APRIL 18, 2016

APPLYING SUSTAINABILITY PRACTICES TO LIGHTING RETROFITS IN THE UW TOWER

AMY KIMcee assistant professorJAMES LEWcee phd studentTROY SWANSONuw tower facilitiesSCOTT BYBEEuw tower facilitiesJEREMY EKNOIANuw real estateSTEVE KENNARDuw real estateGARY QUARFOTHplanning and mgmt

A GREEN SEED FUNDED PROJECT AT THE UNIVERSITY OF WASHINGTON 2015-2016 ACADEMIC YEAR

UW TOWER: A COMPLEX LIGHTING ENVIRONMENT

Criteria for Improvement

- Energy Consumption: ~\$1.1 million, 16.5 million KWh / yr
- Evidence of excessive illuminance, occupant discomfort
- Open office structures, vastly different floorplans
- Additional thermal loading from electrical lights

Basic Dimensions:

- Height: 325 ft (22 floors)
- Footprint: 131.75' x 99.25' ~ 12,965 SF
- Curtain / Window: 12' x 7' = 84 SF
- Window layout and footprint are symmetric



IMPORTANCE OF IEQ FROM A FACILITY PERSPECTIVE

Solar Heat Gain (BTU / SF) H											Heat Gain (Btu / SF)							
July	Hour of Day													3,80	0			
Facing Dire	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
East	4	890	2,700	3,600	3,800	3,400	2,500	1,400	740	640	600	540	460	360	230	67		
South		67	230	390	670	1,300	1,900	2,300	2,500	2,300	1,900	1,300	670	390	230	67		
West		67	230	360	460	540	600	640	740	1,400	2,500	3,400	3,800	3,000	1,700	890	4	



- 1 window: 3,800 BTU/SF @ 84 SF / window ~ ~319,200 BTU / window
- 1 space heater: ~ **5120 BTU**
- 1 window ~62 space heaters (peak)
- Result: huge solar gains in summer => increased demand for cooling

OBJECTIVES ADDRESS ENGINEERING AND PSYCHOLOGY

- Quantify margin of improvement in floor's energy performance (\$ / env)
 - Estimate ROI and influencing factors
 - Identify barriers to implementation
- Improve occupant satisfaction, reduce operation effort (people)
 - Identify primary factors influencing occupant satisfaction (and productivity)
 - Identify primary factor influencing maintenance procedures
- Inform lighting retrofit / commissioning best practices (knowledge)
 - Assess experiment economics and utility
 - Identify indicators of improvement to continuously monitor
 - Provide practice-ready recommendation



IMPACTS: Perception, health, and comfort impact well-being and productivity, fosters branding and reputation

> IMPACTS: Energy consumption, occupant productivity, lifecycle costs, property value

PROJECT SCHEDULE HAS EVOLVED OVER TIME

Task	Task Description	Q1	Q2	Q3	Q4	Q5
Task 1	Kickoff meeting	*				
Task 2	Develop survey tool		*			
Task 3	Submit HSD Application	*	*			
Task 4	Study specifications and scope		*		*	
Task 5	Define lighting study design		*			
Task 6	Spot data monitoring		*	*	*	
Task 7	Data visualization		*	*	*	
Task 8	Pre-retrofit survey & analysis		*		*	
Task 9	Install lighting upgrades			*		
Task 10	Lighting control system			*	*	
Task 11	Final report			*	*	
Task 12	Post-retrofit survey & analysis				*	
Task 13	Focus Interviews				*	
Task 14	Fine-tune Lighting Controls				*	
LEGEND: 🗙	Completed ★ In Progress	•	To Be Co	ompleted		



A YEAR-LONG PROJECT STILL IN PROGRESS



Spot Measurements...

Continuous Monitoring...





Fixture Retrofits and Lighting Controls Commissioning...



Calibration and Analysis...

DATA COLLECTION POINTS PLANNED IN ADVANCE





"Frankie" Station

CONTROLS AND APPEARANCE HAVE CHANGED

Installed December 2015 / January 2016

- LED fixtures with rated warmer color rating, less direct glare
- Wi-Fi controlled fixtures via terminal
- Daylight harvesting (photometric sensors)
- Custom zone definitions and scheduling rules
- Real-time Monitoring and performance visualizations
- Expansion modularity and reporting capabilities





December 2015, 12th Floor of UW Tower



NEW FIXTURE

OLD FIXTURE



80% WOULD PREFER AT LEAST 1 CHANGE

Preference	12th Floor (N = 40)	15th Floor (N = 18)	Both Floors (N = 58)
Change the color appearance of the light produced by the lighting fixtures	42.5%	33.3%	39.7%
Be able to control the brightness/light output of the overhead lighting fixtures with a dimmer or high/low switch	40.0%	50.0%	43.1%
Make the overhead lighting fixtures produce less glare	35.0%	27.8%	32.8%
Change the aesthetic appearance of the light fixtures	27.5%	38.9%	31.0%
Add a task light	20.0%	33.3%	24.1%

Prior to Retrofits...

