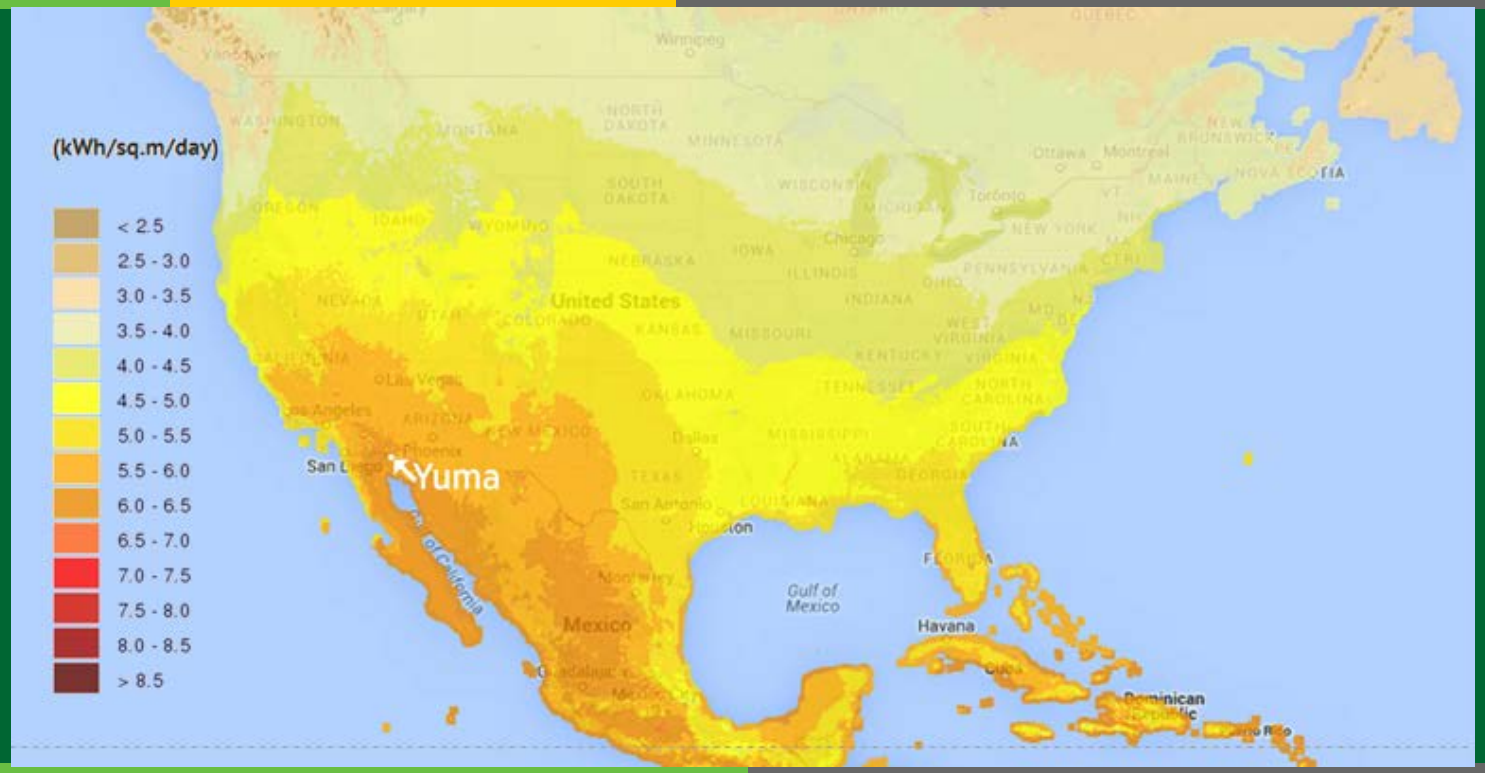
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

