HDR imaging in the field

Kyle Konis
Ph.D Candidate
U.C. Berkeley
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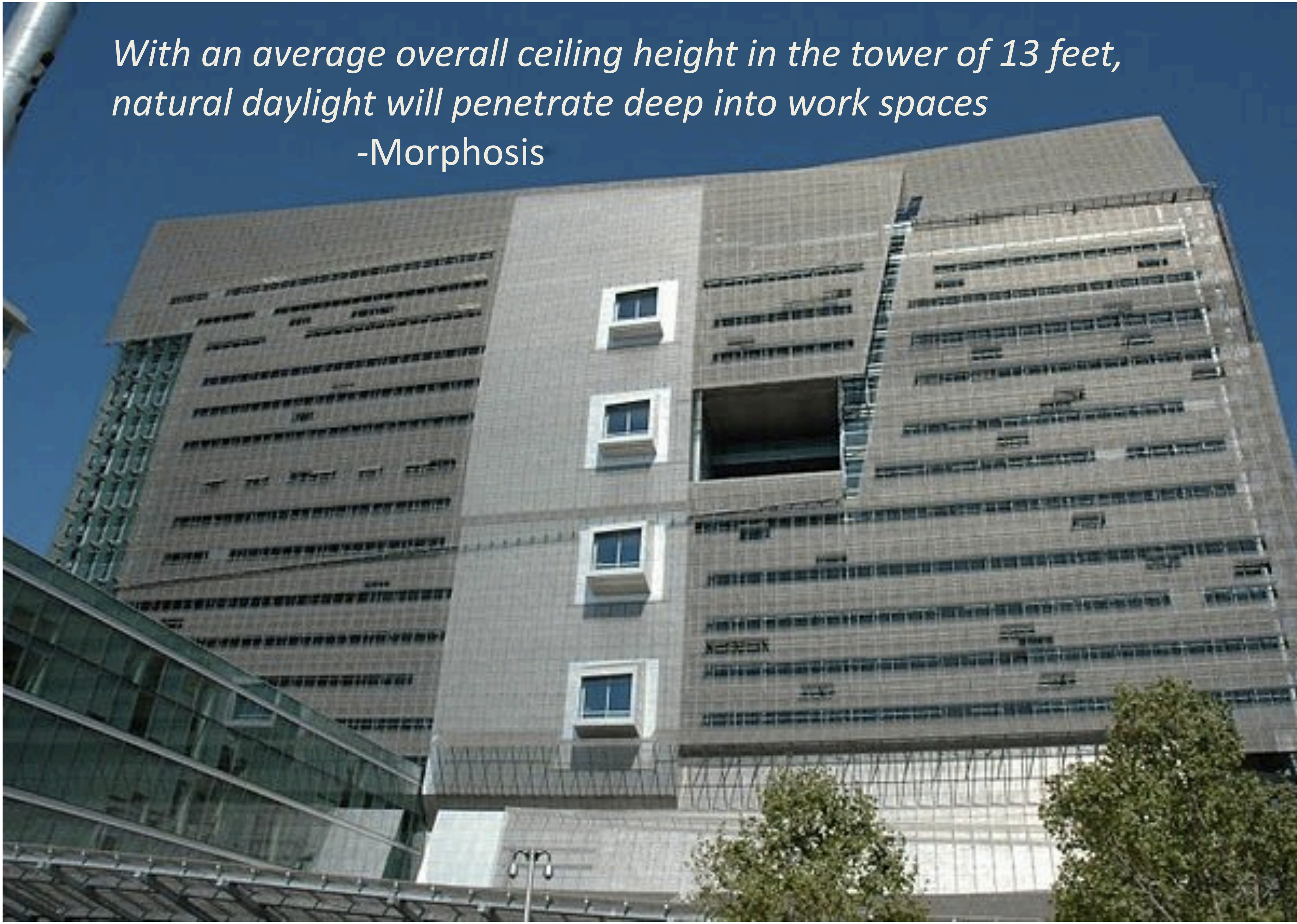


