Spatial Uniformity Optimization in Horticultural Lighting

Agricultural Research Service

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Research interests

- ATRU: Application Technology Research Unit – Wooster OH
  - GPRG: Greenhouse Production Research Group – Toledo OH
    - Plant physiologist – Jennifer Boldt
    - Engineer – me
    - Molecular biologist – TBD

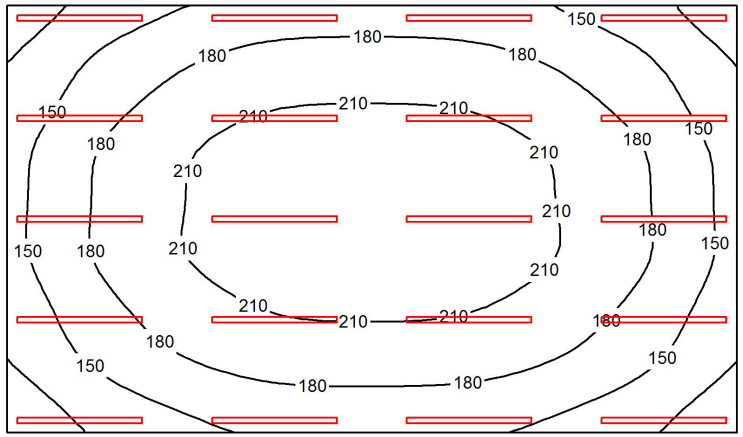
- Light/temp/CO_2 interactions
- Silicon treatments
- Energy modeling
  - Greenhouses
  - Plant factories
- Light modeling
- Lighting controls
- Environmental controls

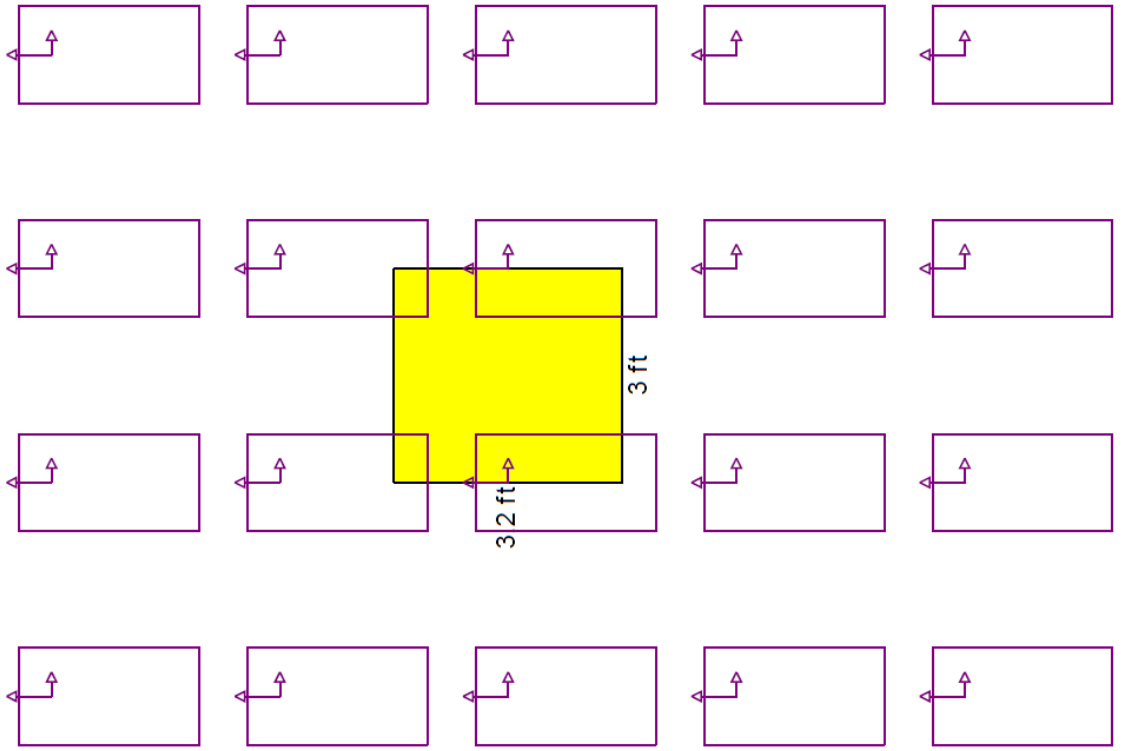
Benefits of Uniformity

- More consistent yield
- Simpler production logistics
- Less wasted space
- Higher quality research data

