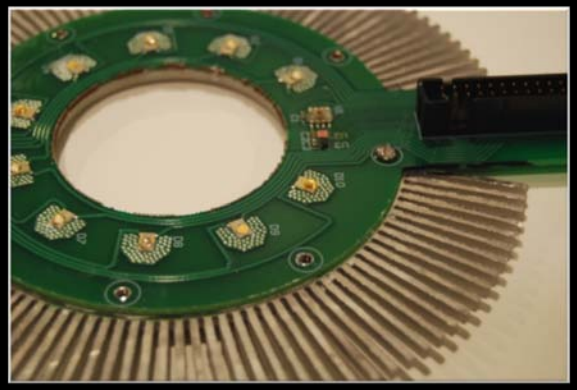
PERSONAL AND ADAPTIVE SSL





- Intelligent infrastructure for personal control of diverse light sources
- Use of LEDs allows for fast modulation (120 Hz – 500 Hz) for illuminance measurements.

IMPLEMENTATION



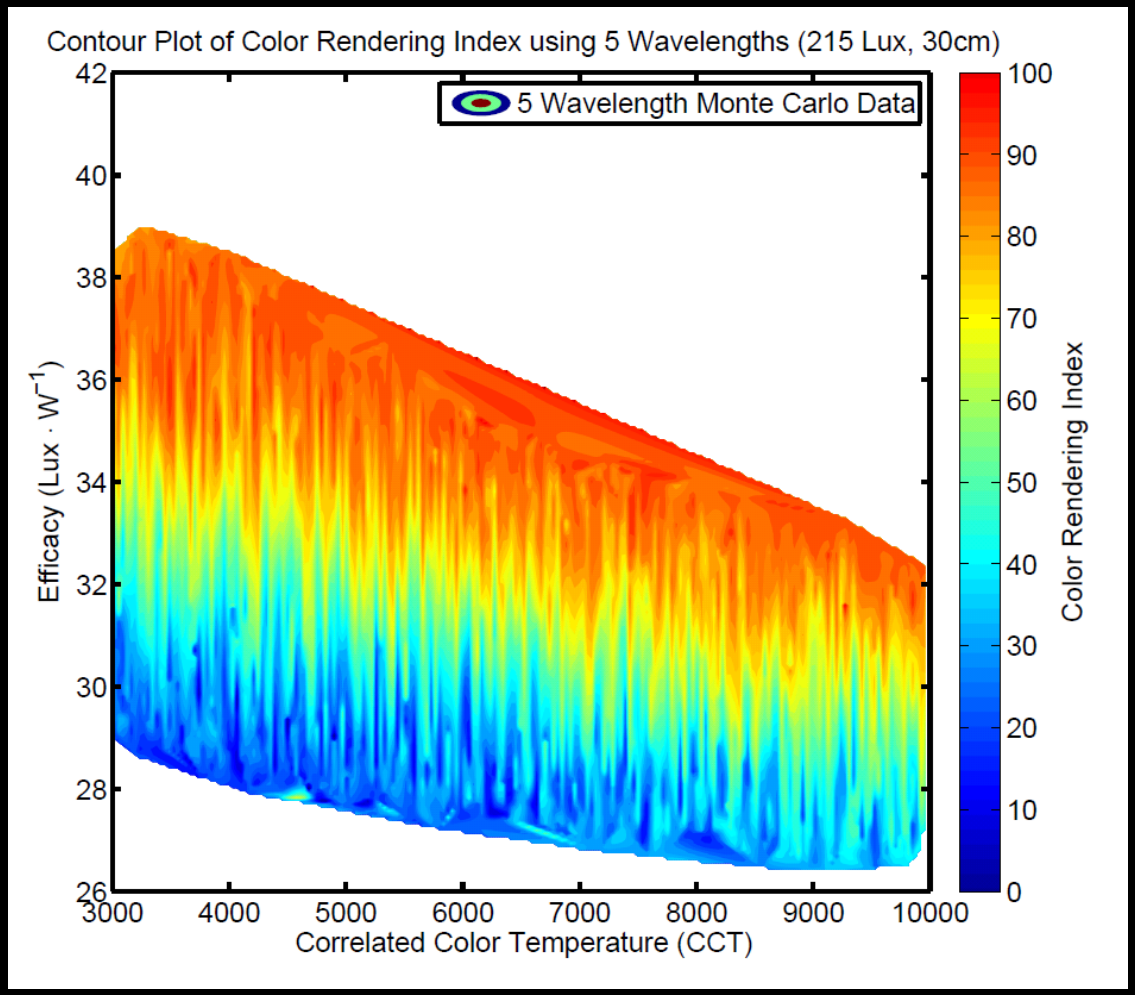
OPTIMAL CONTROL OF SSL

- Offline and Online Optimization
  - Nonlinear Optimization to maximize CRI or efficacy for active-emitter designs
    - Happens once
  - Linear Optimization to minimize network energy consumption based on user input
    - Happens continuously

