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

The University of Florida Nadine McGuire Theatre and Dance Pavilion

LED Lighting in a Performing Arts Building

DOE Webcast

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GATEWAY Demonstrations

Naomi J. Miller, Designer/Scientist

Pacific Northwest National Laboratory

Professor Stan Kaye

Head of the Graduate Lighting Design Program,
University of Florida, Gainesville FL

Pacific Northwest NATIONAL LABORATORY

UF UNIVERSITY of FLORIDA

University of Florida - Nadine McGuire Theatre and Dance Pavilion

University of Florida, Gainesville FL

- 46,000 sf of theatres, dance studios, acting studios, scene shop, and classrooms
- Day and nighttime activity
- UF facility group motivated to reduce energy and experiment with LEDs
- 10c/kWh blended avg. electric rate

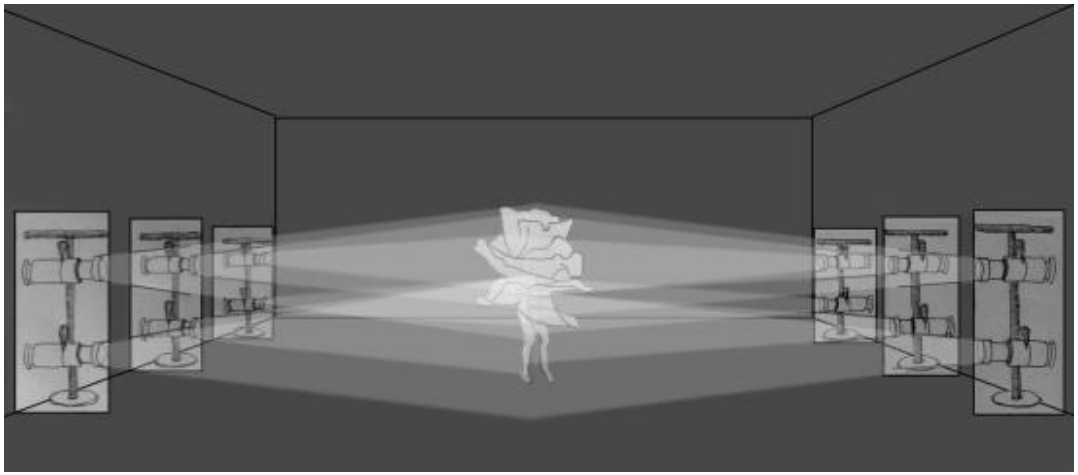
Why study a performing arts building?

- Large volume teaching and rehearsal spaces with open ceilings
- Higher lumen output luminaires
- Vertical footcandles without glare help make body movement and gestures visible
- Spaces duplicated on college campuses across country

University of Florida - Nadine McGuire Theatre and Dance Pavilion

Why study a performing arts building?

- Productions demand color quality and very wide, smooth, dimming range
- Performance lighting traditionally uses halogen (max 21 LPW, luminaire)
- Filtering for color dramatically reduces efficiency of instrument (blue gels usually less than 5% transmission)
- Can LEDs compete?

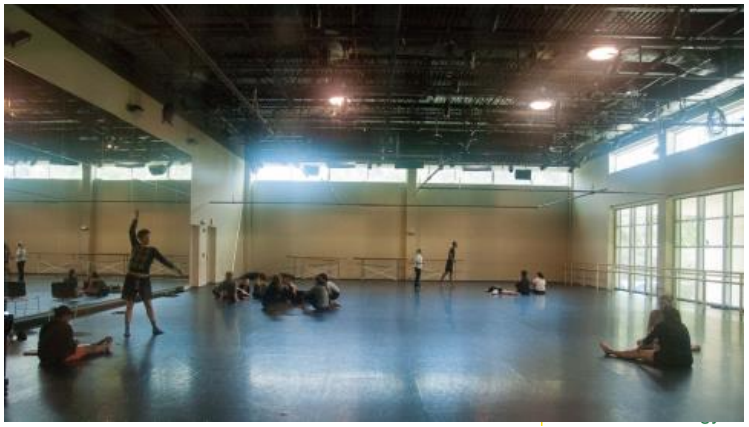


University of Florida - Nadine McGuire Theatre and Dance Pavilion

PNNL installed power monitoring equipment to collect power/energy data

Selected spaces:

- Scene shop
- Acting studio
- Dressing room makeup mirrors
- Dance studio
- Dance studio performance – sidelighting only



University of Florida – Scene Shop

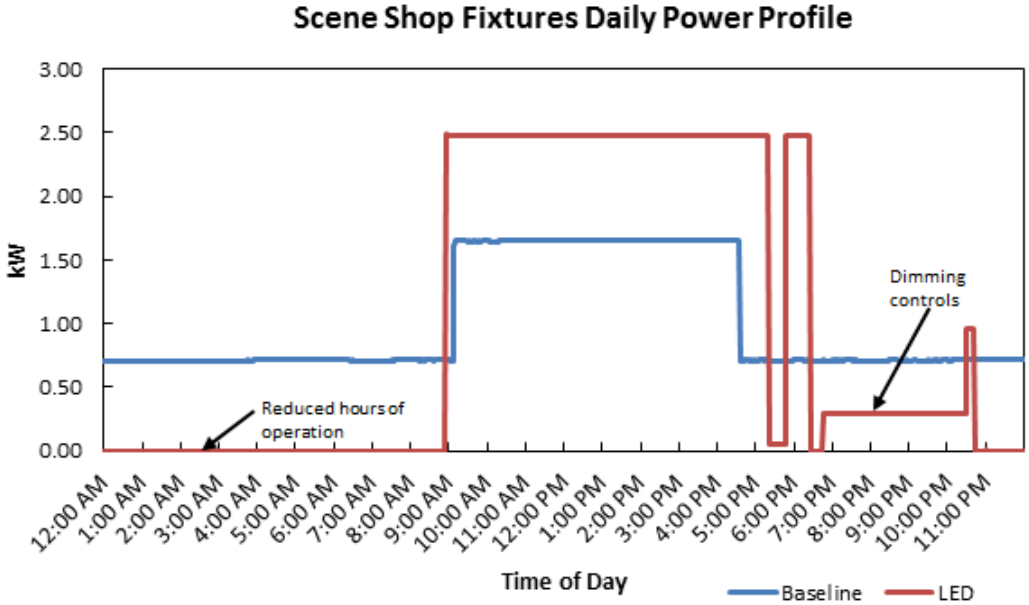
Scene Shop - Before

- 20’ ceiling, open joists
- Industrial fluorescents, retrofitted with T8s, electronic ballasts
- Switched at panels; 1/3 of luminaires erroneously wired to emergency circuits
- Dead lamps, dead ballasts, too difficult to relamp, because maintenance ladders and lifts inconvenient
- 60 – 300 lux at 3’ workplane
- Power tools a safety concern
- 1.19 W/sf if all luminaires functional; 190,890 lumens if all functional

University of Florida – Scene Shop

Scene Shop - After

- Redesigned with 8’ linear LED indirect design industrial luminaires, 3 per row, 6’ o.c.
- 0-10V dimming driver. Mockup step checked for flicker from LED driver. None detected with moving machinery.
- Luminaires kept at full output for safety during core hours, switched or dimmed manually by students
- 600 – 1125 lux at full output at 3’ workplane
- 1.07 W/sf at max output; 277,542 lumens
- Max power use *increased*, compared to compromised (burned out) fluorescent system, but energy use *decreased by 18%* because lights no longer on 24/7 emergency circuit



University of Florida – Scene Shop

Scene Shop, before and after switch to LED lighting

	Before	After
Lamp/luminaire photo		
Lamp/luminaire description	4 ft long, 1-, 2-, and 3-lamp industrial fluorescent, open aperture, with T8 fluorescent lamps	Cree 8 ft linear pendants spaced 6 ft on center
Catalog number	N/A	CS18-82HE-35K
Quantity	38 (total): 14 (3-lamp), 22 (2-lamp), 2 (1-lamp)	34
Color characteristics (CCT, CRI)	3500 K, 86 CRI	3500 K, 90 CRI
Ballast or driver specs	Rapid-start electronic	0–10 V dimming driver
Approx. luminaire lumens – new	190,890 total (estimated)[a]	8163 ea., 277,542 total[b]
Luminaire watts	2728 W total if all lamps burning[c]	71.9 each (2445 W total)
Luminaire efficacy (lm/W)	70 (est.)	113.5
Measured horiz. illuminance on 3 ft workplane Illuminances in lux. Divide by 10 for footcandles.	On 3 × 3 measurement grid (12 × 28 ft) centered in room: 300 lx max, 60 lx min 5.0 max/min ratio	On 3 × 3 measurement grid (12 × 28 ft) centered in room: 1155 lx max, 636 lx min, 1012 lx avg 1.8 max/min ratio
Measured vert. illuminance at 4 ft height, separate values for four cardinal directions at three points of grid in room Illuminances in lux. Divide by 10 for footcandles.	Not measured	548 lx max, 142 lx min, 358 lx avg
Space size (ft^2)	2287	2287
Power density (W/ft^2)	1.19	1.07

(a) Because a mixture of industrial luminaires was installed, lumen output was estimated based on 2900 lm per 4 ft T8 fluorescent lamp, with a 0.88 ballast factor and 85% luminaire efficiency.
(b) Luminaire lumens, input power based on manufacturer LM-79 test report.
(c) Assuming 31 W per lamp for 32 W lamp with rapid-start electronic ballast, ballast factor = 0.88.