With an average overall ceiling height in the tower of 13 feet, natural daylight will penetrate deep into work spaces

-Morphosis

The estimates for lighting in office buildings, they range between 30 – 40% of the total energy use, so if we can absolutely obviate the need for them, and get rid of the heat gains that the lights may be putting into the space, we've gone a long long way towards a sensible solution to the building. - Morphosis

Goal and ?s

- Balance energy objectives with visual comfort
  - In buildings where daylight transmission is implemented as a strategy to reduce electrical lighting energy consumption, are acceptable visual conditions for occupants maintained?

  - If not, what are the conditions associated with visual discomfort responses? And, how do discomfort responses compare to existing indicators (e.g. glare metrics, luminance contrast ratio limits, vertical illuminance)?

Can better indicators be developed from the field?

Lab

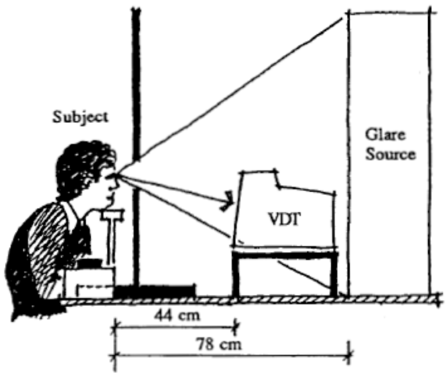
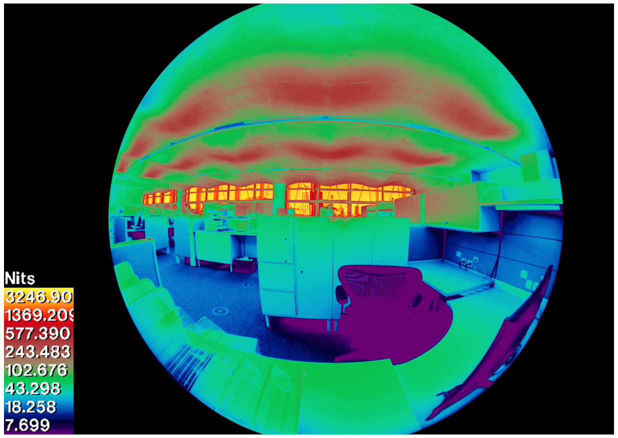


Fig. 1. Experimental set-up.

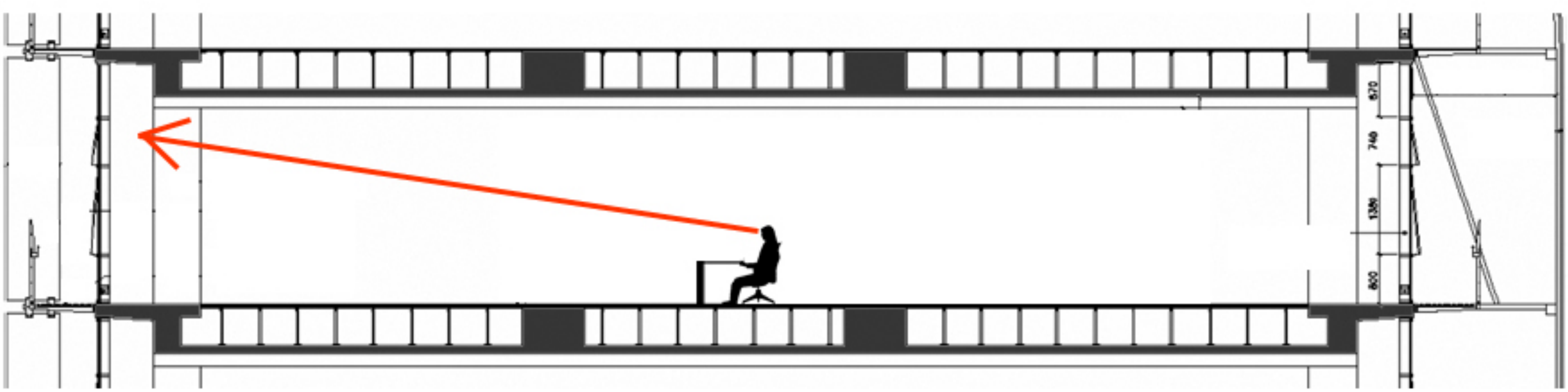
Precision and control over confounding variables