NONLINEAR OPTIMIZATION

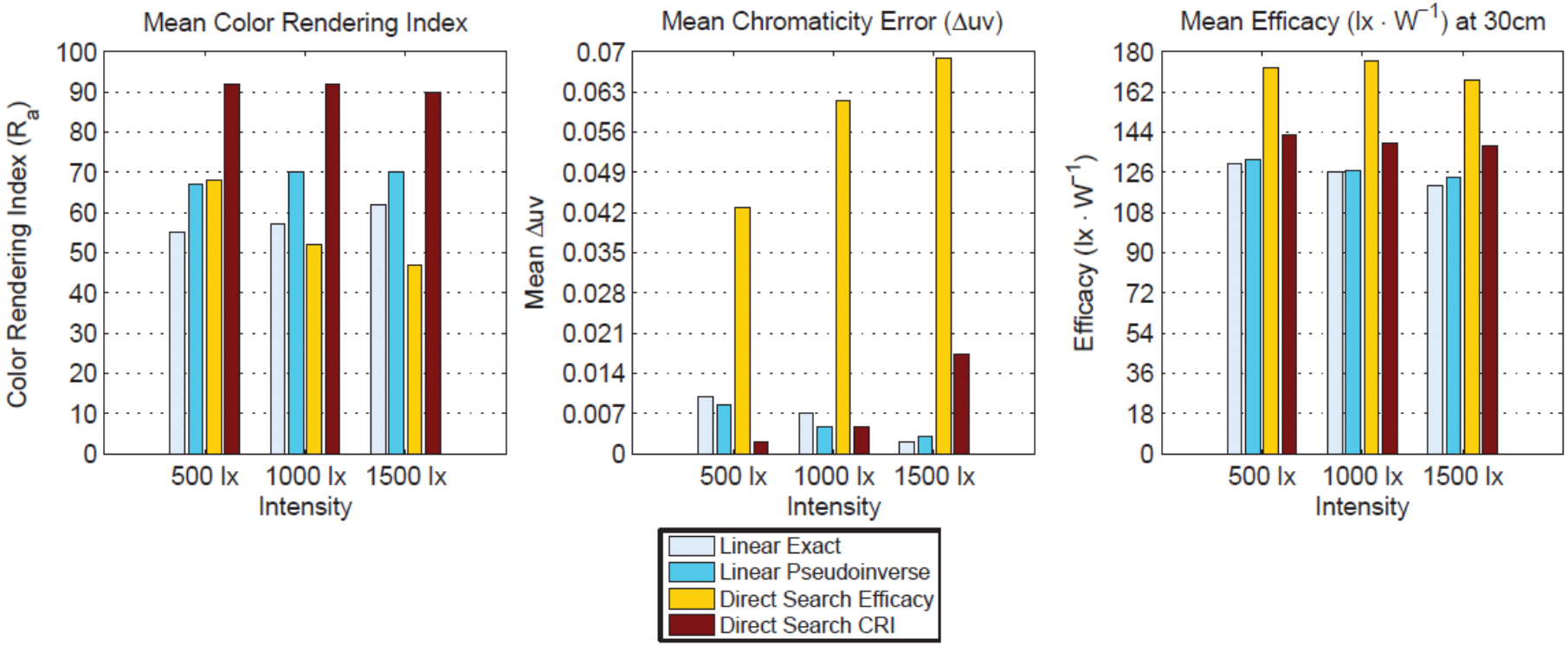
- Active-emitter designs require special care
  - Require gradient free methods constrained by Δ*uv* distance from blackbody curve.
  - Offline optimization based on spectral measurements of system.
  - Solver inputs are user-specified intensity and correlated color temperature.
  - Used the Direct Search algorithm (Torczon, Audet & Dennis)

FIVE WAVELENGTH SYSTEM



- Monte Carlo simulation results.
- LED Array consists of: royal blue, phosphor-converted amber, red, green, and cyan wavelengths