University of Florida – Acting Studio

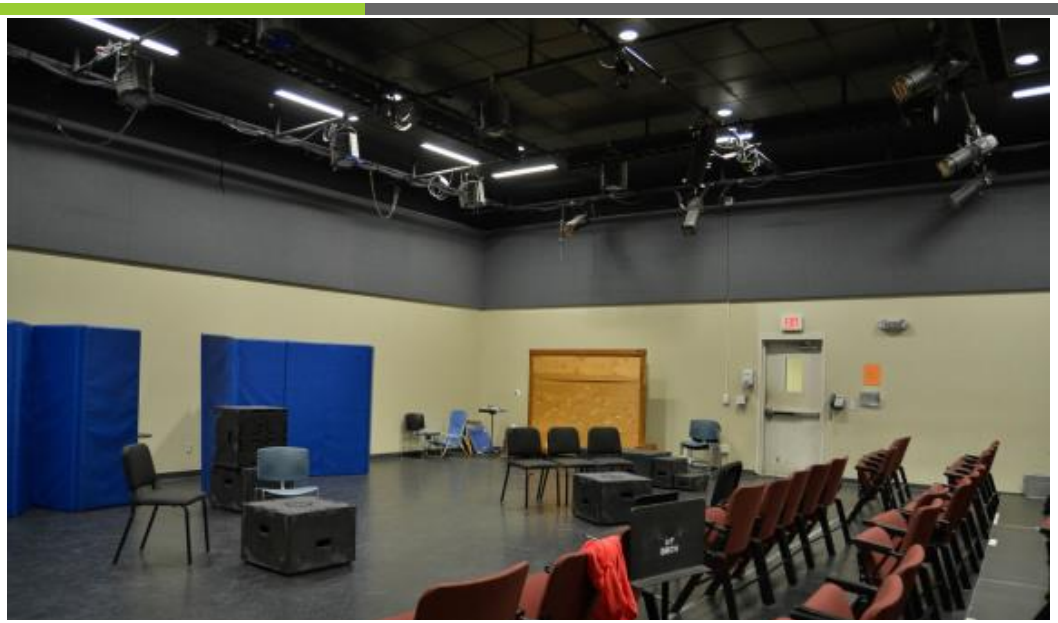
Acting Studio – Before

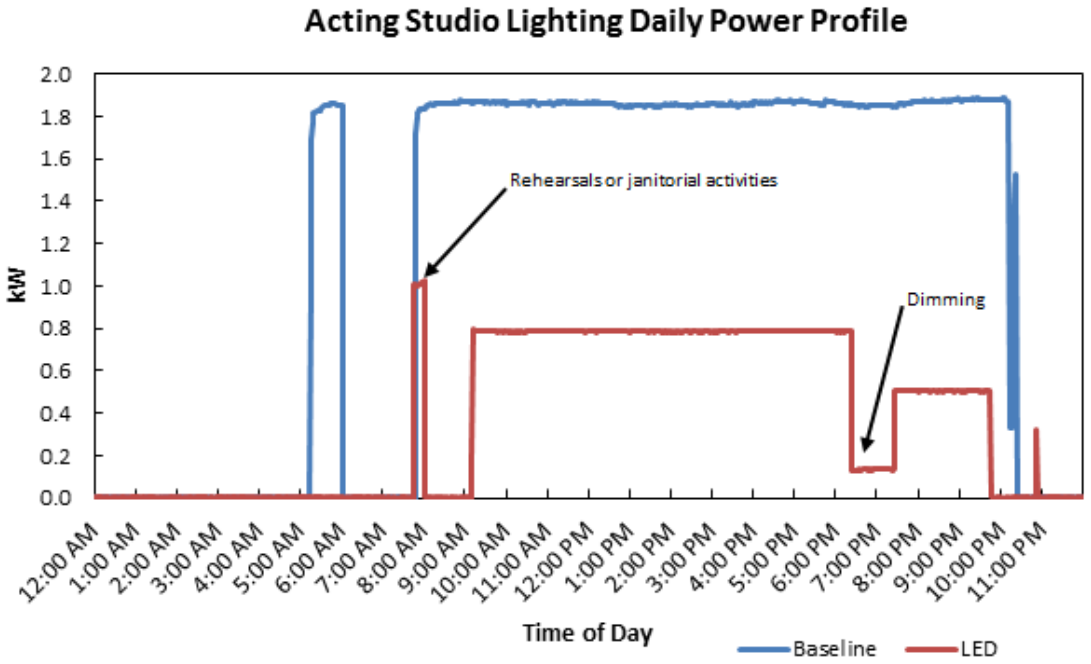
- 15.5’ black ceiling
- (9) 100W PAR38 CMH downlights, electronic ballasts, on wallswitch. Restrike time on MH drives instructors crazy. Lights seldom switched off except by cleaning crew.
- Inadequate lighting supplemented with theatrical “cyc lights” with short-lived 30W CFL R40 lamps. 15 of 72 are burned out. Controlled at wallswitch.
- 25 – 873 lux at 2.5’ workplane. 35:1 max:min uniformity (very poor)
- Facial modeling poor and body gestures difficult to see (vertical illuminance important for performing arts)
- 1.25 W/sf for functional lighting (not counting those burned out).

University of Florida – Acting Studio

Acting Studio - After

- (12) 3000 lm recessed downlights, 37W each, 4000K, 90 CRI.
- (12) 4’ long LED wallwashers, 3 per wall to provide wall brightness and reflected light that improves vertical illuminance. 2942 lm, 4000K, 80 CRI, 43W.
- 0-10V dimming drivers. Mockup step checked for flicker from both LED drivers at all dimming levels. None detected.
- Wall dimmers replaced switches. Dimmers used to change mood and focus of class.
- 314 – 400 lux at full output at 3’ workplane; 1.3 max:min.
- 39 – 108 lux vertical illuminance at 4’ height, considered by instructors to be very good.
- 0.55 W/sf at max output
- Max power use *decreased by half* and energy use dropped by 68%.





