312a Fundamentals of
Networked Lighting Controls

Presented by
Shaun Darragh LC, MIES
Senior Lighting Specialist
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Before we begin...

During the Class
- Attendees will be muted
- Please use the chat feature in the control panel to submit questions to LDL staff
- The presenter will pause to address questions every ~10 minutes
- Please participate in the online polls.

Following the Class
- Please take the short survey
- A recording and the slide deck will be posted on LDL's webpage
- Reach out to LightingDesignLab@seattle.gov with comments or questions.

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It takes a village...

LDL's Four Core Service Areas

- Education & Training
- Technology Evaluation
- Tools & Resources
- Information Aggregation
Brief Survey

- Please tell me a little bit about yourselves....

Selected Awards

- Amgen Helix Campus
- Amgen Helix Pedestrian Bridge
- Canyon Ranch Spa Club
- Harvard University 60 Oxford
- King Street Station
- Lighting Design Lab
- Methodist Hospital Research Institute
- Microsoft B16/17
- One Cambridge Center
- Methodist Hospital Research Institute
- Pacific Place Retail Center
- Real Networks Headquarters
- SFPUC Headquarters
- Tommy Bahama Headquarters
- King Abdullah University of Science and Technology
- San Francisco PUC Headquarters
- More than 30 years in the lighting industry as an architectural lighting designer, instructor, sustainability and daylighting design consultant, and theatrical designer.
- Has taught and consulted on sustainability issues, lighting, and daylighting for the Lighting Design Lab and University of Washington Architecture Department.

Learning Objectives

- Understand and be able to apply common control strategies
- Understand and be able to apply typical controls hardware
- Understand how networked control devices may be configured
- Understand the essentials of system startup for networked systems.
- Pairing devices
- Setting high trim
- Setting timeouts
- Setting daylight zones
- Gaining comfort with hardware and software
Why use advanced lighting controls?

- Flexibility
- Productivity
- User Satisfaction
- Aesthetics
- Maintenance
- LEED / WELL / LBC
- Energy Savings
- Energy Codes

Tommy Bahama Headquarters

Flexibility
- Well designed controls can promote effective use of spaces for a variety of tasks.
- Poorly designed controls can preclude normal use of a space.

UC Davis Lecture Halls
Various Buildings

Productivity
- Tuning light levels
- Balancing contrast / brightness
- Reducing glare

Microsoft One Cambridge Center
SkB
User Satisfaction

- Personal Control
  - We all like to have control over our work environment.
  
- Frequently users will dim to a lower lighting level than current practice recommends when given the option.

Maintenance

- LED Sources generate heat. The less heat, at the junction point of the LED, the longer it will function as intended.
- Under-driving LED lamps may result in increased system life.
- System dashboards may offer data on light source burn time.
- Digital drivers offer talk back functionality raising warning flags.

Sustainability Programs

- LEED
- Built Green
- Living Building Challenge
- WELL
- Others?
Energy Savings

- Most significant control strategies consist of dimming to a desired light level or turning lights off when un-needed.
- Dimming LED is reasonably close to a linear relationship between output and energy consumed.
- The potential savings ranges have been well verified over a large project base.

Energy Codes

- Meeting an energy code should be considered a fundamental baseline.
- Meeting an energy code does not necessarily result in a good lighting control system.
- We'll review more on codes later.

Others?

Any other reasons we should be using advanced lighting controls?
Power Circuit

- The power circuit delivers electricity to the luminaire.
- May be the same grouping as the control zone.
- May be independent from the control zone.
- If the circuit is the same as the control zone, make sure that only contiguous, like type, luminaires are fed by the same circuit.

Control Zone / Channel

- A Control Zone is a logical grouping of luminaires that are controlled together.
- May be the same grouping as the power circuit.
- May be independent from the power circuit.
- Generally, the more control zones, the more flexible the system will be.
- Poor zoning is among the most common errors in controls.
Scene / Preset / Look

- A Scene is a programmed collection of zones set at predetermined light levels
- Repeatable
- May use Dimming or Switching
- May have adjustable Fade Rates

Scene Control
Pop Quiz

▪ What are some of the reasons we might want to use advanced lighting controls?