MEASURED RESULTS

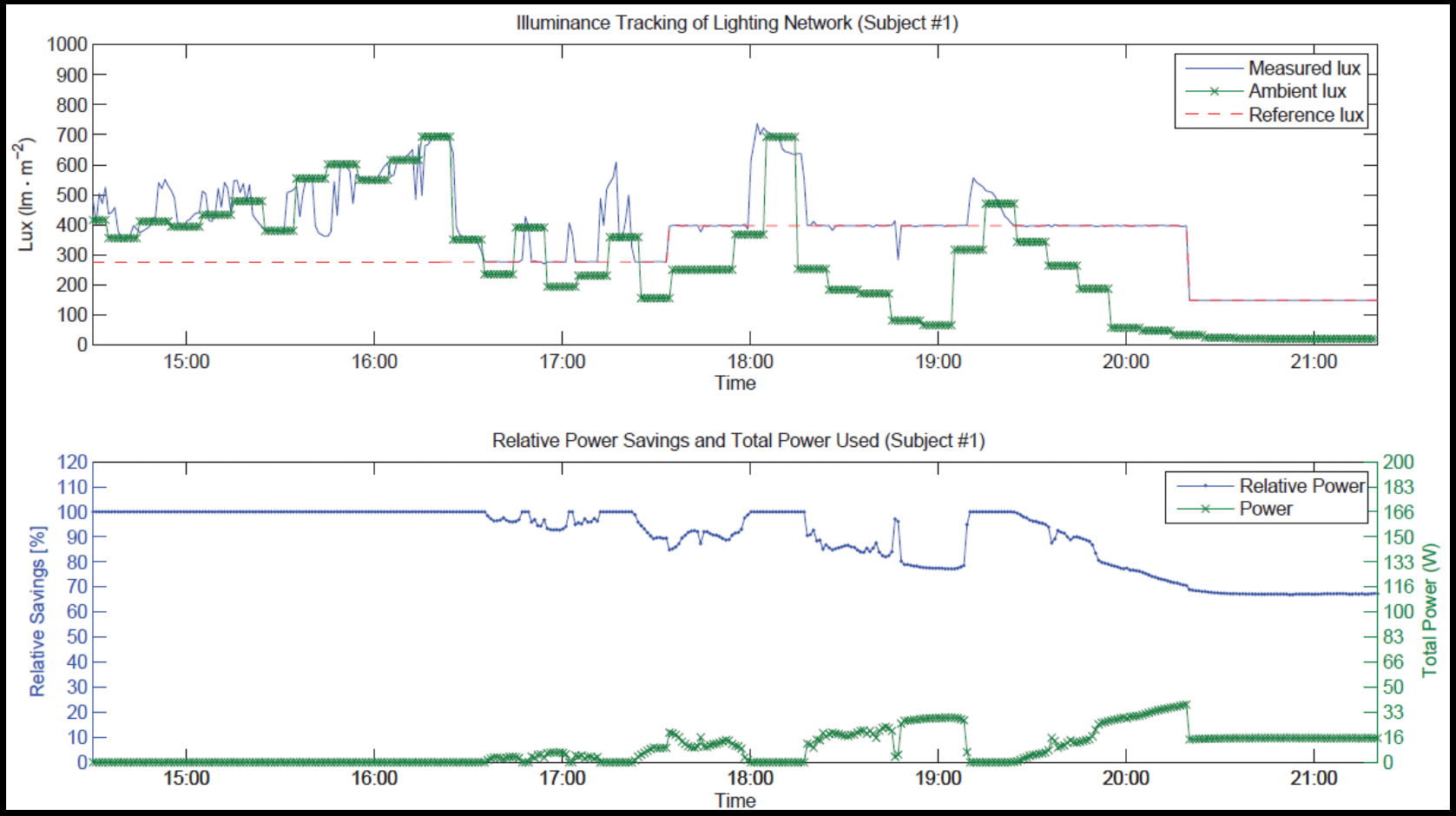


- Nonlinear optimization (Direct Search algorithm)
- Average results for 11 color temperatures at a fixed intensity (500, 1000, and 1500 lx)

LINEAR OPTIMIZATION

- Minimize lighting power consumption
  - Use illuminance to constrain the linear program
  - Obtain mapping between power and intensity for the sources in the network.
  - Measure each light source to weight the constraints