Typical supplemental lighting design

- Planar
- Regularly spaced
- Bulls-eye

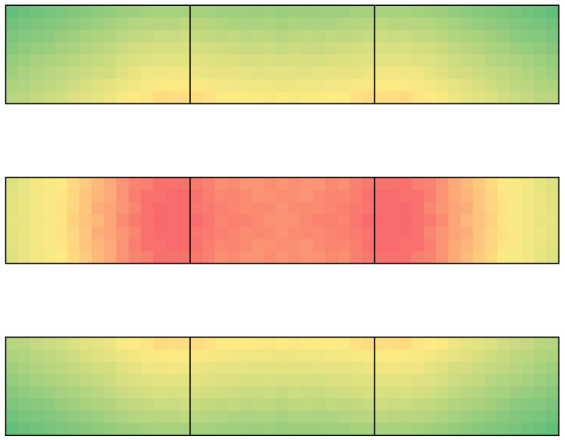




Average (Eav):	**171.7 µmol/m².s**
Minimum (Emin):	**168.1 µmol/m².s**
Maximum (Emax):	**174.5 µmol/m².s**
Emin/Emax:	**96.3 %**
Emin/Eav:	**97.9 %**

Case study: research greenhouse

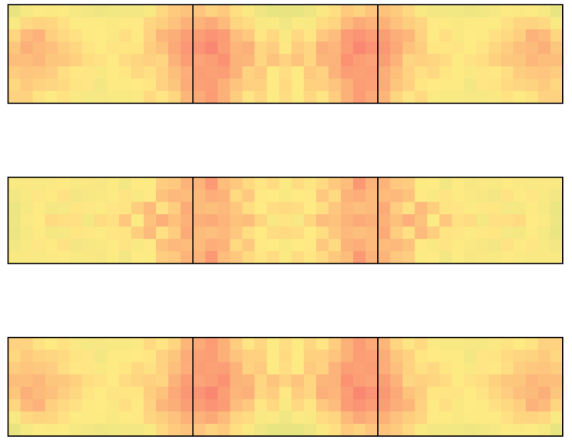
- Leafy greens
- Two growing areas
  - 160 ft^2 (15 m^2)
  - Nine fiberglass ponds
  - Aisles
  - LED and HPS



Max PPFD	201 μmol/m^2/s
Avg PPFD	173 μmol/m^2/s
Min PPFD	136 μmol/m^2/s
Min/Avg	79%
Range	-21%/+14%
Luminaires	20

Can we do better?

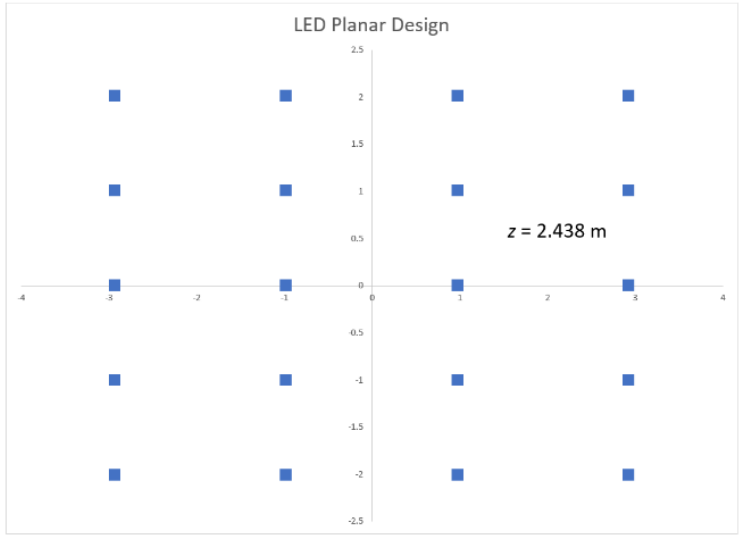
- Use far-field photometry
- Relax regular and planar assumptions
- Simulate XYZ permutations
  - Enforce symmetry constraints
  - Millions of layouts
- Select design that maximizes uniformity

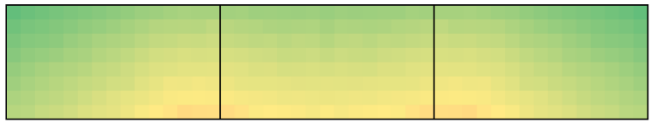


Max	196 μmol/m²/s
Avg	185 μmol/m²/s
Min	175 μmol/m²/s
Min/Avg	95%
Range	-6%/+5%
Luminaires	16