- About 20% would not change anything
- Above all, occupants value the *capacity to control*
- Occupants may prefer different colors depending on time of day
- 70% of 12th floor indicated not having a task light (50% for 15th floor)
- Should task lighting be used to achieve what overhead fixtures cannot?

LIGHT ZONES HAVE DISTINCT PREFERENCES

Aggregated data doesn't distinguish zonal responses...

Q#	Description			12th Floor Response													
1	Color appear	ance of work statior	lighting	10%	31%		28%	21%									
2	Color appear	ance preference for	lighting	7%	31%		31%	14%	10%								
				0.0%	20.0%	40.0	% 60.0% Percent	80.0%	0								
Color Warmth		Do Not Know	Very Warm	n (Somewhat Warm	Neut	ral Somewhat Co	ool	Cool								

SW	W	NW
S	Zone	Ν
SE	E	NE

5	9	6
3	Data Pts	1
3	7	6

...but grouping data by lighting zone reveals distinct zonal preferences

0.2	-0.3	-0.2
-0.3		-1.0
0.3	0.4	-0.5

-1 = average zone occupant wants warmer colored lights
+1 = average zone occupant wants cooler colored light

ZONES GENERALLY AGREE: TOO MUCH LIGHT

Q#	Description			12th Floor Response											
4	Lights flicker	throughout day			24%		28%		24%	7%	/ 0	14%			
5	Work surface	is evenly lit		2	1%	21	%		28%		28%	3%			
7	Amount of lig	nt in work station		30%				65%			5%				
				0.0%	20.09	6	40.0)% Pei	60.0% rcent	80.	0%	100.0%			
Exten	t of Agreement	gree	Disagre	е	N	eutral	Ą	gree	Strongly Agree						
Amou	Int of Light		Jht About right						Too little light						

Lights flicker throughout day?

1.8	2.2	2.7
3.0		2.0
2.7	2.1	2.5

1 = strongly disagree

- 3 = neutral
- 5 = strongly agree

Work surface evenly lit?

3.8	3.2	3.2
3.3		4.0
3.7	3.4	3.3

- 1 = strongly disagree
- 3 = neutral
- 5 = strongly agree

Amount of light in work station?

3.4	3.4	3.0
3.7		3.0
3.7	3.6	3.7

- 1 = too little light
- 3 = neutral
- 5 = too much light

HEAT MAPS VISUALLY CONVEY PERFORMANCE LEVELS

IESNA Recommended Minimum Illuminance Table

Re	Red = closed blinds A-C (30-300))		D-E	(300)-10	00)	F-G (1000-10k)						Extreme (10,000+)											
																									đ	-	E			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
Α	1500	1676	3400			1069	2000				1300	804								690	1600	787					2000	1157	1300	Α
В	1900	1800	2083			1200	1600	1			1200	1100								450	930	740					1650	1300	1300	В
C	2400	1750	1050																				840	720						С
D																							720	600						D
E					900	713	600							330	260	420	500				600	510						1400	600	Ε
F					770	640	620							400	387	500	500				510	420						2200	1400	F
G																							-							G
н	1225	830	730					~		unt	of liz	-h+i	'n																	Н
I	1620	1128	630					A	mou	unto		gnui	I						_	_										
J	2163	1430	1040					W	ork	stat	tion	?							W											J
к	3440	1077	1060										_					c		N]									K
	3440	15//	1000						3.4	3	.4	3.0	_					5	-		l									
L									3.7			3.0							E	J								1400		L
м									3.7	3	.6	3.7																850		Μ
N																												300		Ν
0											1	1	1				7	7		1		1								0
Р																														Р
Q					700	545 •					520	480						620	580	600 F					590	635 •				Q
R					640	390					590	440	570					660	648	620					597	680				R
S	3540	2237	1180		830	733					810	750	700					713	730	680					520	623				S
Т	2680	1990	1687		1037	980					882	1050	990					750	745	690					563	670		1000	1150	Т
U	2510	2063	1890		1300	1140					786	1019	1220					780	810	750					500	585		1033	1300	U
V	1457	1860	1251																									800	710	V
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	

POST-RETROFIT BRIGHTNESS LEVELS ARE LOWER

Α В

С

D

Ε

F

G

Н

J

Κ

L

Μ

Ν

Ρ Q

R

S

Т

U

V

IESNA Recommended Minimum Illuminance Table Red = closed blinds A-C (30-300) D-E (300-1000) F-G (1000-10k) Extreme (10,000+) 12 13 2400 1304 1310 1040 1343 1365 1950 1500 1440 1035 Amount of light in work station? W Ν S 3.0 3.4 3.4 3.7 3.0 Ε 3.7 3.6 3.7 1830 920