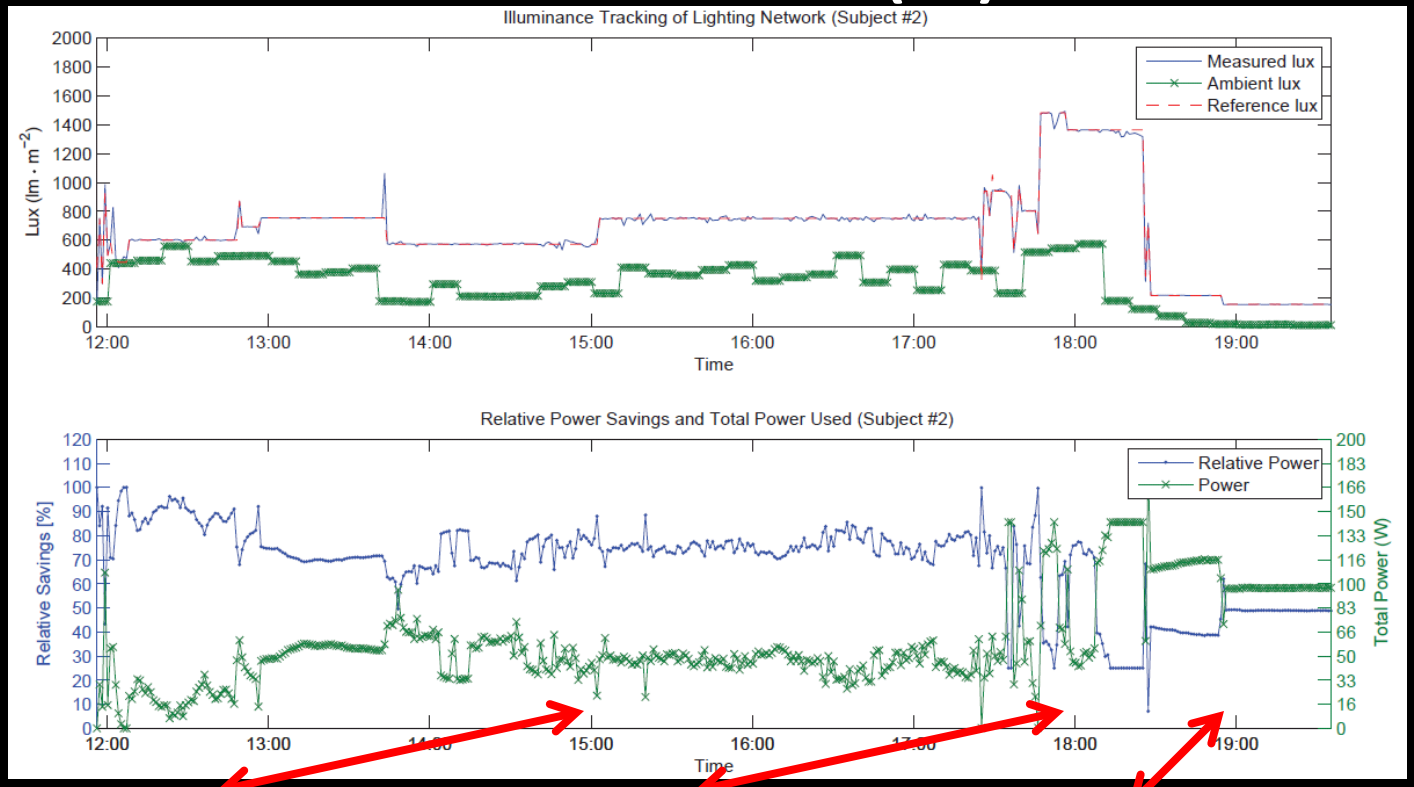
RESULTS (A)