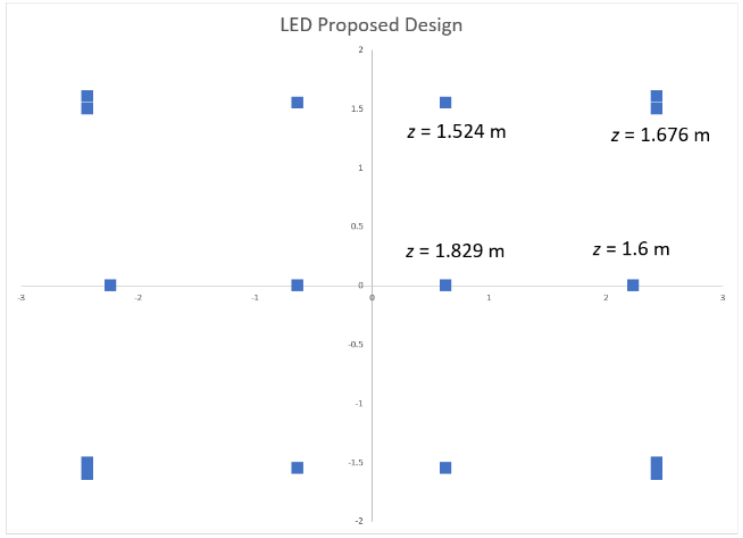
Design comparison - LED

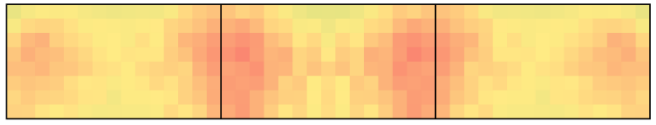
Original

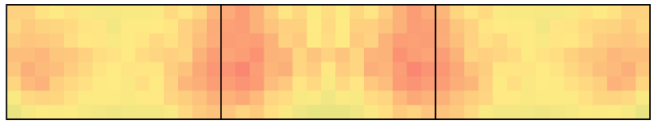




Proposed

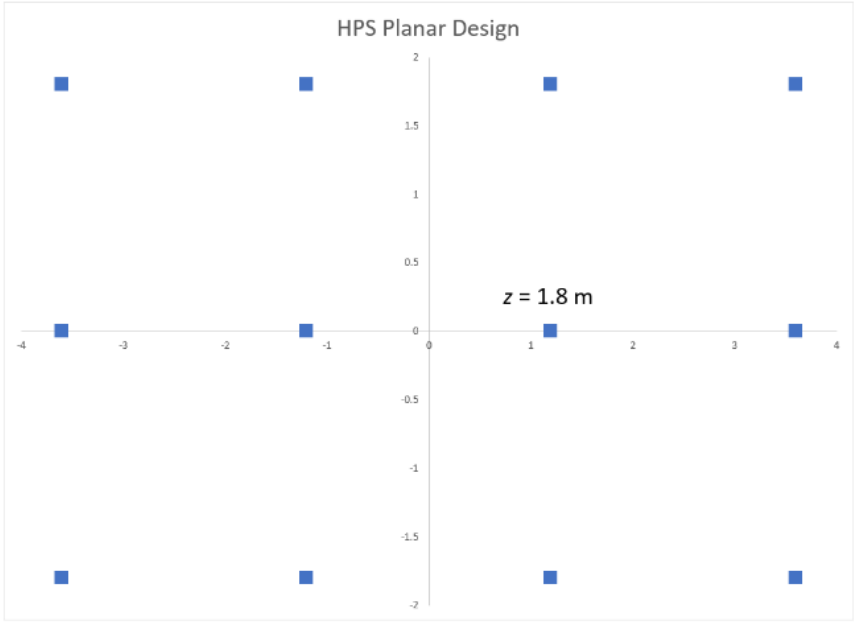




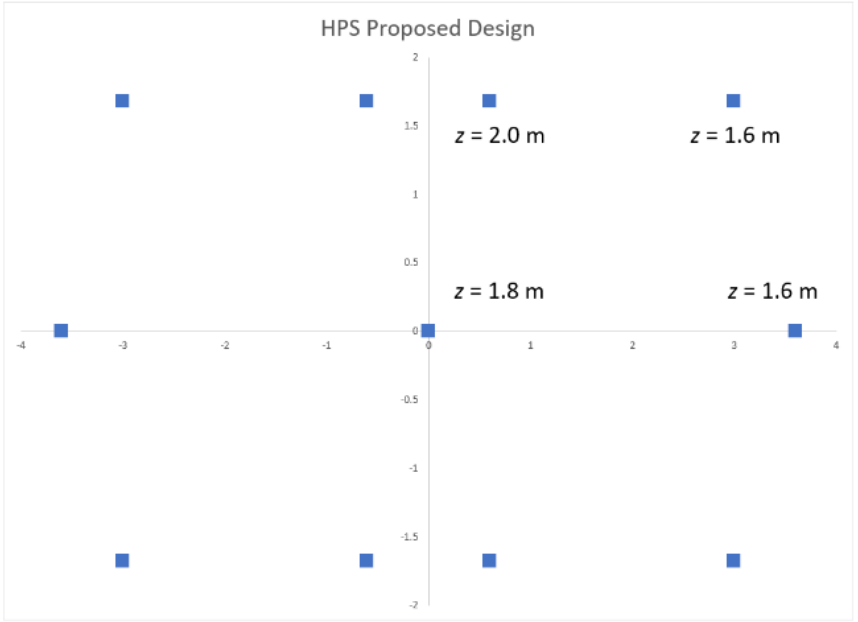


Design comparison - HPS

Original



Proposed

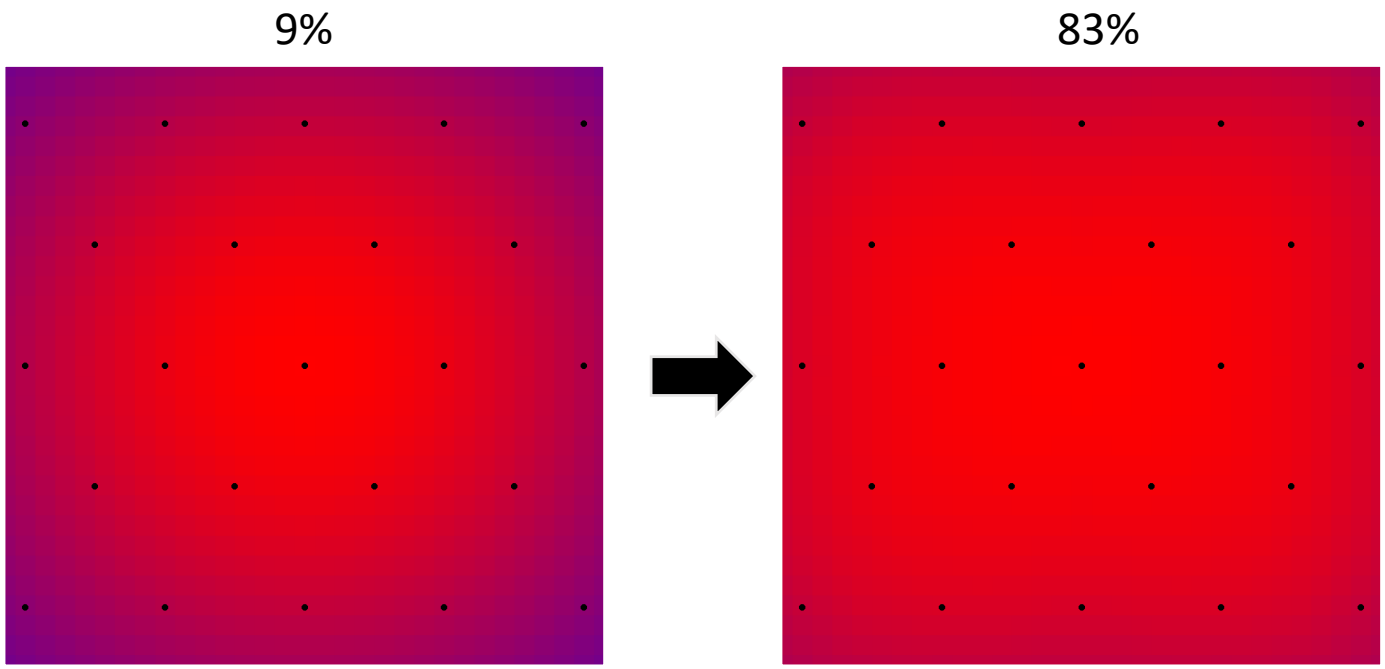


Layouts designed by algorithm

Harbick and Mattson. **Optimization of spatial lighting uniformity using non-planar arrays and intensity modulation** submitted to LightSym 2020

Intensity modulation

- 10 light levels (0 to 100%)
- 23 luminaires
- 10^{23} permutations (intractable)
- Group luminaires according to “neighborhoods”
  - 10^{4} permutations
- Algorithm determines output of luminaire groups to improve uniformity
- One metric: % of lit area within 10 μmol/m²/s of mode



Harbick, Milam, Mattson

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Future work

- Larger arrays
  - Optimize algorithms
  - More computational power (e.g. SciNet)
- Near-field applications
- Spectral uniformity

Thank you

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