Typical Control Strategies

▪ Manual Switching
▪ Manual Dimming
▪ Scene / Preset Control
▪ Occupancy Sensing
▪ Vacancy Sensing
▪ Daylight Harvesting
▪ Task Tuning
▪ Time Scheduling
▪ Astronomic Scheduling

Manual Switching

▪ Line voltage
▪ Low voltage with relays
▪ Zones or groups
▪ Simple to design
▪ Easy to understand
▪ May not meet codes

▪ Residential
▪ Public Space
▪ Mechanical/Electrical
Manual Dimming

- Line voltage
- Low voltage remote dimming
- Networked System
- Zones or groups
- Simple to design
- Easy to understand
- Users like personal control

- Residential
- Commercial

Scene / Preset

- Grouping of zones at specific levels
- More complicated
- Simply Repeatable
- May be confusing
- Consider engraving

- Residential
- Commercial
- Retail
- Hospitality
- Education
- Conference

Switching...Dimming...Scene Control
Occupancy Sensing
- Automatically turn lights on or off depending on occupancy
- May have some residual angst over older systems
- Supplanted by vacancy sensors in many cases.
  - Public spaces
  - Corridors / Stairwells
  - Toilet rooms
  - Warehouses
  - Parking garages
  - Site lighting

Vacancy Sensing
- Automatically turn lights off when no occupants are present
- Requires manual touch to turn on.
- May have some residual angst over older systems.
- Users may require some training.
  - Almost all enclosed commercial spaces
  - Offices
  - Classrooms
  - Storage

Occupancy/Vacancy Sensors
Passive Infrared
- Passively scans the field of view for moving heat sources across sensor segments.
- Must have line of sight to function
- May be wireless or wired
Occupancy/Vacancy Sensors

Ultrasonic
- Emits high frequency sound waves and measures return waves for doppler shift.
- Does not need line of sight to function
- Generally used in larger or obstructed areas
- Great for restrooms
- May have problems in areas with heavy airflow
- Requires wired installation

Occupancy/Vacancy Sensors

Dual Technology
- Uses both technologies to maximize sensing capabilities
- Usually requires wired installation
- Other options exist
  - Microphonics
  - Microwave
  - Radar

Occupancy/Vacancy Sensors

- Coverage area is specific and will be noted on cut sheets
- Confirm the coverage area
- Confirm the coverage area
- Also – confirm the...
Occupancy/Vacancy Sensors

Wall Mounted
- Wall rather than ceiling when line of sight or access is better
- Frequently corner mounted
- Consult product spec sheets for effective coverage area and field of view
- Generally requires a remote relay pack or networked system
- Wired or wireless

Occupancy/Vacancy Sensors

Ceiling Mounted
- Will require a remote relay pack or provide data to a networked system
- Larger coverage areas
- Wired or wireless
Daylight Harvesting

- Luminaires are governed by photo-sensors determining real-time daylight availability
- Continuous range dimming is preferable to threshold based switching.

- Offices
- Education
- Public Spaces
- Circulation
- Warehouse / Industrial

Open Loop

- Open loop sensors look for available daylight only.
- Easier to commission
- Less precise
- Better performance with top light than side light
Closed Loop

- Closed loop sensors look for available light on a workplane.
- More difficult to commission
- More precise
- Finicky

Task Tuning / High Trim

- Setting a high trim tuned to deliver the target illuminance level.
- Can reduce glare
- Can balance brightness
- Can save as much as 20-30% of the energy in a typical system.
  - Offices
  - Education
  - Public Spaces
  - Circulation
  - Warehouse / Industrial

Task Tuning – Adaptive Compensation

- Counterintuitively, we may need less light at night.
- When our eyes are adapted to lower night time light levels, dimming the lighting may be appropriate.
  - Public Spaces
  - Circulation
  - Retail
Time Scheduling

- Lighting is governed by time of day events rather than occupancy or vacancy sensing.
- Multiple calendars required for effective use.
  - Public Spaces
  - Circulation
  - Retail
  - Areas in which OS/VS would pose difficulty