# Real-World Studies: Measuring LEDs in Yuma




## CORM Annual Technical Conference

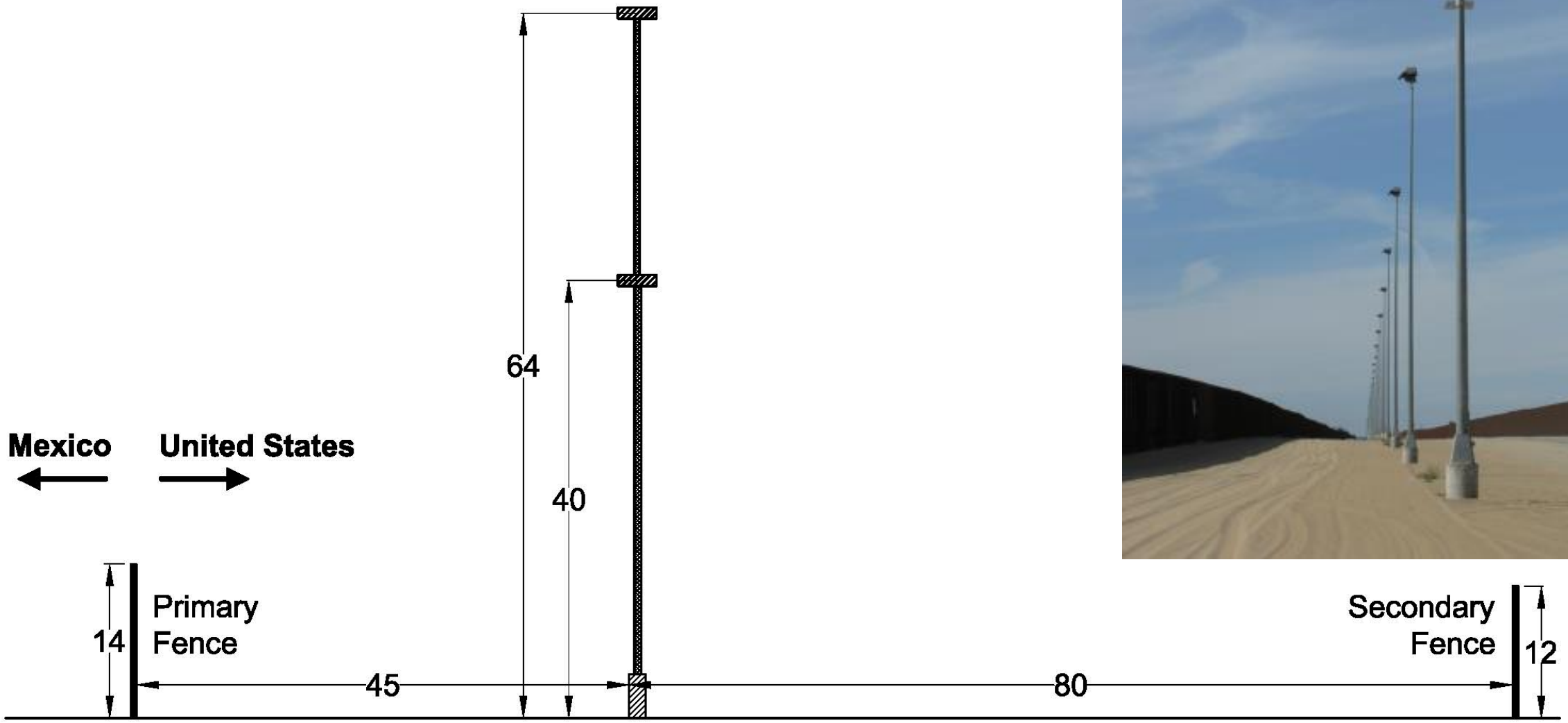
May 2016

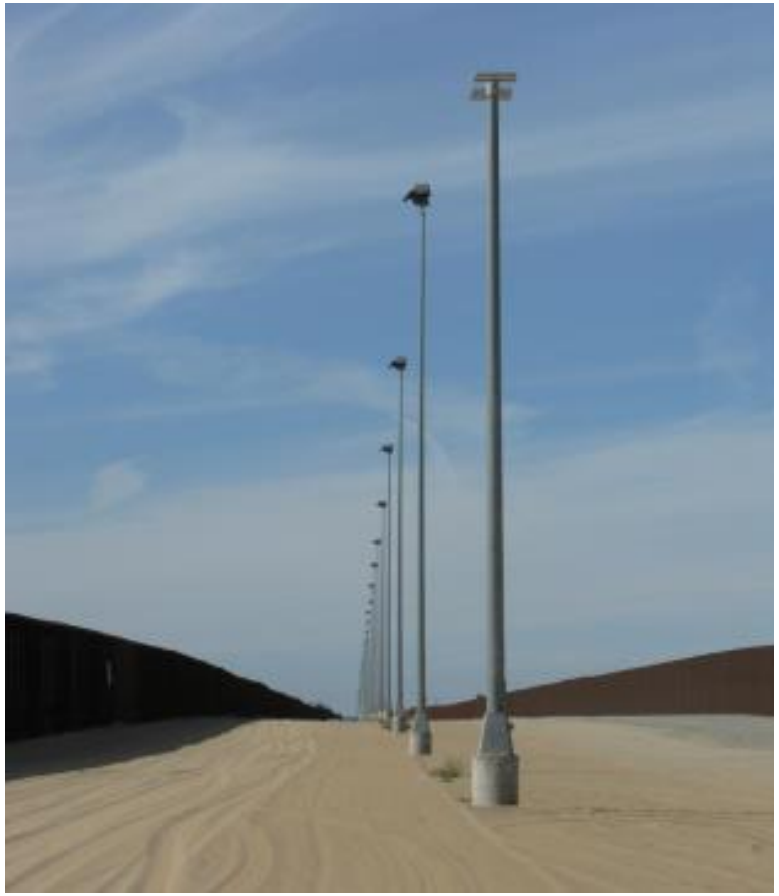

**Andrea Wilkerson, Ph.D., LC**

Lighting Research Engineer

Pacific Northwest National Laboratory

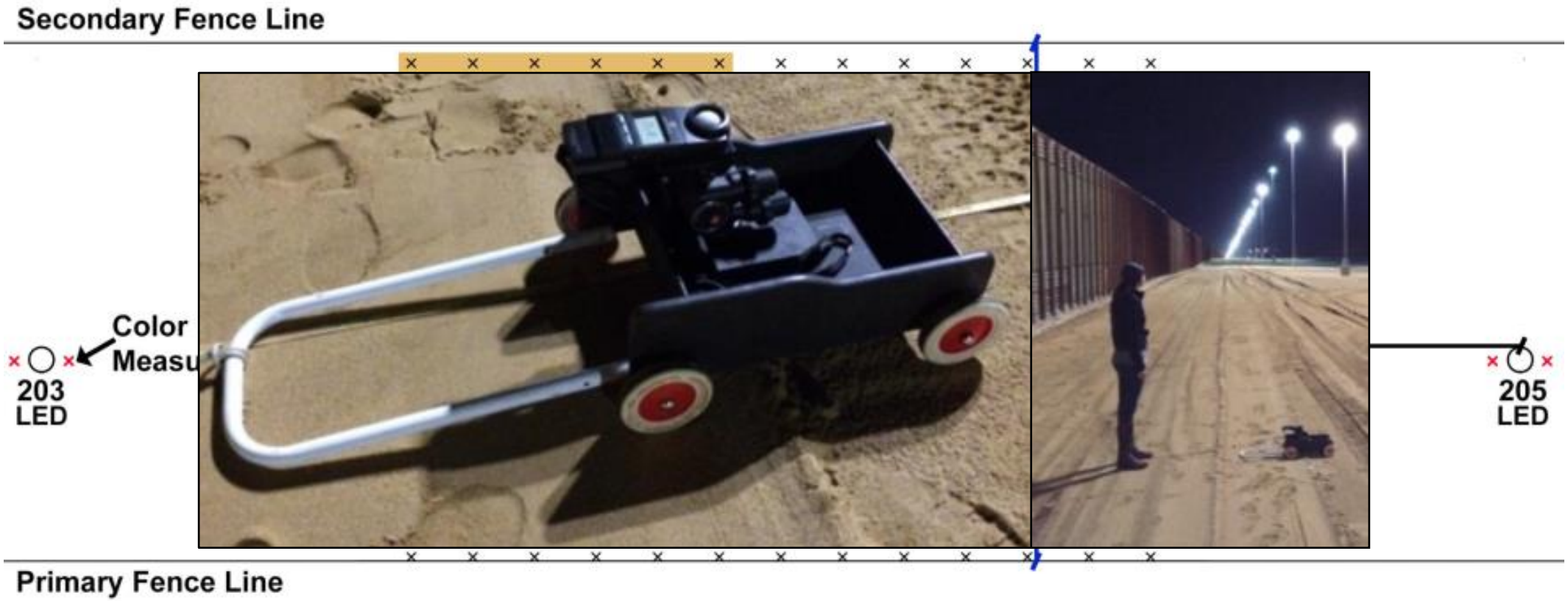
# Background


Mexico
United States
64
40
14
Primary
Fence
45
80
Secondary
Fence
12

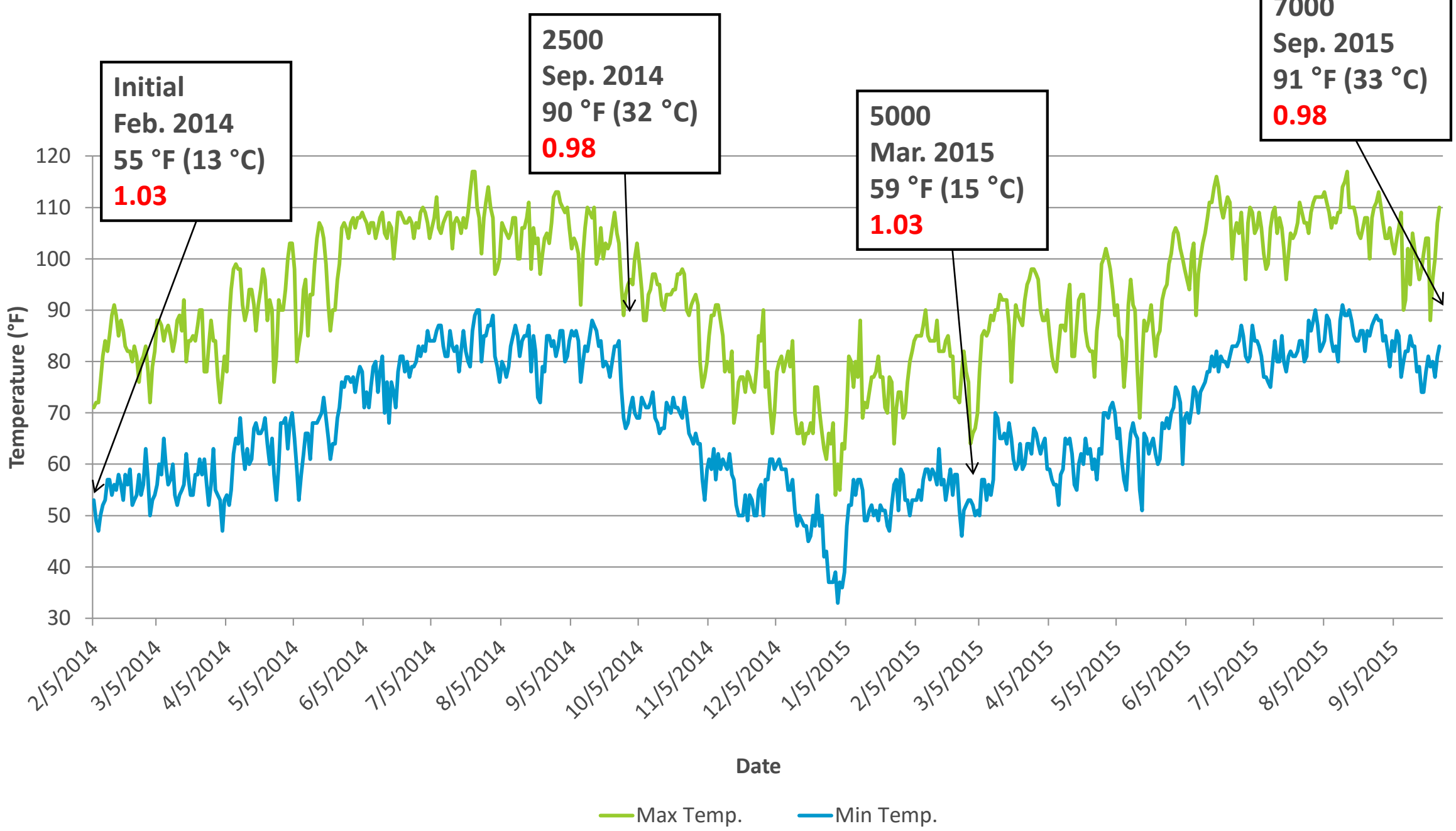


# Background

- 15 x 15 ft. grid
- 9.5 in. above the ground
- 4 ft. and 8 ft. along the fence

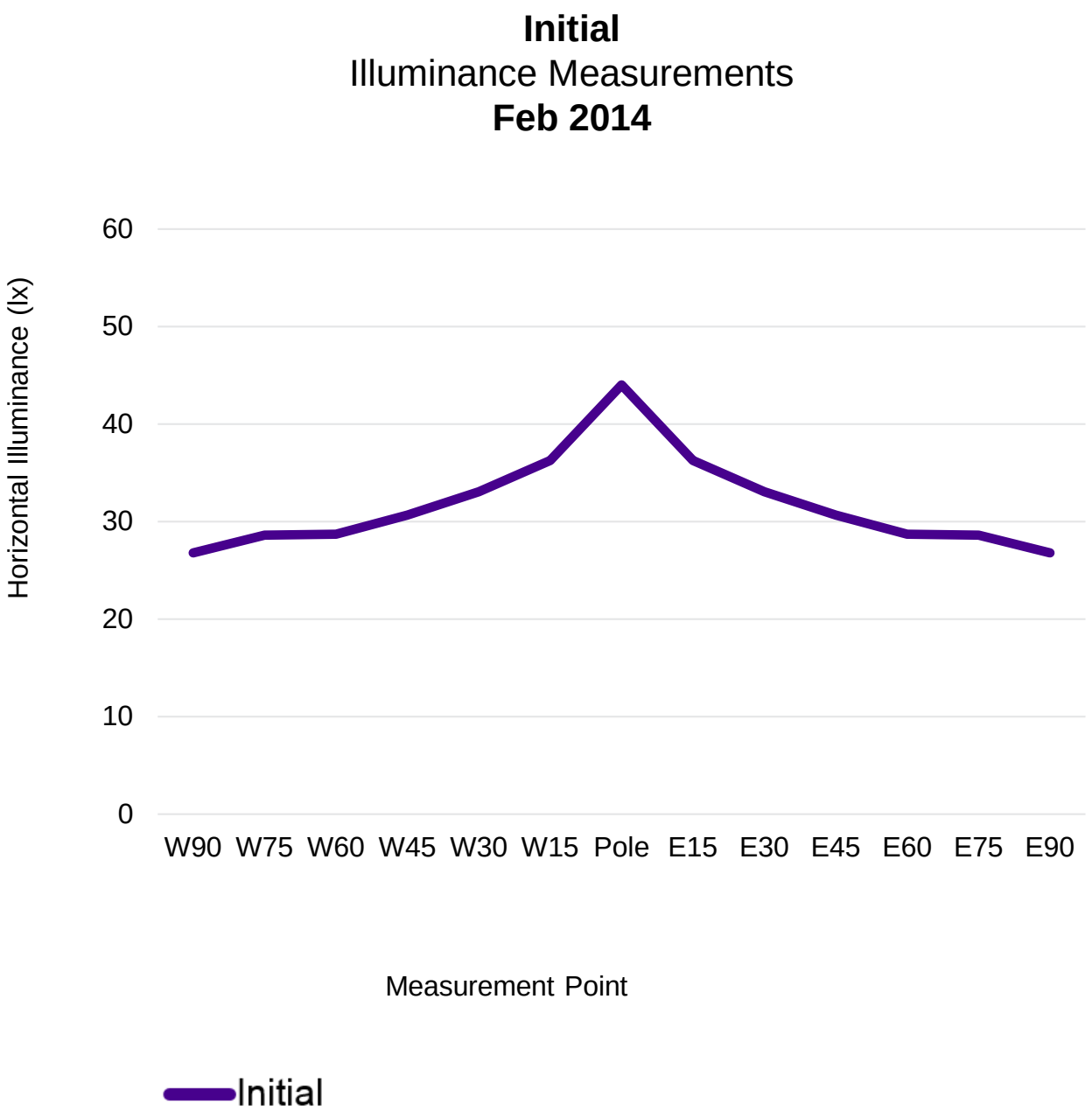



# Luminaire Installation: Daily Max and Min Temperature



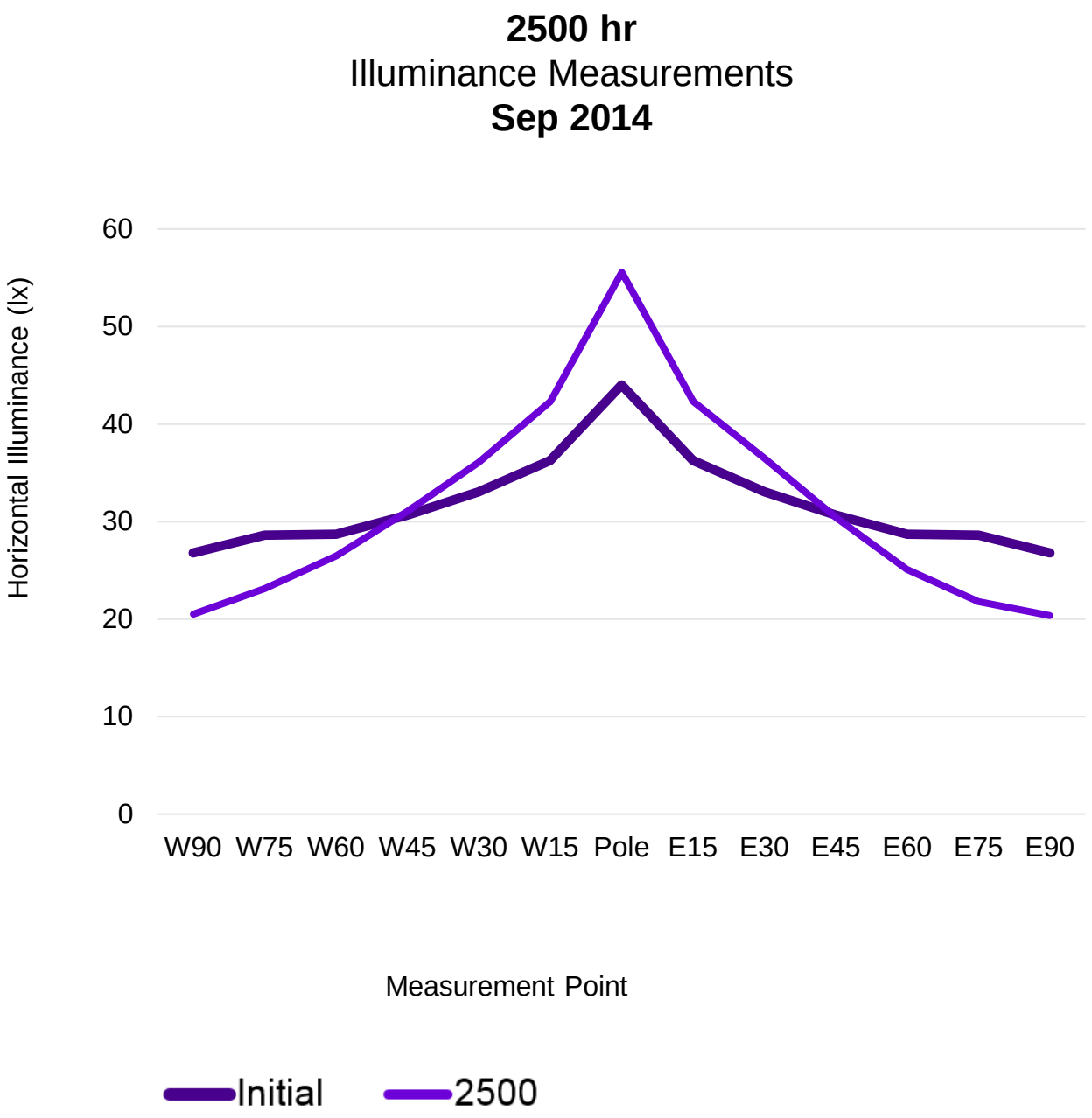
| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 ft | 4.2 | 4.2 | 4.4 | 4.8 | 5.5 | 6.3 | 6.5 | 6.5 | 5.9 | 5.0 | 4.4 | 4.4 | 4.6 |
| 4 ft | 4.5 | 4.6 | 4.9 | 5.5 | 6.5 | 7.2 | 7.4 | 7.4 | 6.9 | 6.0 | 5.5 | 5.4 | 5.7 |
| Secondary Fence | | | | | | | | | | | | | |
| N75 | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 | 4.3 | 4.4 | 4.3 | 4.1 | 4.0 | 3.9 | 3.8 | 3.7 |