Field

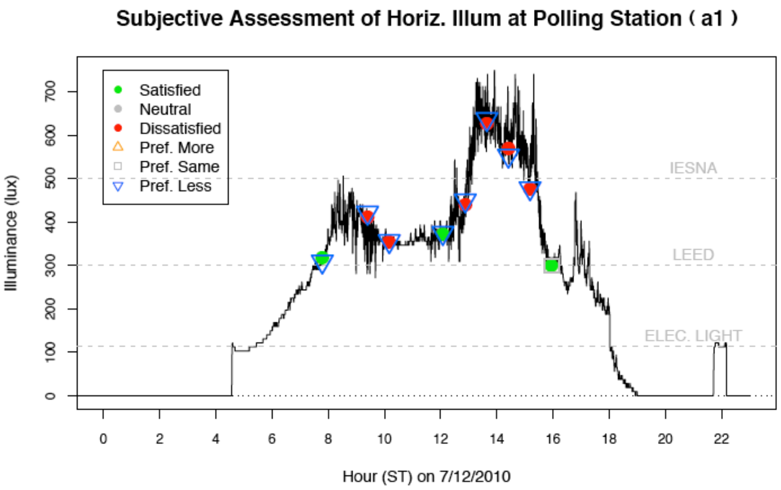


Less control but greater level of "reality"

Field: particularly enticing for examining visual discomfort for core workspaces



Objective



- Develop method of pairing HDR images acquired in the field with occupant subjective responses.
  - In real buildings, where participants perform real work tasks in a familiar environment
  - With multiple study participants
  - With a repeated measures study design

Problem

- HDR imaging is expensive
  - Limits number of study participants

$750

$2100

$600

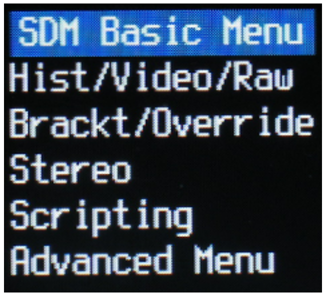
What’s in the box?

Solution!