University of Florida – Acting Studio

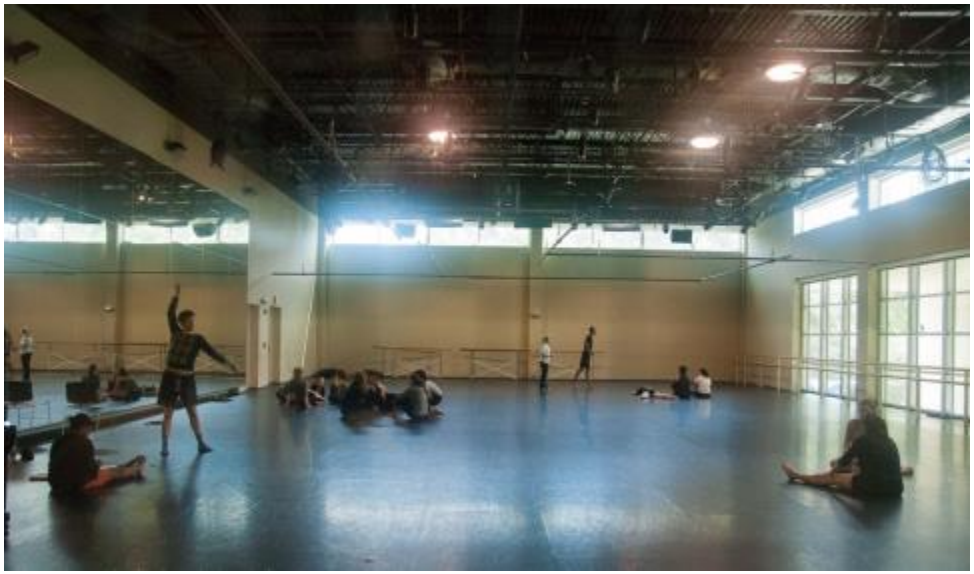
	Before		After	
	Luminaire 1	Luminaire 2	Luminaire 1	Luminaire 2
Lamp/luminaire photo				
Lamp/luminaire description	Recessed clear cone downlight with 100 W ceramic metal halide PAR38 lamp	Temporarily installed "cyc lights," sockets with Longstar 30 W longneck CFL R40 lamps	Recessed LED downlight with 6 in. dia. clear reflector cone, ~3000 lm	Recessed linear LED wallwasher with ribbed acrylic diffuser
Catalog number	N/A	N/A	Cree KR6-30L-40 K with KR6T-SSGC-FF trim	HETW-4-LED-PH30/840-A
Quantity	12	15	9	12
Color characteristics (CCT, CRI)	4000 K, 92 CRI	4100 K, 82 CRI	4000 K, 90 CRI	4000 K, 80 CRI
Ballast or driver specs	Non-dim electronic ballast	Integral ballast in lamp	0–10 V dimming driver	0–10 V dimming driver
Approx. luminaire lumens (estimated from manufacturer data)	5327 lm	1650 lm (per lamp)	3000 lm	2942 lm
Luminaire watts	122 W	30 W (per lamp)	37 W	42.8 W
Luminaire efficacy (LPW)	43.7	55.0 (lamp only)	81.1	68.7
Measured horiz. illuminance on 30 in. workplane (in lux). Divide by 10 for footcandles.	873 lx max (directly beneath dnlt) 25 lx min (4 ft from two corner walls) 367 lx (diagonal ctr of four dnlts) 34.9 max/min ratio in room		On 3 × 3 measurement grid (13 × 13 ft) centered in room: 400 lx max, 314 lx min, 334 lx avg 1.3 max/min ratio	
Measured vert. illuminance at 4 ft height, separate values for four cardinal directions	Not measured		On 3 × 3 measurement grid (13 × 13 ft) centered in room: 108 lx max, 39 lx min, 75 lx avg	
Space size (ft^2)	1528		1528	
Power density (W/ft^2)	1.25		0.55	

CCT is correlated color temperature.

University of Florida – Dance Studio

Dance Studio - Before

- 20’ dark grey ceiling
- (8) 320W MH low-bays, magnetic ballasts, on wallswitch. Restrike time about 10 minutes (!) and ballast buzzing distracting. Lights seldom switched off except by cleaning crew.
- Window wall provides much-loved daylight.
- 90 – 286 lux at 2.5’ workplane. (4 – 149 lux vertical) in performance blackout conditions
- Greenish color of aged MH lamps disliked. Glare disliked.
- 0.71 W/sf

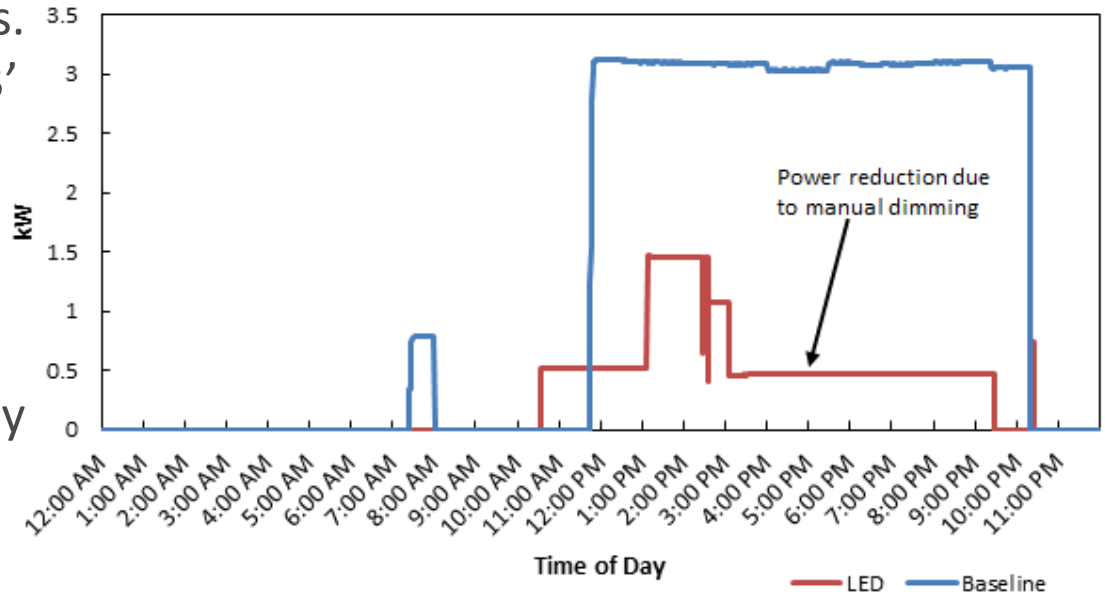


University of Florida – Dance Studio

Dance Studio - After

- (20) 6400 lm edge-lit panels, 72W each, 4000K, 90 CRI. Window wall row on separate dimmer, intended to be controlled by photosensor.
- 0-10V dimming drivers. Mockup step checked for flicker from LED drivers at all dimming levels. None detected.
- Wall dimmers replaced switches. Dimmers used to change mood and focus of class.
- 119 – 251 lux at full output at 3' workplane; 4 – 100 lux vertical illuminance at 4' height, in blackout conditions.
- 0.35 W/sf at max output
- Max power use *decreased by half*, and energy use dropped by 63%.

Dance Studio Daily Lighting Power Profile



University of Florida – Dance Studio

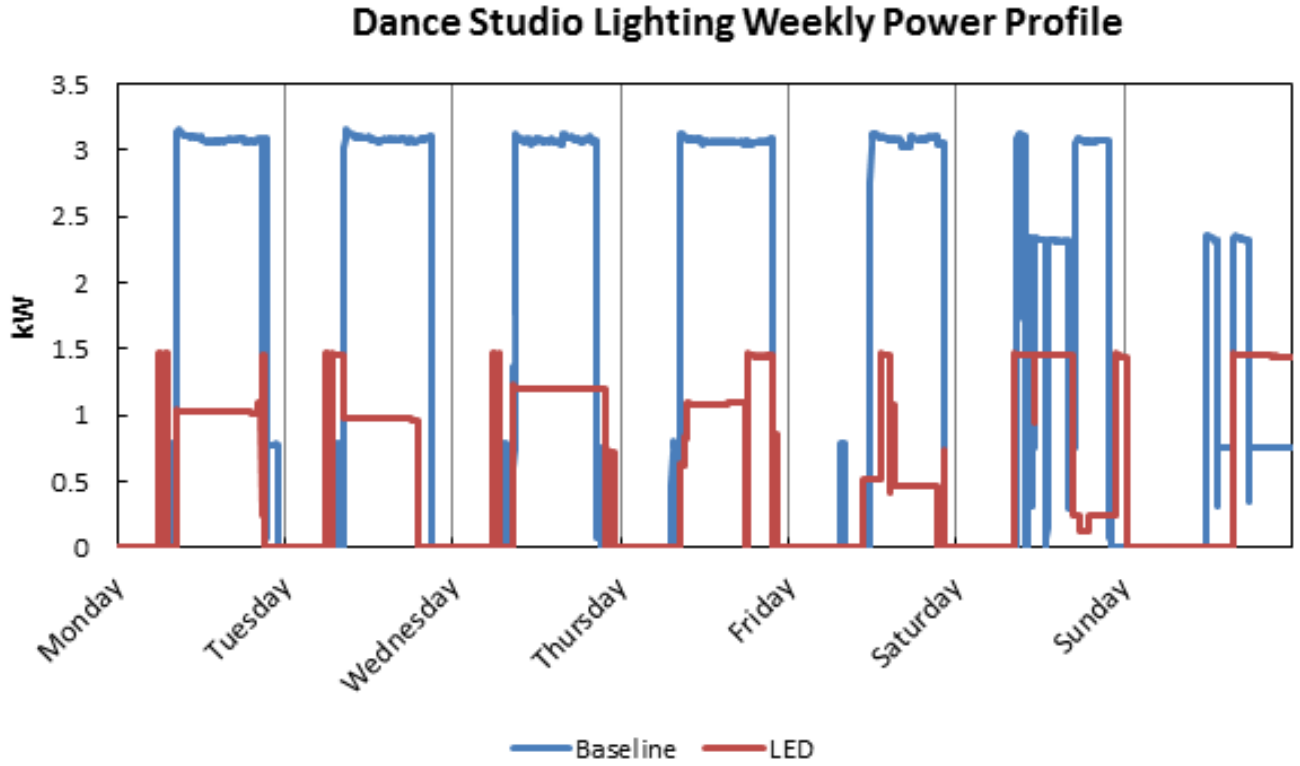
Dance Studio, before and after switch to LED lighting