Astronomic Scheduling

- Lighting is governed by time of day with respect to locally calculated sunrise / sunset.
- Requires longitude and latitude.
- For Seattle: 47.6°N 122.3°W
  - Site Lighting
  - Facades
  - Adaptive Compensation

Load Shed – Demand Response

- The ability to reduce lighting load by a set amount when signaled to do so by a utility.
- Wide area dimming makes load shed events less disruptive.
- Check out www.openadr.org
Bi-Level Switching - Pointless when dimming is standard

- CONFIGURE LUMINAIRE WITH 2 OR MORE SWITCHED CIRCUITS.
- CHARACTERISTICS:
  - SIMPLE
  - EASY TO UNDERSTAND
  - MAY BE USED WITH AN OCCUPANCY SENSOR
- CONSIDERATIONS:
  - ALL LAMPS FREQUENTLY LEFT ON
  - INSTALLED COST MAY BE EQUIVALENT TO DIMMING.
  - MAY CHANGE LIGHT DISTRIBUTION

Newer Controls Strategies

- COLOR SELECTION
- TUNABLE WHITE
- CIRCADIAN LIGHTING
- DIM TO WARM
- ARCHITAINMENT
- BASED ON THE PROPERTIES OF LED LIGHT SOURCES

Color Selection

LED inherent color, and color mixing, coupled with digital control allows for the widespread use of colored light in ways that were difficult or impossible previously.
Tunable White

- Specific color tuning adjusting the correlated color temperature / SPD along the black body radiator curve.
- Meant to affect mood or alertness.
- Circadian lighting.
- Aesthetic reasons.

- Warm Dim
  - Incandescent sources "warm" as they dim.
  - Fluorescent and basic LED sources do not.
  - Warm dim introduces a color curve to the dimmed LED to emulate incandescent red shift.
  - Hospitality
  - Residential
  - Boutique Retail

Tunable White

- Tunable White luminaires and FireTune™ Controls
  - Tunable White
  - FireTune™ Controls
  - Controls
  - Luminaires

Tunable White – Warm Dim

- Courtesy: Cree
- Courtesy: Fagerhult
- Courtesy: Finelite

⚫ 56
⚫ 57
⚫ 58
Hardware Evolution

- Line voltage switch
- Three way switch
- Contactor
- Low voltage hardwired relay
- Strap and wallbox dimmers
- Preset control dimming
- Luminaire addressable hardwired
- Zone control wireless
- Luminaire addressable wireless
- POE (Power Over Ethernet)
- IOT (Internet of Things)

Typical Control Strategies Matrix

<table>
<thead>
<tr>
<th>Space Type</th>
<th>Manual Switch</th>
<th>Manual Dimmer</th>
<th>Occupancy</th>
<th>Vacancy</th>
<th>Daylight</th>
<th>Task Tuning</th>
<th>Time Clock</th>
<th>Luminance</th>
<th>Preset</th>
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</table>

Typical Space Strategy Options

- Lighting Controls
- Space Type
- Manual Switch
- Manual Dimmer
- Occupancy
- Vacancy
- Daylight
- Task Tuning
- Time Clock
- Luminance
- Preset Scene Tunable White RGB

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Pop Quiz

- What are some of the key controls strategies we might employ?

Dimming 101

- LED light sources are inherently dimmable when provided with dimming drivers.
- Almost all quality LED product is dimmable by at least a 0-10v control signal.
- OK – we’re going to dim our light sources… what are some of the key ways we make that happen?

Semiconductors…..

- Semiconductors revolutionized dimming…
- The first triac controlled wallbox dimmer – 1959
- IGBTs and FETs provided forward phase in the 1980s...
- Phase cut dimming
Phase Cut Dimming

Forward Phase Cut

Reverse Phase Cut

Pulse Width Modulation

How about a demonstration?
Electric Lamps
- Resistive
  - Incandescent
  - Halogen
  - Low Voltage
- Discharge
  - Fluorescent
  - Metal Halide
  - High/Low Pressure Sodium
  - Mercury Vapor
- Solid State
  - LED
  - OLED
  - Electroluminescent

A History of Light Sources
- LED – the defacto light source du jour....
  - Solid state light source
  - Extremely flexible
  - Potentially long lamp life
  - Dynamic color opportunities
  - White light
  - Poor to excellent color rendering

Architectural Impacts of LED
- Smaller fixtures
- Better efficacy
- Possibly better color
  - More flexibility in control
- Longer lamp life
- Reduced maintenance
- Better optics
- Back to dimming
- Better integration
- Potential confusion
LED Lamps

Consumer lamps tend to be cast into familiar shapes.