Α

В

С

D

Ε

F

G

н

J

Κ

Μ

Ν

Ρ

Q

R

S

Т

U

V

DIFFERENCES IN MEASUREMENTS: LOWER BRIGHTNESS LEVELS

	Blue = Post-Retrofit						Red = Post-Retrofit								White = No change															
	measurement is dimmer					measurement is brighter																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	71	22	23	24	25	26	27	28	29	
Α	260	761	1960			450	1550				-1100	-500								-233	70 T	233					680	136	-70	Α
В	682	825	1048			-200	675				-750	-400								-590	37	150					308	-65	-68	В
С	960	715	360																				530	340						С
D																							340	150						D
Е					340	270	150							53	-60						350	235						218	-760	Е
F					330	320	250							130	92						235	120						1195	218	F
G																														G
Н	773	451	361																											н
I	1095	372	270																	_										I
J	685	-330	143																W											J
к	1290	507	490															S		N										к
	1250	507	150															5	-									010		
L																			E	l								910		
M																												140		M
N																												-440		N
0									ì										1	ì										0
Р О					240	455					245	100						100	100	275					100	252				Р
Q					340	122					215	132	150					190	180	275					190	255				Q
ĸ	0	407	260		200	-30					490	204	152					200	238	370					160	312 20E				ĸ
э т	723	960	637		407 516	242					310	204	342					-58	200	100					223	200		230	50	э т
- I - II	1210	836	690		790	530					136	325	500					-50	130	115					130	255		-145	-130	
v	565	/185	302		790	550					130	525	500					50	130	113					130	2.55		-535	-130	v
v	1	40J 2	392	Л	5	6	7	8	9	10	11	12	13	14	15	16	17	18	10	20	21	22	23	24	25	26	27	28	29	v
	*	2	5	-	5	U	1	0	<u> </u>	10	**	12	10	74	10	10	1/	10	17	20	~ 1	~~	23	27	25	20	~ /	20	25	

SENSORS DON'T DETECT EVERYTHING



* 2 data points removed as outliers

ROI DEPENDS ON REDUCTION IN ELECTRICITY USAGE

Assumptions:

- \$1 million total energy costs for building
- ~ \$50k / yr / floor x 20 floors
- ~35% energy usage for lighting fixtures
- \$17.5k / yr / floor for lighting
- ~\$85 / fixture alone, \$200 including control
- ~\$70k / floor x 16 floors

~\$1.12 million to perform lighting retrofit entire UW Tower



*Calculation excludes additional factors which would reduce the ROI TECHNOLOGY SHOULD ENABLE OCCUPANTS TO DO MORE

To be truly useful, technology should enable facility staff to do more. Occupant behavior, perception, and health particularly matter because their needs are addressed by facility staff.

Key Recommendations

- Minimize time between fixture installation and controls commissioning
- Involve occupants in the choice of installation dates, lighting fixture choice
- Develop strategy for periodic recalibration
- Use reporting / monitoring features to develop performance benchmarks

ACKNOWLEDGEMENTS

a special thanks to occupants of 12th and 15th floor for their patience and engagement throughout the process

> **UW Tower Facilities and Operations Staff UW Green Seed Fund Environmental Stewardship Committee Members Norm Menter**, UW Tower Facility Services **Encelium Staff** Lindsay McCunn, Assistant Professor at UW Tacoma Nick Yasinski, Biostatistics (15th floor) **Thomas Cheong**, undergraduate researcher Michael Stolp-Smith, HDR photographer and alumni

QUESTIONS, COMMENTS?

THANKS FOR LISTENING!