	Before	After
Lamp/luminaire photo		
Lamp/luminaire description	Pendant-mounted "low-bay" industrial luminaire with prismatic lens and 320 W pulse start clear quartz arc tube metal halide lamp	4 ft long linear edge-lit LED panel suspended from ceiling with remote-mounted driver
Catalog number	N/A	GE ELO40A2GV-white
Quantity	8	20
Color characteristics (CCT, CRI)	4000 K, 65 CRI	4000 K, 82 CRI
Ballast or driver specs	Pulse-start magnetic ballast	0–10 V dimming driver
Approx. luminaire lumens – initial	23,560 (31,000 lamp)	6400
Luminaire watts	368	72
Luminaire efficacy (LPW)	64	89
Horiz. illuminance[a] on a 30 in. workplane. Walls are draped in black for performance, so reflectances (%) are 5-5-5. Illuminances in lux. Divide by 10 for footcandles.	On 10 x 10 calc grid (5 × 8 ft) centered in room: 286 lx max, 90 lx min, 204 lx avg 3.2 max/min ratio	On 10 x 10 calc grid (5 × 8 ft) centered in room: 251 lx max, 119 lx min, 190 lx avg 2.1 max/min ratio
Vert illuminance(a) at 4 ft height , separate values for four cardinal directions, reflectances (%) are 5-5-5. Illuminances in lux. Divide by 10 for footcandles.	On 10 x 10 calc grid (5 × 8 ft) centered in room: 149 lx max, 4 lx min, 71 lx avg	On 10 x 10 calc grid (5 × 8 ft) centered in room: 100 lx max, 4 lx min, 59 lx avg
Space size (ft^2)	4150	4150
Power density (W/ft^2)	0.71	0.35
(a) Illuminance values were calculated using AGI32®. See Appendix B for input values.		

University of Florida – Dance Studio

Remember the daylight dimming controls?

- Detailed power meter data showed no dimming due to daylight
- Further investigation showed all power reduction was due to manual dimming
- What was learned: Photocontrols had been installed, but never commissioned. No one knew this. (Thank goodness for data!)



University of Florida – Dressing Room

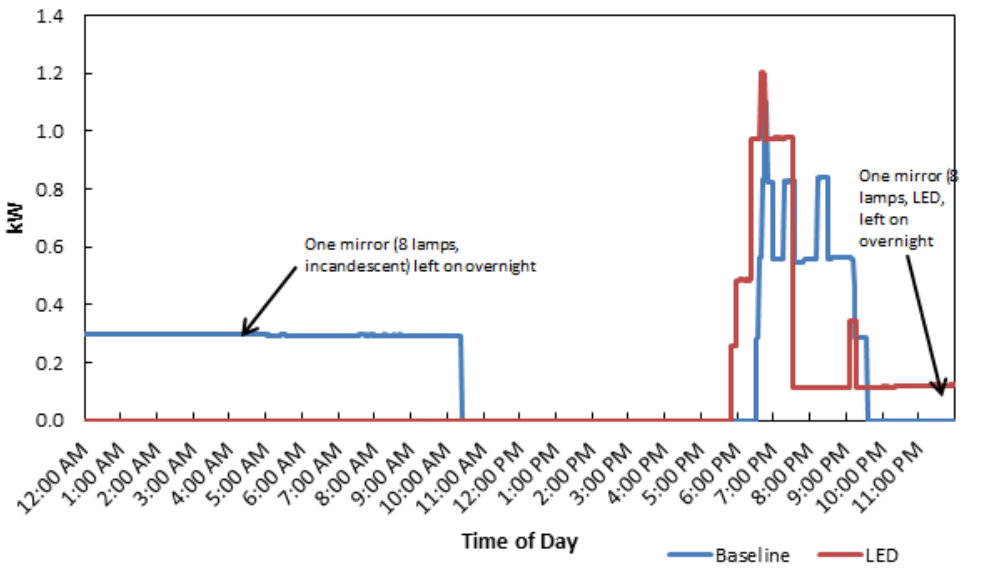
Dressing Room Mirror Lighting - Before

- 8’ ceiling spaces
- (8) 40W G25 130V (35W) 209 lm incandescent lamps per mirror. Each mirror switched individually.
- Used for makeup lighting, intended to duplicate color of light from halogen stage lighting
- 573 – 777 lux vertical measured on face, no ambient light
- Heat from lamps disliked by actors and dancers.
- 12.66 W/sf of mirror lights contributed to dressing room

University of Florida – Dressing Room

Dressing Room Mirror Lighting - After

- (8) 450 lm 2700K 93 CRI lamps per mirror, 8.5 W each.
- Forward phase cut (incandescent) dimmers installed per mirror. Smooth dimming, but dimmers/lamps buzzed when dimmed. A different model dimmer was recommended by the lamp manufacturer instead.
- 1741 – 2102 lux vertical measured on face at max output, no ambient light contribution from room.
- 3.08 W/sf at max output contributed to room.
- Makeup instructor observed that color was truer to stage lighting than 130V incandescent
- Max power use was about the same (depends on number of mirrors in use), but typical energy use dropped by 72%.