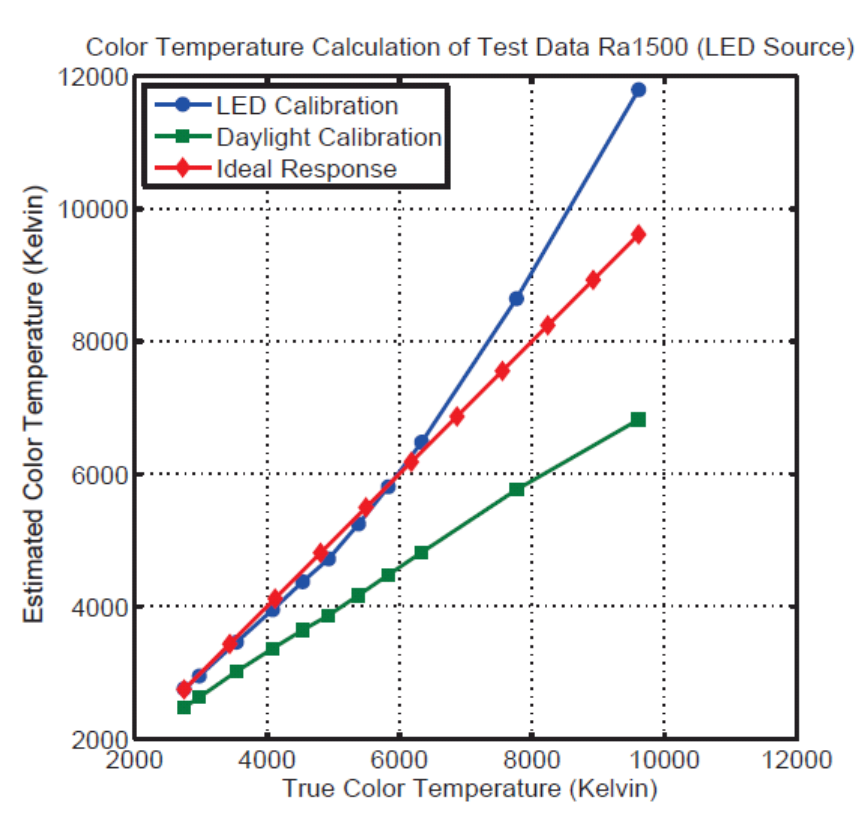
Ambient light logged every ten minutes

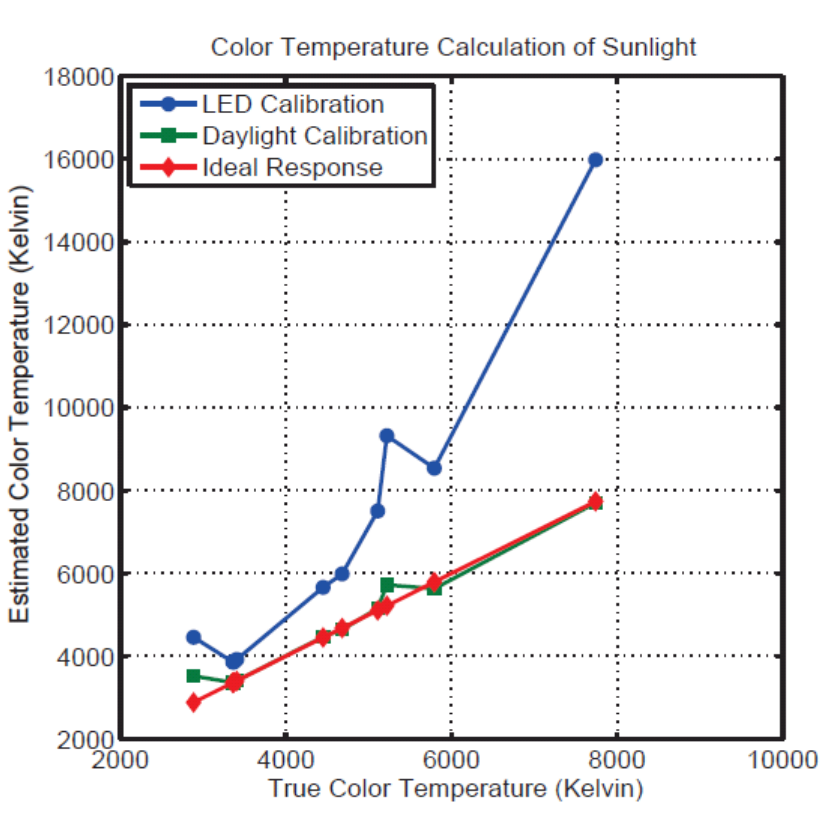
Sensor data was logged every minute (update rate 10 Hz)

RESULTS (B)


Illuminance Tracking of Lighting Network (Subject #2)
Lux (lm · m⁻²)
Time
Measured lux
Ambient lux
Reference lux
Relative Power Savings and Total Power Used (Subject #2)
Relative Savings [%]
Total Power (W)
Relative Power
Power

MEASURED CCT RESULTS





- Higher responsivity in more channels improves accuracy.
- Suitable for monitoring ambient light.

VIDEOS

CONCLUSIONS

- Solid-state lighting offers new potential for energy efficient and adaptive control
- SSL design can benefit from nonlinear and linear optimization
- Tradeoffs between color rendering and efficacy can be applied using polychromatic systems
- Phosphor-based systems are readily controlled using a linear program to minimize energy consumption
- Asynchronous measurement leads to aliasing and possible errors in illuminance measurements
- Integrating color temperature measurements in feedback loop requires more than three channels of measurement

THANKS

- MIT Media Lab for direct funding of this research.
- John Warwick and Philips-Color Kinetics for donation of color-tunable white-LED fixtures.
- Responsive Environments Group for testing, editing, and comments.

QUESTIONS?