LED Lamps

Native LED sources come in a staggering variety of shapes and configurations.

LED Drivers

- Microprocessor switching power supply:
  - Voltage (typically 12-24)
  - Direct Current
  - Power Regulation
  - Power Conditioning
  - Similar to fluorescent ballasts
- Constant Current
- Constant Voltage
Which Driver?

- Allows deep dimming.
- Higher flicker risk.
- Typically lower cost.
- Constant Current
- Constant Voltage

<table>
<thead>
<tr>
<th>Driver Type</th>
<th>Characteristics</th>
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<tbody>
<tr>
<td>Constant Current</td>
<td>Allows deep dimming.</td>
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<td>Difficult to achieve deep dimming.</td>
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<td>Lower flicker risk.</td>
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<td>Better system efficacy in some cases.</td>
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<tr>
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<td>Constant Voltage only</td>
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</tbody>
</table>

Flicker

- All light sources can flicker under the right circumstances.
- LED sources may be particularly susceptible with low quality drivers or in specific cases.
- This may be ok, mildly annoying, hugely annoying, or disastrous.
- In some cases (think LiFi very high frequency flicker is desirable)

Flicker

- Is it flicker, flutter, shimmer, or other?
- % flicker = amplitude
- Amplitude and frequency both matter.
- Check at multiple dimmed light levels.
- Do the research upfront to ensure compatibility
- When in doubt ask for samples and test

Lehman/Wilkins Flicker Risk Graph

- Recommended 1% Risk Maximum of 3% (i.e., 3% Risk)
- % flicker at 1% Dimmed Level (998 Hz)
- Maximum Dimming 5% at 998 Hz, 10% Dimmed 988 Hz, 15% Dimmed 978 Hz, 20% Dimmed 968 Hz

Thank you for your attention.
Flicker

Please take out your flicker checkers.....

Pop Quiz!

- What is doing the actual dimming in most LED systems?

Dimming Control Protocols

Control Protocols include a wide range of options

- Line Voltage
- 0-10v
- Dali
- DMX-512
- KNX
- Proprietary flavors
0-10v
- Fluorescent
- LED
- Metal Halide
- Simple
- Widespread
- Defacto LED Standard
- Limited communication
- Imprecise

DMX-512 – Digital Multiplex 512 Channels
- Color changing
- Color tuning
- Theatrical lighting standard
- Flexible / Complicated
- Reasonably precise 256 steps
- Bi-directional communication
- Distance limitations
- Each universe limited to 512 zones
- Various flavors

DALI – Digitally Addressable Lighting Interface
- Fluorescent
- LED
- Incandescent
- Metal Halide
- Open Source Standard
- Each Ballast/Driver/Controller has a unique address
- 64 addresses per node
- Maximum Flexibility
- Maximum Commissioning
Proprietary Protocols

- Many manufacturers have some flavor of proprietary digital communications.
- Usually a 2 wire data bus
- May have wiring limitations
- Cat 5/6
- POE

Wireless Communications

- Zigbee
- Bluetooth
- BLE
- EnOcean
- Zwave
- WiFi
- IEEE 802 Networks
- Proprietary
- Others

Wireless Communications

- Variety of communication protocols.
- Multipoint – Hub / Spoke
- Point to Point Peer
- Mesh Network
Wireless Communications Considerations

Wireless communications is robust, but there are some considerations:

- Physical obstacles and mass
- Distance between devices
- Number of devices per node or hub
- Other systems on similar frequencies
- E-mag interference
- IOT

Cybersecurity:

- In an increasingly connected digital realm, lighting may be a gateway to attack just like other building systems.
- Expect this to become a greater issue over time.
- Lighting controls and building automation may be precluded from corporate networks.