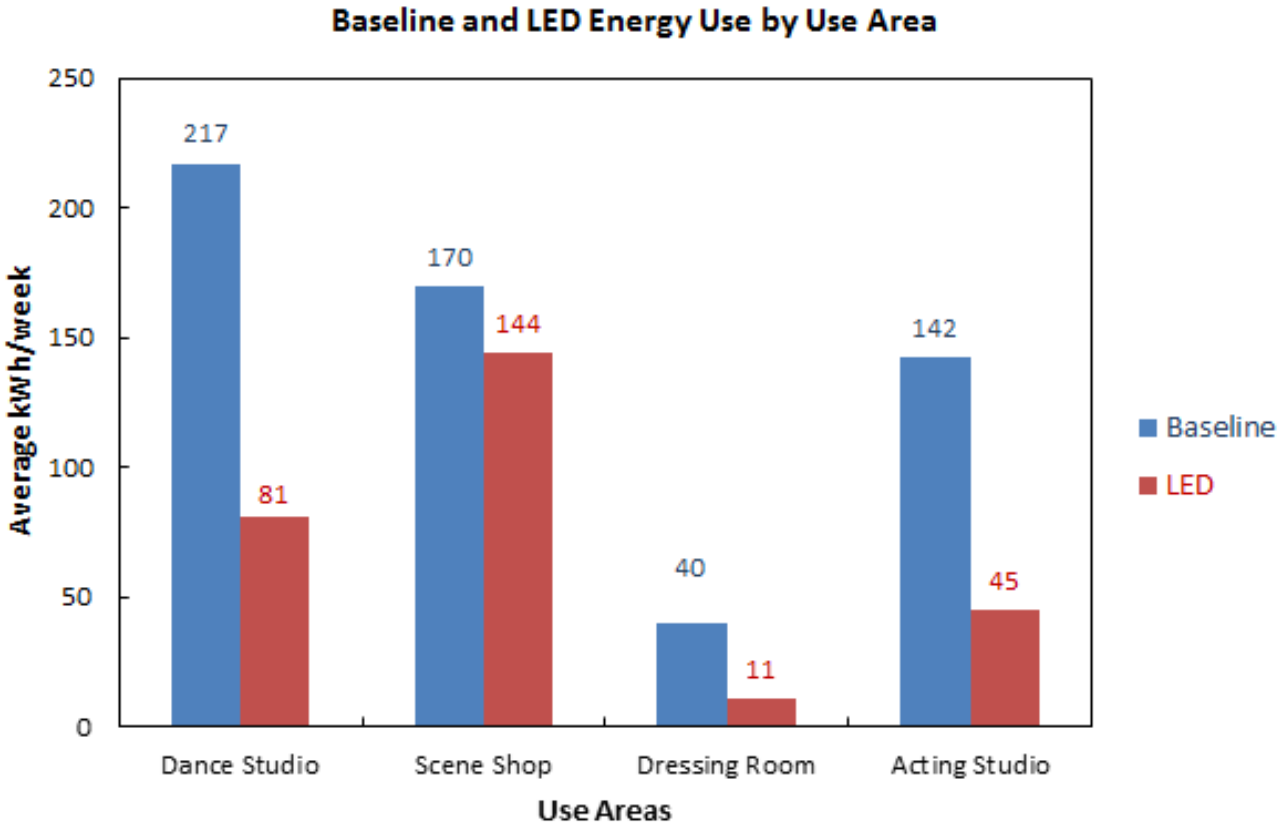
University of Florida – Dressing Room

Dressing room, before and after switch to LED lighting

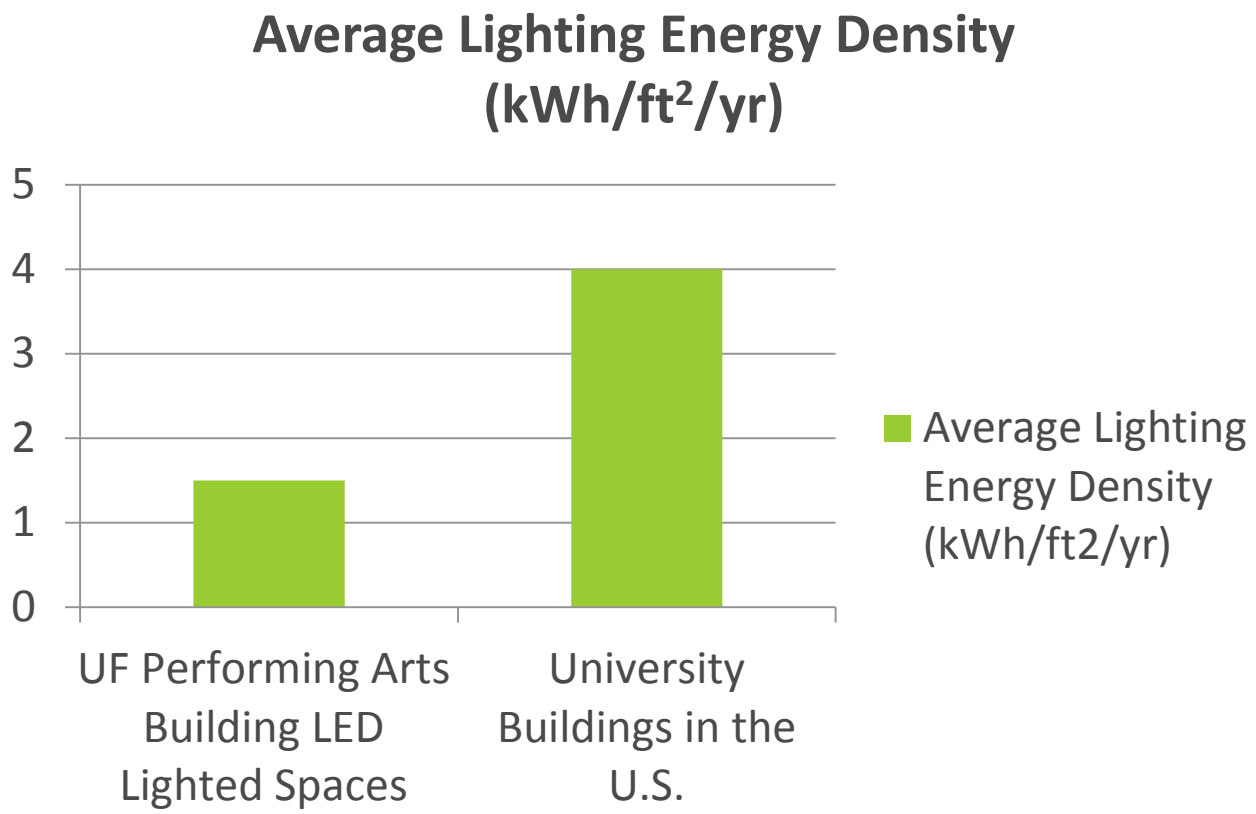
	Before	After
Lamp/luminaire photo		
Lamp/luminaire description	40 W 130 V G25 softwhite incandescent	Cree TW softwhite LED bulb
Quantity (9 mirrors)	72	72
Color characteristics at 120 V (CCT, CRI)	2756 K, CRI 100	2700 K, 93 CRI
Ballast or driver specs	None	Driver integral to lamp
Approx. per-lamp lumens at 120 V	209	450
Lamp watts at 120 V	35	8.5
Lamp efficacy (lm/W) at 120 V	6	52.9
Horiz. illuminance (max/min/avg lx)	N/A	N/A
Measured vert. illuminance on face facing mirror at 4 ft and 7 ft above floor, 16 in. from single mirror, no ambient light	777 lx max, 573 lx min, 694 lx avg. [77.7 fc max, 57.3 fc min, 69.4 fc avg]	2,102 lx max, 1,741 lx min, 1,974 lx avg. [210.2 fc max, 174.1 fc min, 197.4 fc avg]
Space size (ft^2)	199	199
Power density (W/ft^2)	12.66	3.08

University of Florida – All Four Spaces

Summary of energy use (avg kWh per week) in the four spaces, before and after switch to LED lighting



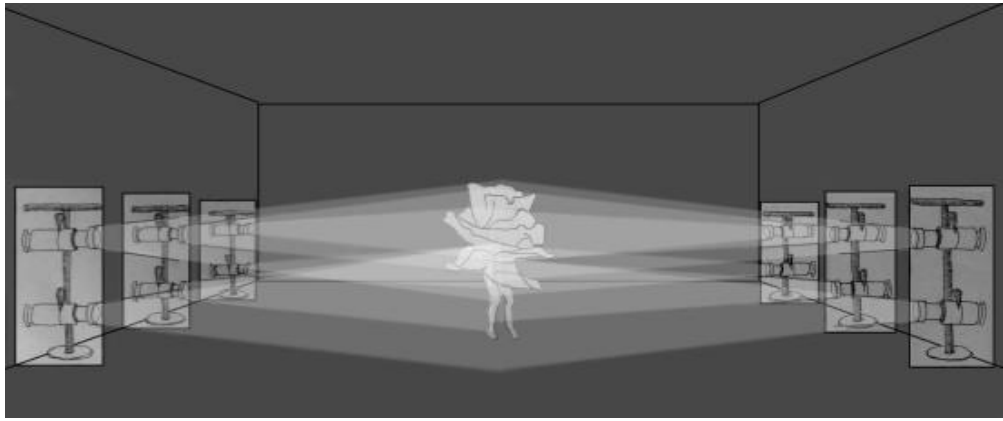
University of Florida – Overall lighting energy density



University of Florida – Dance Performance Sidelighting

Dance Performance Sidelighting - Before

- All walls draped in black for performance
- (12) 575W ETC Source Four 50° 12,000 lm halogen ellipsoidal theatrical instruments mounted to booms flanking stage, equipped with green, red, blue, and pale pink gels.
- ETC theatrical dimming system
- Top lighting all done with PAR56 halogen. No ambient light.
- 7 light cues



University of Florida – Dance Performance Sidelighting

Test of visual effect of halogen vs. LED theatrical sidelighting - **(Before, halogen)**

- Dance Professor Ric Rose choreographed a 2-minute dance with single dancer wearing billowy silk costume, as homage to Loïe Fuller
- Dance performed during Fall 2013 BFA Dance Showcase using conventional halogen ETC Source Four instruments.
- Lighting designer given free reign in design. Selected saturated red, green, and blue gels, plus pale pink gel for white light.
- Seven lighting cues created, plus a blackout cue.
- Controlled by lighting console that sent DMX-512 signals to the portable dimmer rack to communicate dimmer output for each instrument. One 1.2KW dimmer assigned to each instrument.

Still from the dance performance showing effect from halogen toplighting only. Dancer: Isa Garcia-Rose.