| N60 | 6.5 | 6.5 | 6.7 | 6.8 | 7.2 | 7.6 | 7.8 | 7.6 | 7.2 | 6.8 | 6.7 | 6.5 | 6.5 |
| N45 | 13.1 | 13.1 | 12.6 | 12.9 | 13.6 | 14.7 | 14.9 | 14.7 | 13.6 | 12.9 | 12.6 | 13.1 | 13.1 |
| N30 | 19.3 | 20.7 | 22.0 | 22.0 | 23.8 | 25.4 | 25.4 | 25.4 | 23.8 | 22.0 | 22.0 | 20.7 | 19.3 |
| N15 | 25.1 | 25.8 | 26.7 | 27.2 | 32.7 | 38.8 | 40.7 | 38.8 | 32.7 | 27.2 | 26.7 | 25.8 | 25.1 |
| Pole | 26.8 | 28.6 | 28.7 | 30.7 | 33.1 | 36.3 | 44.0 | 36.3 | 33.1 | 30.7 | 28.7 | 28.6 | 26.8 |
| S15 | 27.1 | 27.7 | 28.6 | 29.7 | 33.5 | 37.7 | 40.2 | 38.0 | 35.3 | 32.2 | 31.6 | 29.8 | 27.4 |
| S30 | 26.2 | 26.8 | 27.0 | 27.0 | 27.9 | 29.2 | 29.2 | 29.7 | 29.7 | 28.1 | 29.8 | 28.9 | 26.4 |
| S45 | 22.3 | 23.0 | 21.6 | 21.3 | 22.7 | 23.2 | 23.7 | 24.1 | 23.2 | 21.8 | 22.2 | 22.0 | 20.4 |
| Primary Fence | | | | | | | | | | | | | |
| 4 ft | 24.2 | 25.4 | 27.1 | 28.2 | 29.8 | 32.0 | 30.8 | 31.1 | 29.3 | 25.8 | 27.5 | 25.2 | 23.4 |
| 8 ft | 20.7 | 22.8 | 26.9 | 31.4 | 32.6 | 35.3 | 35.6 | 35.3 | 33.4 | 30.9 | 27.9 | 22.6 | 20.8 |
| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |

N



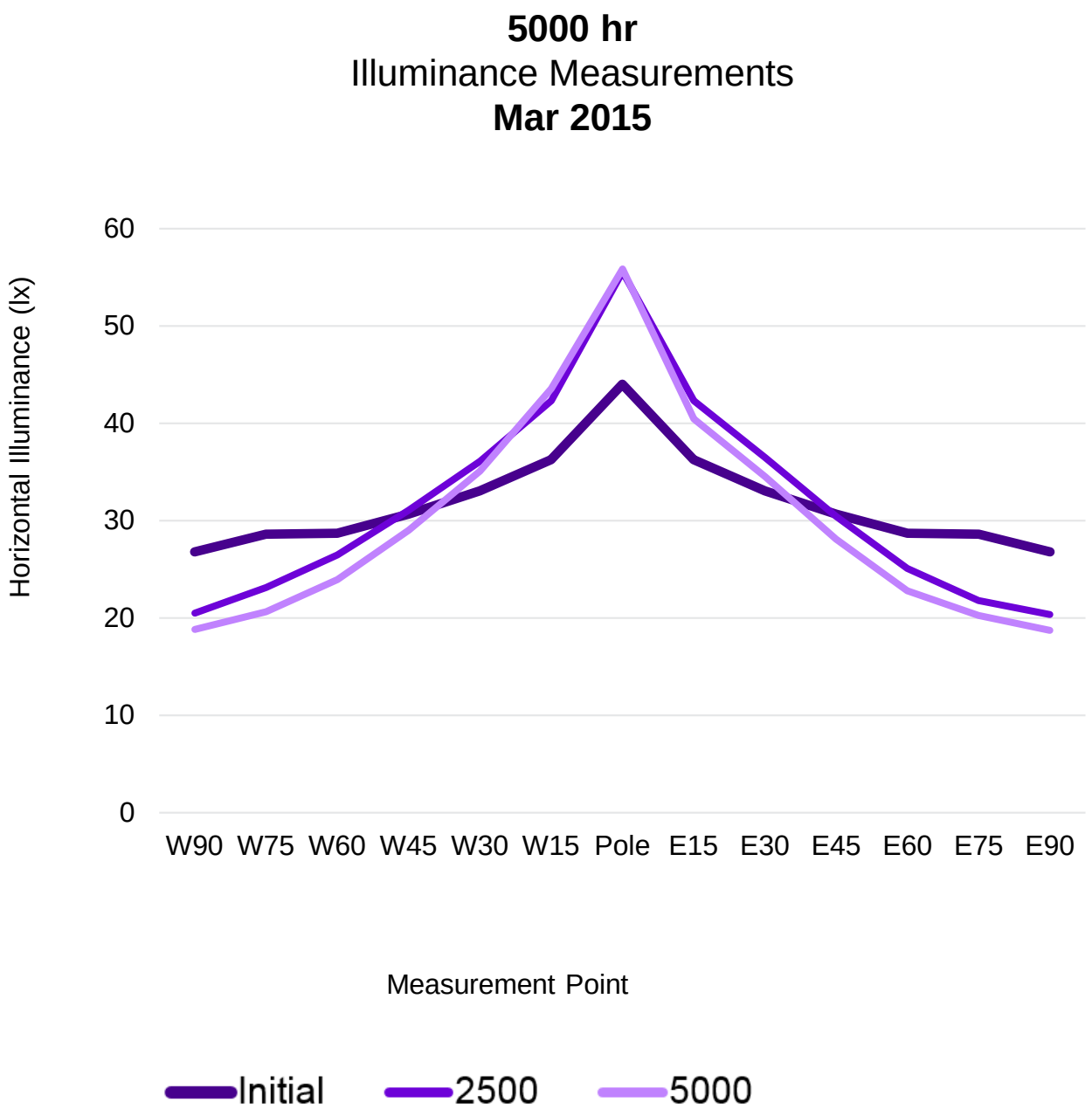
| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 ft | 4.4 | 4.5 | 4.7 | 5.2 | 5.9 | 6.6 | 6.9 | 6.8 | 6.2 | 5.3 | 4.7 | 4.6 | 4.7 |
| 4 ft | 4.8 | 4.9 | 5.2 | 5.9 | 6.9 | 7.6 | 7.8 | 7.8 | 7.2 | 6.3 | 5.7 | 5.5 | 5.6 |
| Secondary Fence | | | | | | | | | | | | | |
| N75 | 2.5 | 2.8 | 3.2 | 3.5 | 4.0 | 4.2 | 4.0 | 4.0 | 4.0 | 3.7 | 3.5 | 3.4 | 3.4 |
| N60 | 4.5 | 4.8 | 5.4 | 6.2 | 6.8 | 8.0 | 7.4 | 7.5 | 6.9 | 6.6 | 6.2 | 5.7 | 5.5 |
| N45 | 8.7 | 9.2 | 10.0 | 11.5 | 13.8 | 15.5 | 14.7 | 15.4 | 13.9 | 12.3 | 11.3 | 11.2 | 10.6 |
| N30 | 15.3 | 16.6 | 18.4 | 20.0 | 24.4 | 27.2 | 27.3 | 28.0 | 25.6 | 21.9 | 19.7 | 17.3 | 15.7 |
| N15 | 19.2 | 21.2 | 23.0 | 27.8 | 35.9 | 43.5 | 45.8 | 44.8 | 36.5 | 28.1 | 24.1 | 20.9 | 19.7 |
| Pole | 20.5 | 23.1 | 26.5 | 31.1 | 36.1 | 42.3 | 55.6 | 42.3 | 36.5 | 30.5 | 25.1 | 21.8 | 20.4 |
| S15 | 19.3 | 22.2 | 25.6 | 29.8 | 36.7 | 43.3 | 46.8 | 43.4 | 36.3 | 28.1 | 22.9 | 20.1 | 19.5 |
| S30 | 17.6 | 20.0 | 22.6 | 25.1 | 28.2 | 30.6 | 31.1 | 29.4 | 25.6 | 21.1 | 18.8 | 17.5 | 17.5 |
| S45 | 15.5 | 16.5 | 16.2 | 17.1 | 19.2 | 19.8 | 20.2 | 19.3 | 17.1 | 14.8 | 13.4 | 12.9 | 13.2 |
| Primary Fence | | | | | | | | | | | | | |
| 4 ft | 16.4 | 18.7 | 20.0 | 21.2 | 23.9 | 27.3 | 26.5 | 25.7 | 22.5 | 19.7 | 17.8 | 15.9 | 15.3 |
| 8 ft | 14.4 | 16.6 | 23.5 | 25.2 | 26.2 | 29.3 | 29.9 | 28.4 | 26.1 | 20.0 | 16.7 | 14.0 | 13.7 |
| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |

N



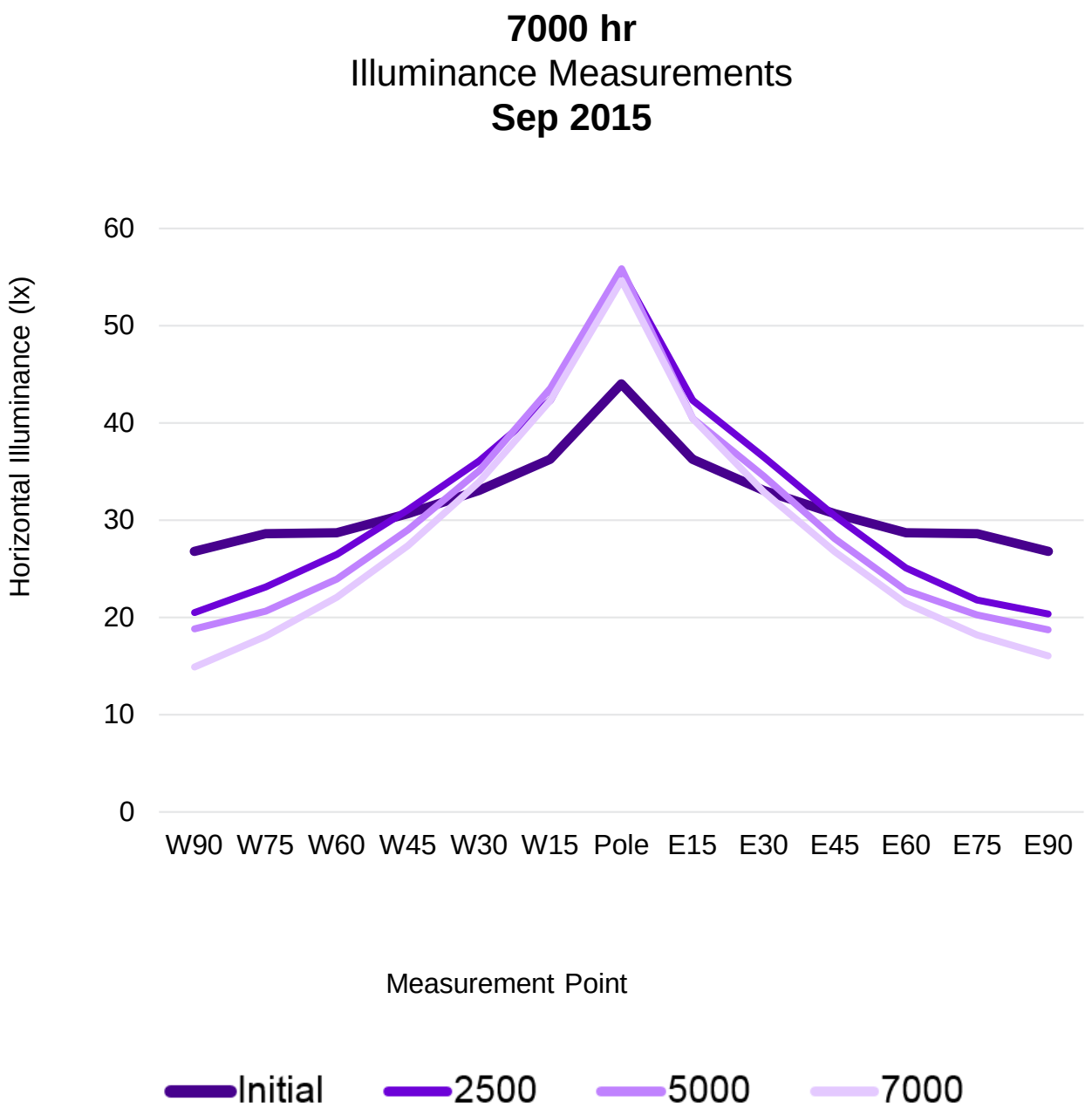
| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 ft | 4.1 | 4.2 | 4.5 | 4.9 | 5.7 | 6.5 | 6.7 | 6.7 | 6.1 | 5.1 | 4.6 | 4.4 | 4.6 |
| 4 ft | 4.6 | 4.7 | 5.1 | 5.8 | 6.9 | 7.6 | 8.6 | 7.6 | 7.2 | 6.2 | 5.6 | 5.4 | 5.5 |
| Secondary Fence | | | | | | | | | | | | | |
| N75 | 3.1 | 3.2 | 3.2 | 3.5 | 3.9 | 4.3 | 4.3 | 4.1 | 4.0 | 3.7 | 3.6 | 3.4 | 3.2 |
| N60 | 4.8 | 5.1 | 5.3 | 6.0 | 6.9 | 7.9 | 8.0 | 7.8 | 7.1 | 6.4 | 5.9 | 5.4 | 5.0 |
| N45 | 8.7 | 8.7 | 9.5 | 11.2 | 13.3 | 15.2 | 15.5 | 15.3 | 13.7 | 11.7 | 10.6 | 9.7 | 9.1 |
| N30 | 14.1 | 14.7 | 16.6 | 19.3 | 24.0 | 27.1 | 28.0 | 27.7 | 24.7 | 20.6 | 17.8 | 15.1 | 13.4 |
| N15 | 17.4 | 18.4 | 20.9 | 26.6 | 35.0 | 43.6 | 46.5 | 44.0 | 34.6 | 25.9 | 21.7 | 18.7 | 17.4 |
| Pole | 18.8 | 20.7 | 24.0 | 29.0 | 35.1 | 43.6 | 55.9 | 40.5 | 34.5 | 28.1 | 22.8 | 20.3 | 18.7 |
| S15 | 17.9 | 19.8 | 23.0 | 27.4 | 34.4 | 42.0 | 45.3 | 40.2 | 32.8 | 25.6 | 22.1 | 19.6 | 18.5 |
| S30 | 17.0 | 18.4 | 20.3 | 22.5 | 25.6 | 28.3 | 28.3 | 27.5 | 24.4 | 21.1 | 19.5 | 18.1 | 17.4 |
| S45 | 14.8 | 15.5 | 15.4 | 16.9 | 19.1 | 20.5 | 20.8 | 20.2 | 18.2 | 16.1 | 15.1 | 14.3 | 13.9 |
| Primary Fence | | | | | | | | | | | | | |
| 4 ft | 16.2 | 17.3 | 16.4 | 19.9 | 24.1 | 27.2 | 27.6 | 26.5 | 24.6 | 19.3 | 19.1 | 16.9 | 15.9 |
| 8 ft | 13.5 | 15.5 | 18.0 | 22.6 | 26.7 | 30.2 | 30.6 | 29.6 | 25.8 | 21.3 | 18.3 | 15.2 | 13.9 |
| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |

N



| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 ft | 3.7 | 3.8 | 4.2 | 4.8 | 5.7 | 6.4 | 6.4 | 6.2 | 5.5 | 4.8 | 4.1 | 3.7 | 3.7 |
| 4 ft | 4.5 | 4.6 | 4.9 | 5.6 | 6.7 | 6.9 | 7.2 | 7.0 | 6.3 | 5.2 | 4.5 | 4.1 | 3.8 |
| Secondary Fence | | | | | | | | | | | | | |
| N75 | 2.2 | 2.6 | 3.0 | 3.4 | 3.8 | 4.0 | 4.1 | 4.1 | 3.8 | 3.6 | 2.9 | 3.1 | 2.9 |
| N60 | 3.9 | 4.4 | 5.1 | 5.7 | 6.7 | 7.7 | 7.6 | 7.6 | 7.1 | 6.0 | 5.4 | 5.1 | 4.7 |
| N45 | 7.5 | 8.0 | 9.5 | 10.2 | 12.8 | 14.9 | 15.1 | 15.1 | 13.7 | 11.2 | 10.3 | 9.5 | 8.6 |
| N30 | 11.7 | 13.5 | 15.6 | 18.0 | 22.3 | 25.9 | 26.8 | 26.9 | 24.9 | 19.4 | 16.9 | 14.7 | 12.7 |
| N15 | 14.5 | 16.9 | 19.4 | 24.0 | 32.4 | 41.7 | 45.2 | 42.8 | 33.7 | 24.5 | 19.9 | 17.5 | 15.3 |
| Pole | 14.9 | 18.1 | 22.1 | 27.4 | 33.9 | 42.3 | 54.7 | 40.5 | 32.9 | 26.8 | 21.5 | 18.2 | 16.0 |
| S15 | 13.9 | 17.2 | 21.0 | 26.3 | 33.6 | 41.2 | 45.3 | 40.6 | 33.2 | 25.6 | 20.7 | 17.2 | 15.2 |
| S30 | 12.8 | 15.5 | 18.6 | 20.5 | 24.3 | 28.8 | 29.7 | 28.1 | 24.1 | 18.0 | 17.3 | 15.1 | 13.9 |
| S45 | 10.8 | 12.7 | 13.6 | 15.5 | 18.1 | 19.5 | 19.8 | 19.0 | 16.7 | 13.9 | 12.5 | 11.2 | 10.5 |
| Primary Fence | | | | | | | | | | | | | |
| 4 ft | 11.8 | 13.9 | 18.6 | 21.8 | 22.9 | 25.5 | 26.0 | 24.8 | 20.7 | 16.2 | 14.3 | 12.6 | 10.9 |
| 8 ft | 10.6 | 13.3 | 19.0 | 22.4 | 25.9 | 27.6 | 28.2 | 26.4 | 22.1 | 16.1 | 13.4 | 10.5 | 9.5 |
| | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |

N



**7000 hr – Initial**

**Initial**

**Sep '15 – Feb '14**

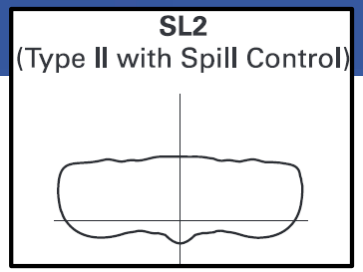
**Feb '14**

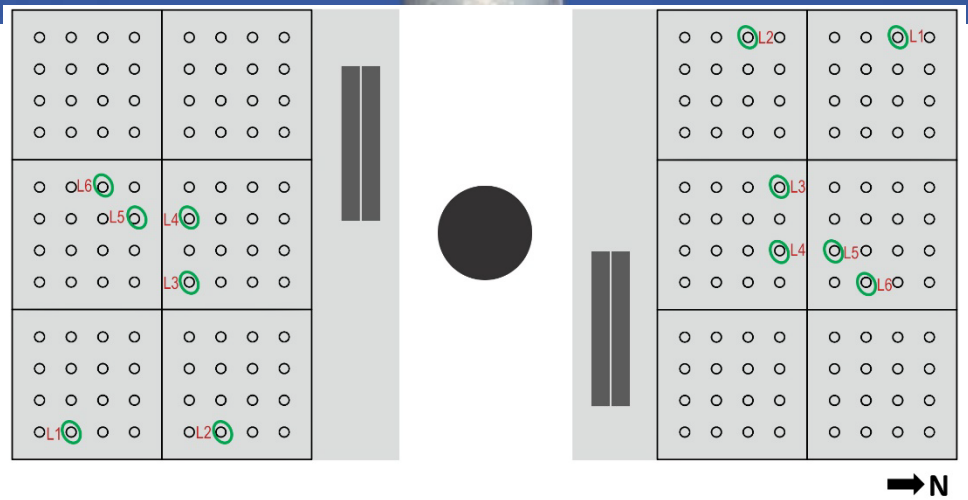
| | | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vertical | 8 ft | 0.12 | 0.10 | 0.06 | 0.01 | 0.03 | 0.02 | 0.01 | 0.04 | 0.07 | 0.05 | 0.09 | 0.18 | 0.21 |
| Vertical | 4 ft | 0.02 | 0.02 | 0.01 | 0.01 | 0.03 | 0.04 | 0.03 | 0.05 | 0.08 | 0.14 | 0.19 | 0.25 | 0.34 |
| **Secondary Fence** | | | | | | | | | | | | | | |
| Horizontal | N75 | | | | | | | 0.08 | 0.04 | 0.07 | 0.10 | 0.26 | 0.19 | 0.22 |
| Horizontal | N60 | | | | | | | 0.03 | 0.01 | 0.01 | 0.11 | 0.19 | 0.21 | 0.27 |
| Horizontal | N45 | | | | | | | 0.02 | 0.03 | 0.00 | 0.13 | 0.18 | 0.27 | 0.34 |
| Horizontal | N30 | | | | | | | 0.05 | 0.06 | 0.05 | 0.12 | 0.23 | 0.29 | 0.34 |
| Horizontal | N15 | | | | | | | 0.11 | 0.10 | 0.03 | 0.10 | 0.25 | 0.32 | 0.39 |
| Horizontal | Pole | 0.44 | 0.37 | 0.23 | 0.11 | 0.03 | 0.17 | 0.24 | 0.12 | 0.01 | 0.13 | 0.25 | 0.36 | 0.40 |
| Horizontal | S15 | 0.49 | 0.38 | 0.27 | 0.12 | 0.00 | 0.09 | 0.13 | 0.07 | 0.06 | 0.21 | 0.34 | 0.42 | 0.44 |
| Horizontal | S30 | 0.51 | 0.42 | 0.31 | 0.24 | 0.13 | 0.01 | 0.02 | 0.05 | 0.19 | 0.36 | 0.42 | 0.48 | 0.47 |
| Horizontal | S45 | 0.52 | 0.45 | 0.37 | 0.27 | 0.20 | 0.16 | 0.16 | 0.21 | 0.28 | 0.36 | 0.44 | 0.49 | 0.48 |
| **Primary Fence** | | | | | | | | | | | | | | |
| Vertical | 4 ft | 0.51 | 0.45 | 0.31 | 0.23 | 0.23 | 0.20 | 0.15 | 0.20 | 0.29 | 0.37 | 0.48 | 0.50 | 0.54 |
| Vertical | 8 ft | 0.49 | 0.42 | 0.29 | 0.29 | 0.21 | 0.22 | 0.21 | 0.25 | 0.34 | 0.48 | 0.52 | 0.54 | 0.54 |
| | | W90 | W75 | W60 | W45 | W30 | W15 | Pole | E15 | E30 | E45 | E60 | E75 | E90 |

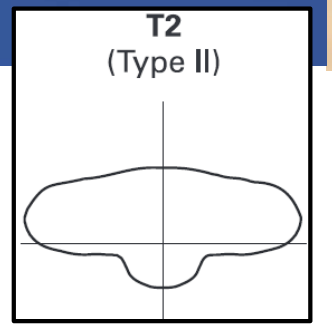
N

# Possible Causes of Changes

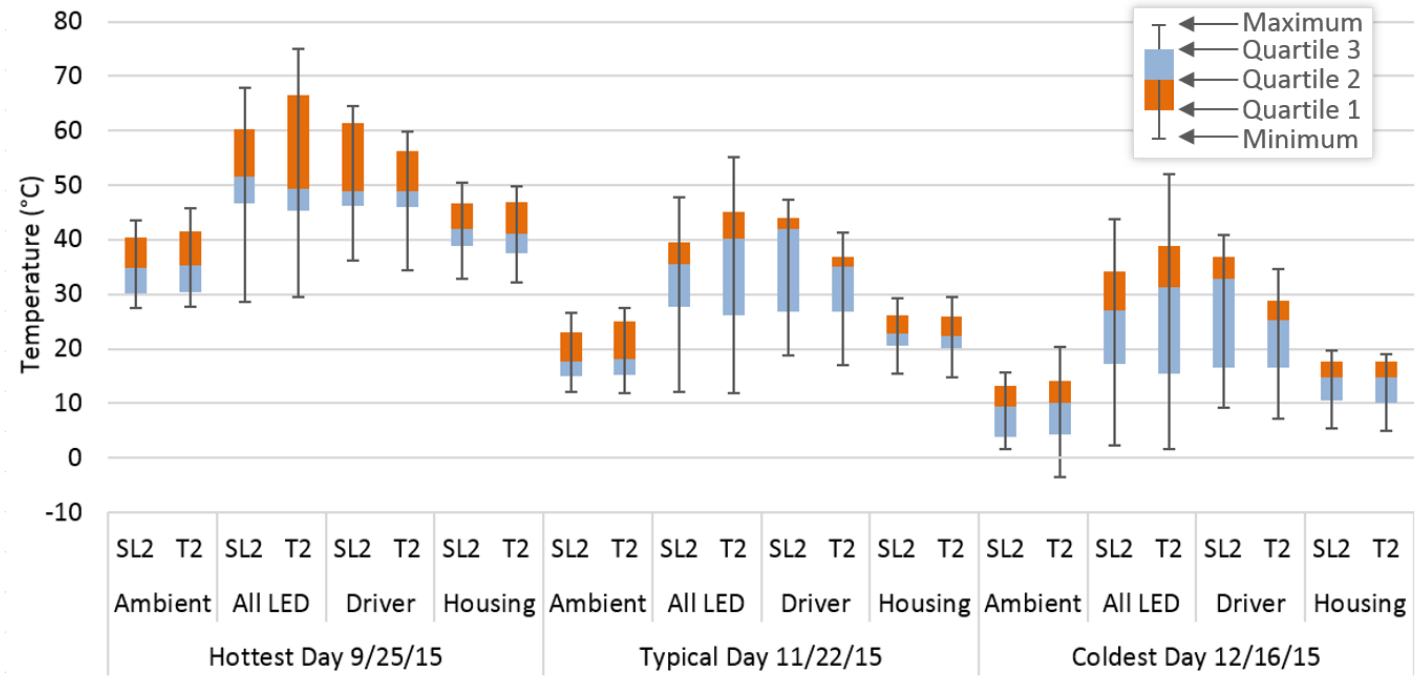
- Dirt Depreciation
- LED Depreciation
- Lens Material
- Driver
- Measurement Error
- Orientation of Luminaires
- Electrical Changes