Lighting Control Systems

- May be power handling
- May use relay packs
- May be networked
- May be automatic
- May be manual
Low Voltage Relay Systems

Characteristics:
▪ On/off switching control only
▪ May be hardwired analog or digital
▪ Generally includes scheduling capability
▪ Will accept input from occupancy sensors, photo-controls, and other systems

Considerations:
▪ May require considerable commissioning
▪ Older method of whole building control
▪ Home run circuiting required for each zone
▪ Digital control is simpler than hardwired
▪ Still relevant?

Preset Architectural Dimming Systems

Characteristics:
▪ Dimmers located in remote cabinets
▪ Advanced programming and playback
▪ Will include scheduling capability
▪ Will accept input from occupancy sensors, photo-controls, and other systems

Considerations:
▪ Dimming modules may be load type specific
▪ May require coordination with AV systems
▪ Likely to require digital protocols like DMX-512
▪ Still relevant?

Distributed Systems

Characteristics:
▪ May be stand alone or integrated.
▪ Will be a scalable digital system.
▪ May incorporate scheduling capability
▪ Will accept input from devices including occupancy sensors and photo-controls
▪ Inherently Flexible

Considerations:
▪ Coordinate digital protocol - LON, Bachnet, etc
DALI – Digitally Addressable Lighting Interface
- Open Source Standard
- Each device has a unique address
- Maximum flexibility
- Maximum commissioning
- All controls strategies possible
- Energy management software
- Lumen Maintenance
- Scheduling
- Data Logging

Luminaire Level Lighting Controls
- Wrap all of the sensors and most of the logic into the luminaire itself
- Simple to specify and install
- Will require commissioning to function most effectively.
- May be capable of all control strategies
- May be capable of only OS/VS and Daylight harvesting
- Smarter systems will be more capable

POE – Power over Ethernet
- Open Source Standard?
- Each device has a unique address
- Maximum flexibility
- Maximum commissioning
- All controls strategies possible
- Energy management software
- Lumen Maintenance
- Scheduling
- Data Logging
Networked Lighting Controls Today

- Distributed
- Wireless
- More Capable
- More Complex
- Less Complicated
- Less Costly
- Easier to Install / Commission
- Compatible
- Integrated
- Better!

Sequence of Operations

Ok...so now we have all of this great hardware...now what?

- Who is going to tell us what it's really supposed to do?
  - Lighting Designer?
  - Electrical Engineer?
  - Architect?
  - Owner?
  - Factory Tech?
  - Contractor?

Pop Quiz!

- What is the most common dimming control protocol in use today?
Sequence of Operations

Ok...so now we have all of this great hardware...now what?

- Who is going to tell us what it’s really supposed to do?
  - Lighting Designer? May not be contracted to design controls...
  - Electrical Engineer?
  - Architect?
  - Owner?
  - Factory Tech?
  - Contractor?

Whoever winds up doing it...a sequence of operations is required to tell the contractor, startup technician, and commissioning agent how the system is supposed to function.

- What are the time and astronomic schedules
- Which sensors are vacancy and which are occupancy?
- What is the vacancy timeout?
- What are the target light levels for task tuning?
- What switches or dimmers are tied to which zones?
- What zones are included in each preset and at what levels?
- What are the daylight zone dimming thresholds?
- Are there any specialty programming tasks like partition controls?
Sequence of Operations

There are lots of ways that Sequence of Operations (SOO) information may be conveyed.

- Basic Matrix
- Narrative
- Detailed Matrix
- Panel Schedule
- Dimming Schedule
- Most manufacturers have their own system

---

**Sequence of Operations**

1. Typical office
   1. All general lighting will be programmed to automatically turn "ON" as the user enters the room through the Occupancy Sensor; initial light level will be 80% of full output.
   2. Four task switches with off and intense/low intensity switches located at each workstation with a dimmer switch located at the set point for the daylight sensor during daytime hours.
   a. Pressing Button 1 will turn all fixtures to 95% light output.
   b. Pressing Button 2 will turn all fixtures to 70% light output.
   c. Pressing Button 3 will turn all fixtures to 50% light output.
   d. Pressing Button 4 will turn all fixtures to 100% light output.
   e. Pressing Button 5 will turn all lighting fixtures "OFF".
   3. Photosensor will continuously sense the light beam output depending on the amount of daylight present. Photosensor is used to calibrate the system to provide an average of 20%-30% fixture/cell dimmed as work area (10' height of floor) above finished floor.
   4. When the user leaves the room, the lights will automatically turn "OFF" after a 15 minute delay from in-occupied status.