University of Florida – Dance Performance Sidelighting

Test of visual effect of halogen vs. LED theatrical sidelighting – (**After, LED)**

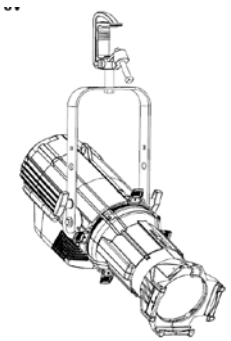
- Dance performed during Spring 2014 BFA Dance Showcase using Philips Selecon and ETC LED theatrical instruments.
- Lighting designer again given free reign in design except to simulate lighting effects from fall performance. Selected saturated red, green, and blue LED settings, plus pale pink white light.
- Same seven lighting cues created, plus a blackout cue.
- Controlled by lighting console that sent DMX-512 signals directly to the 12 sidelighting instruments to communicate color and intensity. Each instrument was powered with 120V power cords, a total of (8) 20A circuits. The dimmer rack was by-passed for these circuits.

Still from the “Herald” dance performance showing effect from halogen toplighting only. Dancer: Isa Garcia-Rose.

University of Florida - Dance Performance Sidelighting

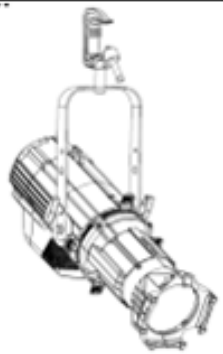
Dance Performance Sidelighting - After

- (6) 4200 lm 3200K, 84 CRI ETC LED Lustr+ 50° theatrical instruments, drawing a max of 94 W. Seven LED colors (R,G,B,I,A,C,W) combined at focal point with diffusing media to unify emitted light. 5W standby power.
- (6) Philips Selecon PLProfile4 LED (36°) theatrical instruments, drawing a maximum of 778 W in max output mode. 4 LED colors (R, B, G, CW). 27W standby power.
- Max output modes are unlikely to be used in either luminaire, so actual power draw is far lower.



University of Florida – Dance Performance Sidelighting

Dance Performance Lighting, before and after switch to LED lighting

	Before	After	
		Luminaire 1	Luminaire 2
Lamp/luminaire photo			
Lamp/luminaire description	ETC Source Four 50° Halogen	ETC Source Four LED Lustr+ (50°)	Philips Selecon PLProfile4 LED (36°)
Quantity	12	6	6
Color characteristics at 120 V (CCT, CRI) at 100% (halogen) or best LED spectral mix, per mfr data	3050 K, 99 CRI	3200 K, 84 CRI	3200 K, CRI not available
Maximum lumen output per mfr's photometric data (ETC) or technical data sheet (Philips Selecon)	12,153	4189	>6000
Max possible watts (measured by GATEWAY at max output)	575	94	778[a]

(a) Although maximum power draw for this product was measured at 778 W, this operating mode is highly unlikely. Furthermore, this product is overpowered for this dance sidelighting application, although it worked well at low levels and can also work for productions where much higher light levels are required.

University of Florida – Dance Performance Sidelighting

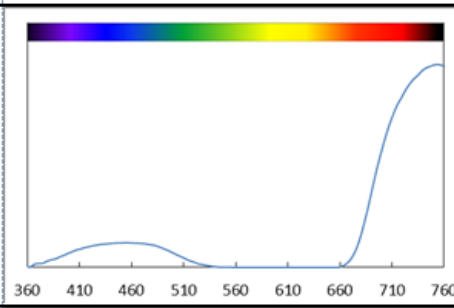
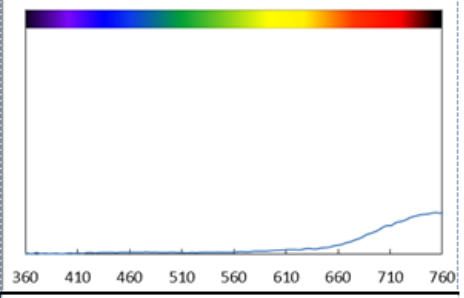
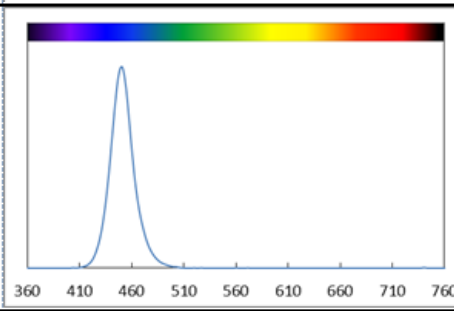
Side by side video clip of “Herald”