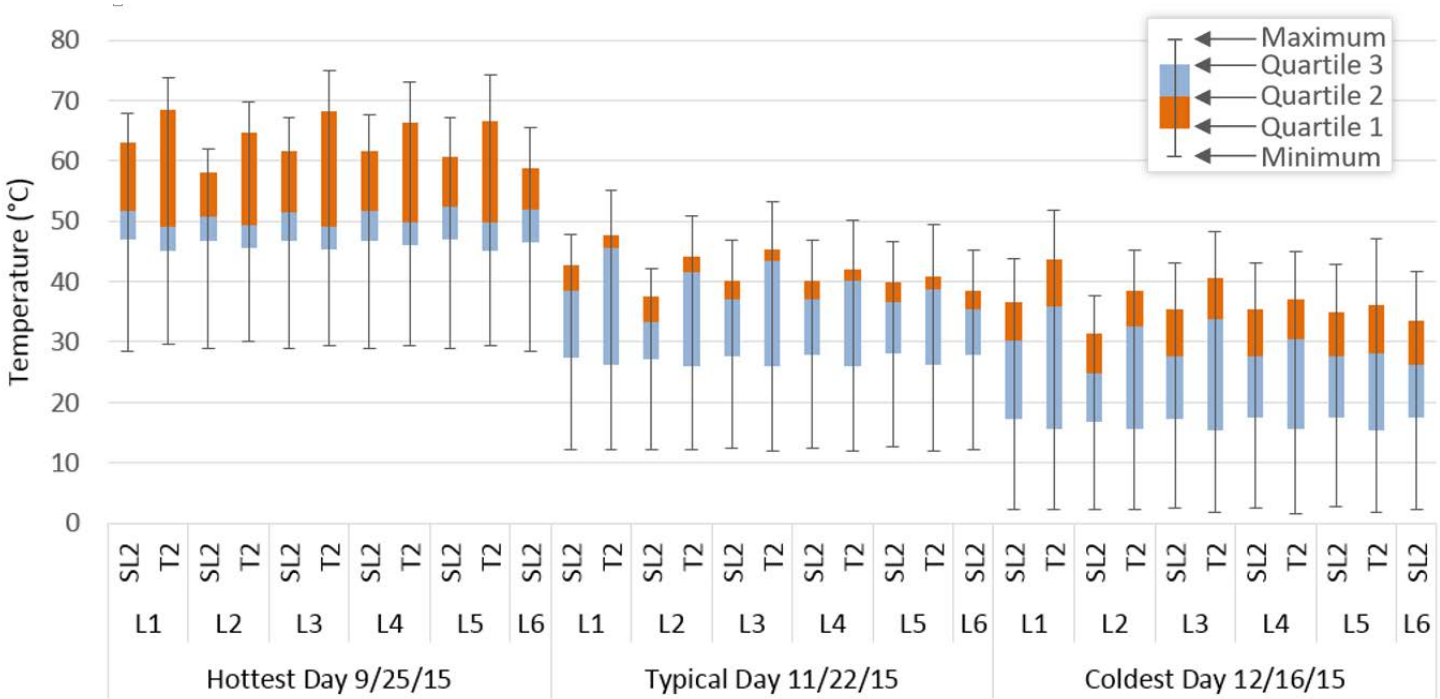



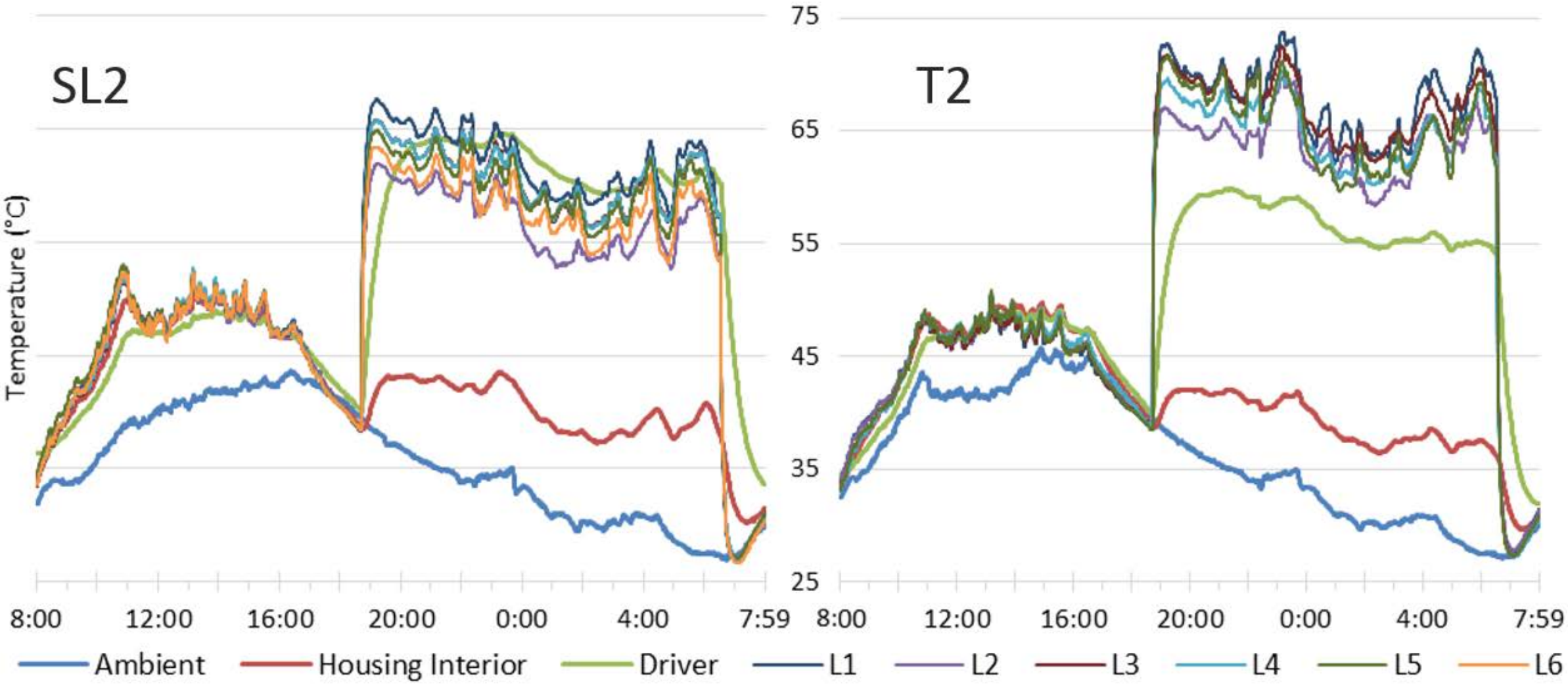



# Temperature Measurement Box and Whisker Plots

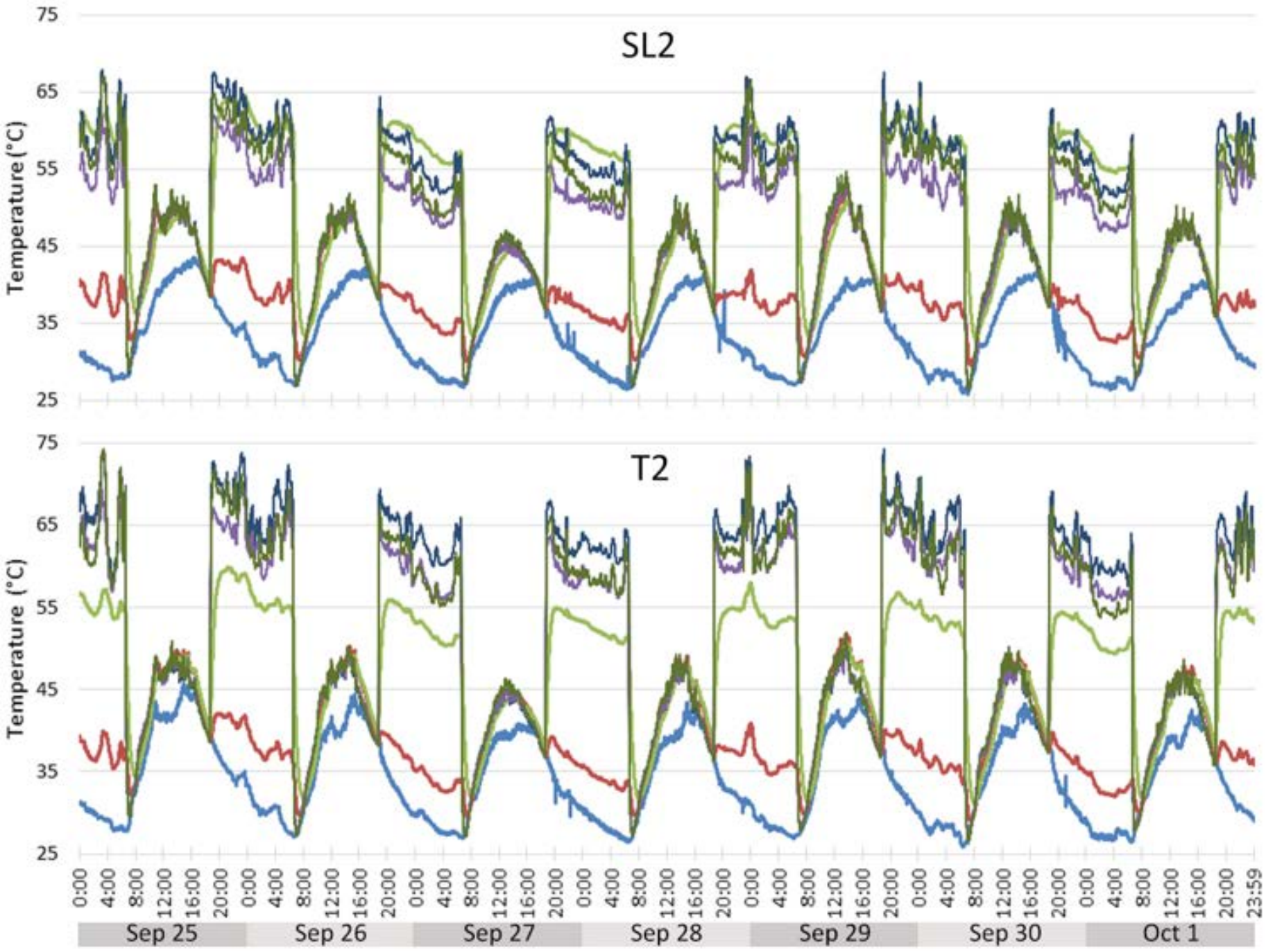


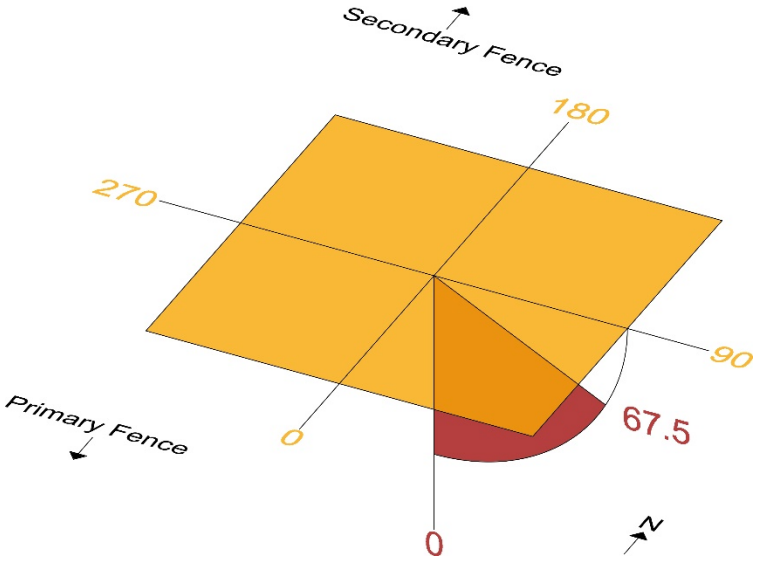
# Thermocouple Measurements: September 25 8:00 am to September 26 7:59 am, 2015

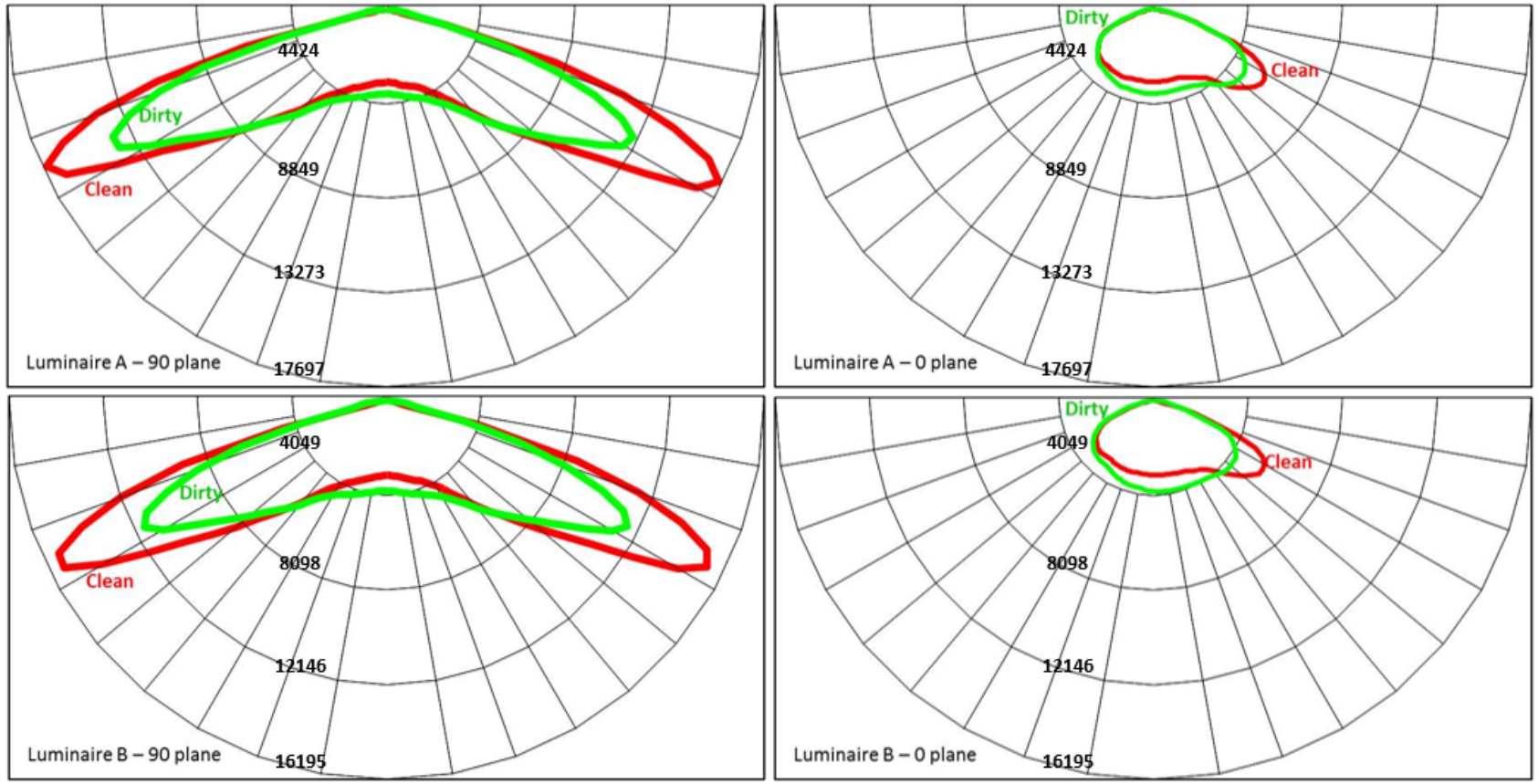


# Thermocouple Measurements: September 25 to October 1, 2015



# Lab Testing: Clean vs. Dirty




| Test | Total Output (lumens) | Peak Intensity at 90° Horizontal Angle (candela)[b] | Peak Intensity at 0° Horizontal Angle (candela)[c] | Intensity at Nadir (candela) |
|---|---|---|---|---|
| Dirty B Eaton | 24,956 | 11,643 | 4,226 | 3,883 |
| Clean B Eaton | 27,472 | 15,471 | 5,565 | 3,218 |
| **Percent Change Due to Dirt** | **-9.2%** | **-24.7%** | **-24.1%** | **+20.7%** |
| Dirty A Eaton[a] | 27,782 | 12,970 | 5,208 | 3,990 |
| Clean A Eaton[a] | 29,881 | 17,558 | 6,138 | 3,436 |
| **Percent Change Due to Dirt** | **-7.0%** | **-26.1%** | **-15.2%** | **+16.1%** |