(A)	C Building	g (continued)	T Building	T-59 (continue)	T-54 Department of Health Services	T-19 (comment)
a	CLL	UW-IT Information Atlanagement	741	Patient Financial Servers		Intellectual Pricently Lonneirig
	LAW Toware Alast & Repowering	0-01-	Duilding Services - Clusteduil	Radiclogy Support	HSERV Office of Finance and Resourch	Markesrg
	(C-01	SJW-TT Information Management	T-01	7-09 UW Medicine	Seattle Quality of Life Group	Manazing Distribution
	Chief Information Security Officer (C	0.64			T-15 School of Public Health	T-25 UW Educational Outreach (UWEO)
	Emergency Operations Center	Auditorium	UW Advancement Gift Processing	T-10 UW Medicine	Department of Biostatistics	Academic Programs
	LW Emergency Management	University of Washington Press	T-05 UW Medicine Neighborhood Clinics	Patient Financial Services	Center for Biomedical Statistics	Orber Lifelong Leanwag Institute of UW
I	C-00	S Ballding	Accounting UWPN	Petert Freiträs Sarvicus Adr. Inistation T-11 School of Medicine & School of Nitra	Genetics Coordinating Center	T-21 UW Liducational Outreach (UWEO) Augdemid Programs
10	W Technology Services	S-01 UW Advancement	T-06 UW Medicine	Continuing Medical Education (CME)	Platistical Genetics Laboratory	Assistant Vice Provest -Operation
00	ы	Advancement Services	Accounting	Continuing Nursing Education (CNE)	T-16 Office of Research	Conferences
Cale	stenas North & South	Advancement Research & Relationship Ma	T-07 UW Medicine & UW Medical Center	mittel Informatics Research Group (C)R	G Human Sub Los LAsion	Destance Learning Design
UNT	umer Cala	Finance & Administration	Clinical Program Strategy & Patients First	Living Well with Stroke Research Group	Office of Sponsored Programs (QSP	D Executive Director - Operations
	-	8-02	Human ReQuirces	12 Office of Planning & Budgeting	T-17 Office of Research	Facilities Management
	O Building	UW Alumni Association	Organization Development & Training	Capital Resource Planning	Humen Subject Division	Hurn Ryson IS
01		-Washington Commons	Nutsing Staff Development	Data Management & Instantional Resea	errt Officof Sponred Programs (C	(C2) International & English Language Pro
V Benefit	ts Office	S-03 Individual Giving Programs	Patient & Fally Centered Care	Operating Resource Planning	T-18	Market Research
Combin	ed Fund Drive	Corporate & Foundation Relations	Patient & Family Education	Real Estate Office (REO)	Attorive General's Office (AGC	a) UW Division Oublic Relations
awroll C	Mice	Planned Giving	Performance Improvement/LEAN	Inversity Architect & Campus Plannie	ng Partners for Our Children	Software Development Services
and Off		Principal Giving	Planning & Referral Development	Vice Provost's Office	T-19 UW Educational Outree	ch (UWEO) Summer Quarter
		Regional Giving	T-08 UW Medicine	T-13 UW Educational Outreach (UW	VEO) Academic Programs	Vice Provost
		C.M.	Lento for Classal Excellence	Information Technology Operations	Enrollment Advising Center	T-22 Conference Center
*		Industing	Design & Construction Management	International & English Language F	Cicel on Finance & Planning	Office of the President
ssenze		Marxening		Program Central Support	International Program Se	nport UW Tox or Orienations De
search l	Information Services		Finance			

EXTRA SLIDE INDEX

IESNA RECOMMENDED MINIMUM ILLUMINANCE MCKINSTRY DASHBOARD: HISTORICAL PERFORMANCE MCKINSTRY DASHBOARD: AVERAGE PERFORMANCE 12TH AND 15TH FLOOR LIGHTING PLANS WORKSPACES AND EQUIPMENT MAPS

STATIONARY MEASURING EQUIPMENT

RECOMMENDED MINIMUM ILLUMINANCE TABLE

Category	Descrip	Recommended Min. Illuminance Level	
А	Public spaces	30 lx	
В	Simple orientation for short visi	its	50 lx
С	Working spaces where simple v	100 lx	
D	Performance of visual tasks of h	300 lx	
E	Performance of visual tasks of h low contrast + large size	r 500 lx	
F	Performance of tasks of low cor	1000 lx	
G	Performance of visual tasks nea	3000 - 10,000 lx	
From IESNA Lighting – Ready F	Reference (4 th Edition)		
A-C (30-300 lu	IX) D-E (300-1000 lux)	F-G (1000-10k lux)	Extreme (10,000+ lux)

IMPORTANCE OF IEQ FROM A FACILITY PERSPECTIVE



IMPORTANCE OF IEQ FROM A FACILITY PERSPECTIVE



SPACE CATEGORIZATION



Ú

WORKSPACES AND EQUIPMENT MAP



STATIONARY MEASURING EQUIPMENT (FRANKIE)



52.0.

OUND LEVEL METER

50-4021

622

TECHNOLOGY SHOULD ENABLE OCCUPANTS TO DO MORE

Questions to be answered

- To what extent should occupants have control over the lighting fixtures?
- What reporting and monitoring features are most useful to facilities O&M?
- What strategies will further reduce the ROI?
- To what extent can the technology achieve occupant satisfaction?

Lessons Learned

- Lighting fixture = largest contributor to economic / energy savings
- Lighting controls key to occupant satisfaction + productivity (including mgmt.)
- New fixtures produce less light, seemingly reduce brightness gradients ('caves')
- Occupants value changes that improve their an ability control their lighting quality
- Each floor requires slightly different designs due to unique floor plans + occupant tasks
- Retrofitting / commissioning process can potentially create an extended, disruptive interim period
- Manual equipment can detect things the light sensors cannot