https://www.youtube.com/watch?v=CsVRJjRSnLw

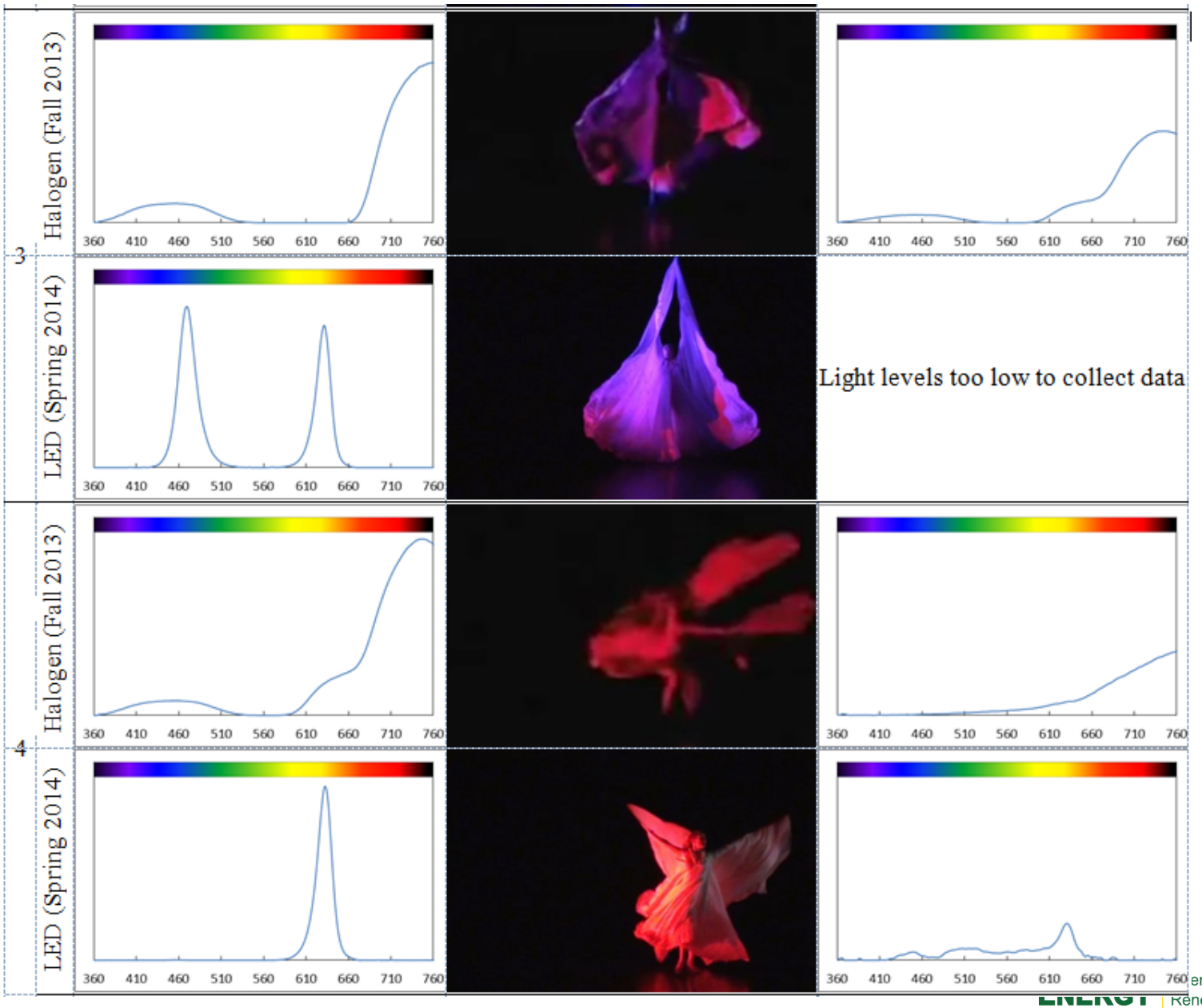
or

http://energy.gov/eere/ssl/gateway-demonstration-indoor-projects

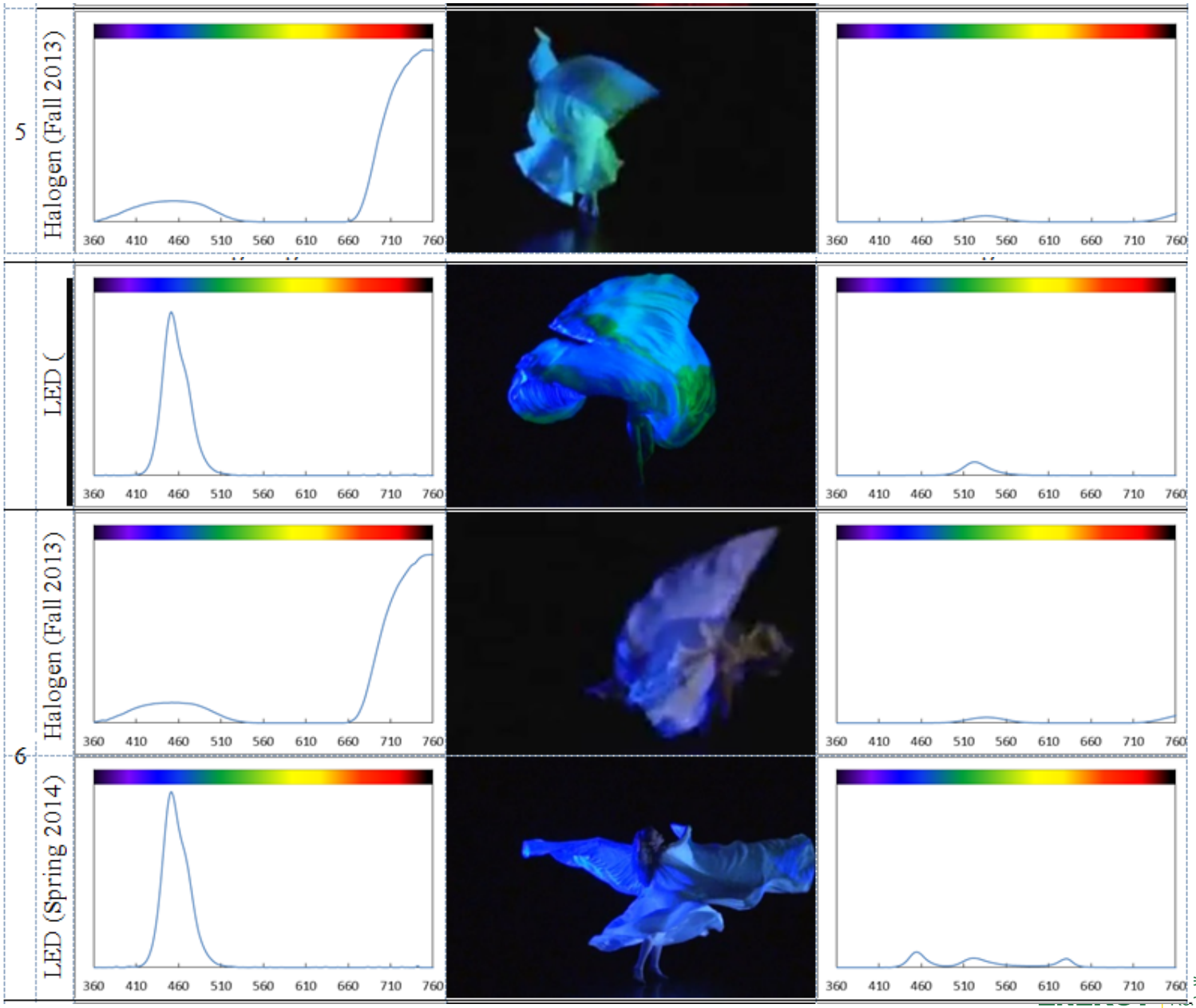
University of Florida – Dance Performance Sidelighting

		Stage Right		Stage Left
1[a]	Halogen (Fall 2013)	No side lighting used		Light levels too low to collect data
	LED (Spring 2014)	No side lighting used		No side lighting used
2	Halogen (Fall 2013)			
	LED (Spring 2014)			Light levels too low to collect data

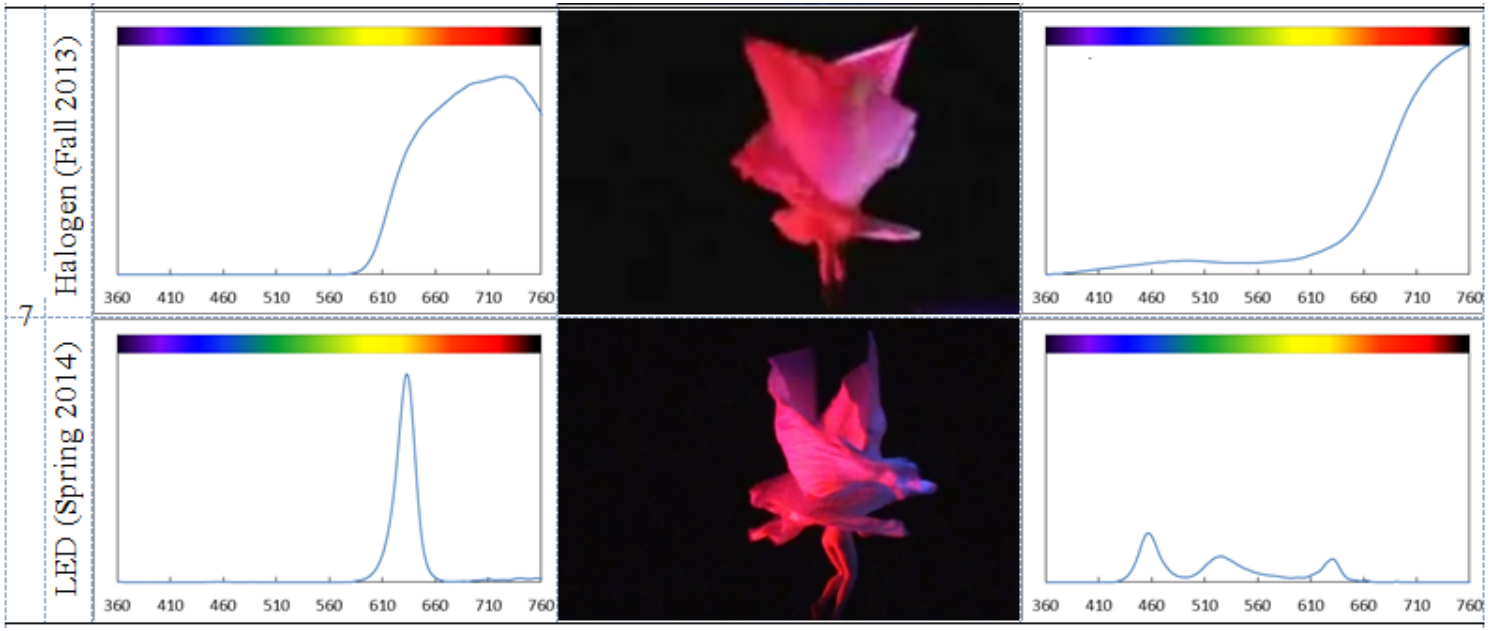
University of Florida – Dance Performance Sidelighting