---

**Sequence of Operations**

<table>
<thead>
<tr>
<th>Area</th>
<th>Sequence</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>Stage 5</th>
<th>Stage 6</th>
<th>Stage 7</th>
<th>Stage 8</th>
<th>Stage 9</th>
<th>Stage 10</th>
<th>Stage 11</th>
<th>Stage 12</th>
<th>Stage 13</th>
<th>Stage 14</th>
<th>Stage 15</th>
<th>Stage 16</th>
<th>Stage 17</th>
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<tbody>
<tr>
<td>Office</td>
<td></td>
<td>L.1</td>
<td></td>
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<td>L.2</td>
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</tbody>
</table>

---
Let's look at part of a typical Tech Office TI:

- Plan
- Section
- Renderings
- Luminaire Schedule
- Initial Light Levels

<table>
<thead>
<tr>
<th>Type</th>
<th>Image</th>
<th>Product Description</th>
<th>Bunker Size (L x W x H)</th>
<th>Luminaire Type</th>
<th>Luminaire Number</th>
<th>Total Luminaire Size (L x W x H)</th>
<th>Total Luminaire Number</th>
<th>Finish</th>
<th>Mounting</th>
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</thead>
<tbody>
<tr>
<td>L1</td>
<td></td>
<td>REGOJ 0907 (M4) (H)</td>
<td>800 x 500 x 300 mm</td>
<td>T3</td>
<td>1</td>
<td>204 x 34 x 30 mm</td>
<td>2</td>
<td>WH</td>
<td>136 x 115</td>
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<tr>
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<td>REGOJ 0907 (M4) (H)</td>
<td>800 x 500 x 300 mm</td>
<td>T4</td>
<td>1</td>
<td>204 x 34 x 30 mm</td>
<td>2</td>
<td>WH</td>
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<td>L3</td>
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<td>204 x 34 x 30 mm</td>
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<td>800 x 500 x 300 mm</td>
<td>T5</td>
<td>1</td>
<td>204 x 34 x 30 mm</td>
<td>2</td>
<td>WH</td>
<td>136 x 115</td>
</tr>
</tbody>
</table>

Room | Target Light Level | Initial Light Level |
-----|-------------------|---------------------|
I    | 20                | 45                  |
II   | 20                | 45                  |
III  | 25                | 30                  |
IV   | 40                | 35                  |
Great day!

Questions?

Same Time Tomorrow!
And now – a few words from LDL

Upcoming LDL Online Events

<table>
<thead>
<tr>
<th>LDL Course</th>
<th>Delivery Date</th>
<th>Time</th>
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<tbody>
<tr>
<td>Fundamentals of NLC (Side B – Practical Application)</td>
<td>July 15</td>
<td>10:00- Noon</td>
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<tr>
<td>The Lighting Design Process</td>
<td>July 28</td>
<td>10:00- Noon</td>
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<tr>
<td>Audit and Retrofit Techniques</td>
<td>August 11</td>
<td>10:00- Noon</td>
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<td>Introduction to Codes and Standards</td>
<td>August 25</td>
<td>10:00- Noon</td>
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<tr>
<td>Promoting Energy Efficient Lighting Systems</td>
<td>September 8</td>
<td>10:00- Noon</td>
</tr>
</tbody>
</table>

Today’s slide deck and previous online courses can be found on our website

Click – Call – Connect

- Armando Berdiel Chavez
- 206-475-2722
- armando.berdiel@gmail.com

Visit us online

OR
Email Us
lightingdesignlab@seattle.gov

Todays slide deck will be posted here!
Please take the online survey once you exit the webinar

We’ll SEE you on the next call... 😊