University of Florida – Dance Performance Sidelighting



University of Florida – Dance Performance Sidelighting

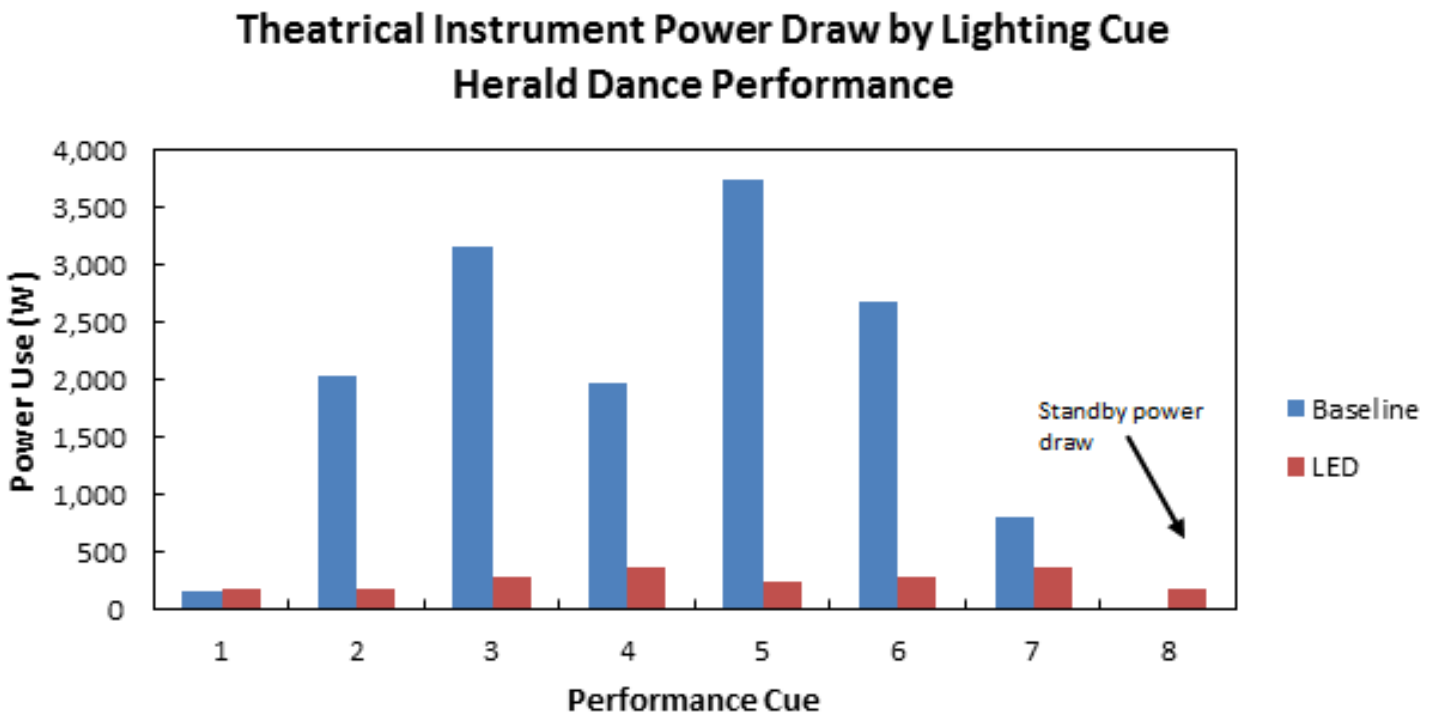


What do we learn from the performance and SPDs of halogen vs LED?

- To the audience the visual effect from saturated colors is very similar even though the SPDs were different.
- To the audience the light and shadow pattern was very similar.
- Both LED and halogen in saturated colors looked stunning on flowing silk
- Body and costume were the canvas for the lighting. Skin tones were not an issue in this performance, or the LEDs might have evoked a different reaction.

University of Florida – Dance Performance Sidelighting

Summary of power draw by lighting cue during performance of “Herald” in Fall 2013 (halogen) and Spring of 2014 (LED).



Total energy savings over the duration of the performance is 87% from LEDs. (Air conditioning savings and improved comfort for the performers not included.)

University of Florida – LED Theatrical Lighting Thoughts

Cost

- There is still a large initial cost difference between LED and halogen instruments. ROI alone can't justify a wholesale change based on energy savings for most projects.
- For new projects, consider a mix of LED and halogen instruments
- For existing theatres, consider buying LED instruments to replace aging or damaged halogen units
- On some projects, operational savings may help justify their use: (long hours of use, hard to reach locations, frequent color filter replacement, lamp replacement cost and labor).

Flexibility

- Our student designers enjoy using LEDs (easy color selection without gels, dynamic color change over long periods of time, and ease of accommodating changing artist requests "on the fly".

University of Florida – LED Theatrical Lighting Thoughts

Color

- This dance piece did not evaluate skin tones. Most LED theatrical instruments are shy in long-wavelength red, so they may not be as well received in drama productions where skin tones are higher priority.
- Some new LED instruments DO feature longer-wavelength red LEDs and may be as good as halogen for skin tones.
- This dance piece used rich, saturated colors from LED instruments on the dancer, and visually performed as well as gelled halogen lighting.
- The audiences perceived no noticeable difference in color between the two performances.

University of Florida – LED Theatrical Lighting Thoughts

Control

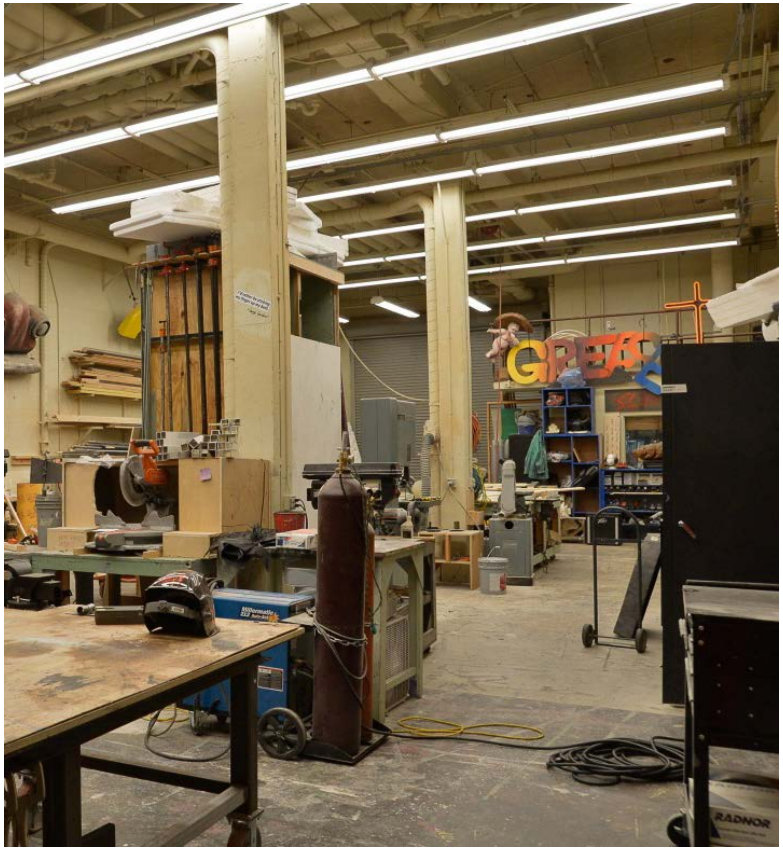
- Controlling LED theatricals with older lighting controllers is cumbersome.
- Standardization on color-picking among different manufacturers of theatrical lighting and controls would make the lighting designer's life easier.
- Perfectly smooth dimming to OFF is hard with LEDs.
- Be aware of intensity control "stepping" especially at low intensities, which can cause a distraction.
- All LED theatrical instruments are not created equal.

University of Florida – Lessons Learned

- **LEDs can be excellent solutions in high-ceiling educational spaces.** (Compare to metal halide and fluorescent for restrike, controllability, audible noise, relamping frequency, flicker, life)
- **Mockups help with wise product selection and layouts**. Cut sheets alone inadequate for visualizing space, color, flicker, glare, etc.
- **Manual dimmers not only reduce lighting energy use, but improve functionality of classrooms and buildings.** Teaching usage is not static or consistent.
- **Uniformity of workplane and vertical illuminance is important in classrooms and studios**…. Where facial features and body movements need to be visible
- **Photosensors and dimming drivers or ballasts can dramatically reduce energy use in academic rooms with significant window area, but only if commissioned properly**.

University of Florida – Lessons Learned

- **Vampire power in LED theatrical instruments could be responsible for significant energy use if not switched off at the conclusion of a performance**. (Circuits are listening for instructions.)
- **LED theatrical lighting offers power savings…** of 50% to 90%, compared to halogen instruments with filtered with color gels. Adding broadband white LEDs to the mix can improve color rendering of skin tones compared to RGB.
- **LEDs can reduce maintenance** …especially in spaces with difficult access because of tall ceilings or heavy tools and equipment in the way of ladders and lifts.



University of Florida - Nadine McGuire Theatre and Dance Pavilion

Thanks for your attention!

Naomi Miller, naomi.miller@pnnl.gov

Stan Kaye, stankaye@mail.ufl.edu

And now for questions????

GATEWAY
Demonstrations