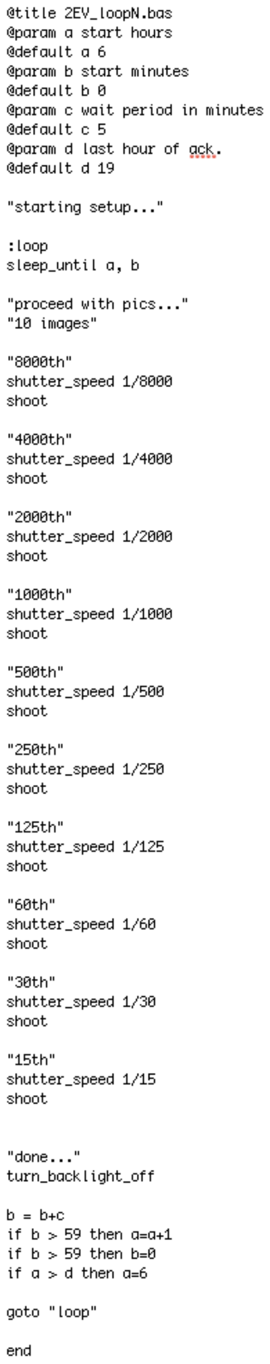
http://stereo.jpn.org/eng/sdm/index.htm

Opteka HD² 0.20X
$35

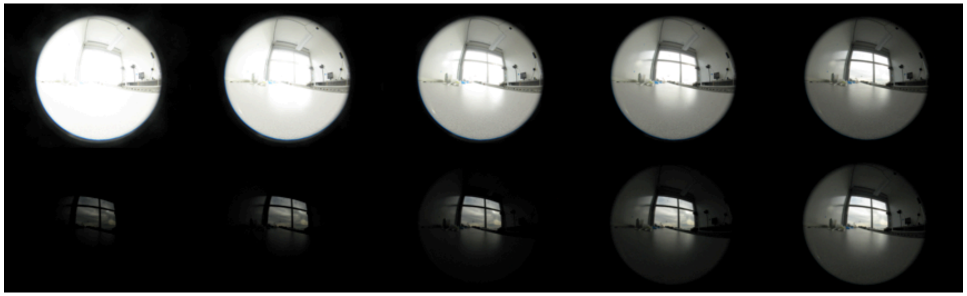
Canon A570
$80



Stereo Data Maker
Firmware “upgrade”
Free!



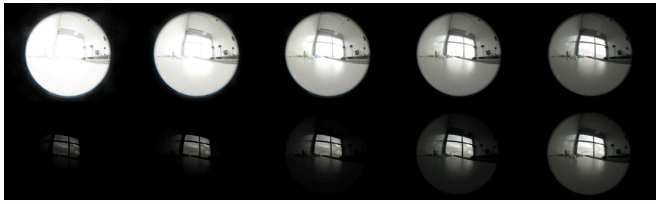
```
@title 2EV_loopN.bas
@param a start hours
@default a 6
@param b start minutes
@default b 0
@param c wait period in minutes
@default c 5
@param d last hour of ack.
@default d 19

"starting setup..."

:loop
sleep_until a, b

"proceed with pics..."
"10 images"

"8000th"
shutter_speed 1/8000
shoot

"4000th"
shutter_speed 1/4000
shoot

"2000th"
shutter_speed 1/2000
shoot

"1000th"
shutter_speed 1/1000
shoot

"500th"
shutter_speed 1/500
shoot

"250th"
shutter_speed 1/250
shoot

"125th"
shutter_speed 1/125
shoot

"60th"
shutter_speed 1/60
shoot

"30th"
shutter_speed 1/30
shoot

"15th"
shutter_speed 1/15
shoot


"done..."
turn_backlight_off

b = b+c
if b > 59 then a=a+1
if b > 59 then b=0
if a > d then a=6

goto "loop"

end
```



Bracketed JPEGs for compositing to HDR

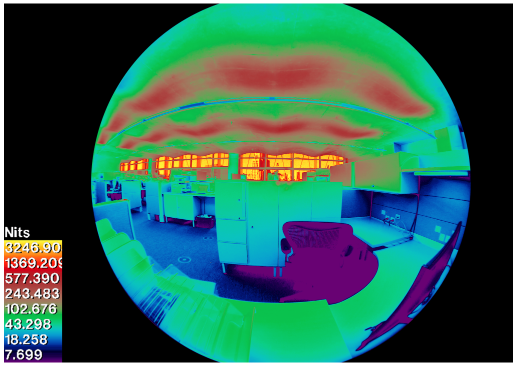
$8

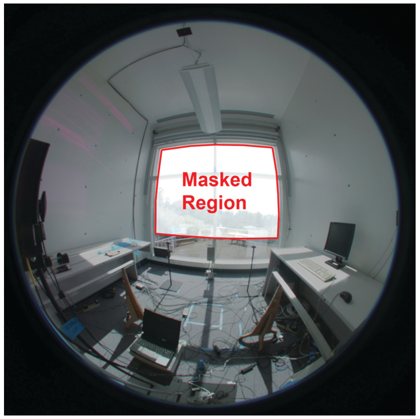
(enough space for
168 HDR/day * 30 days)

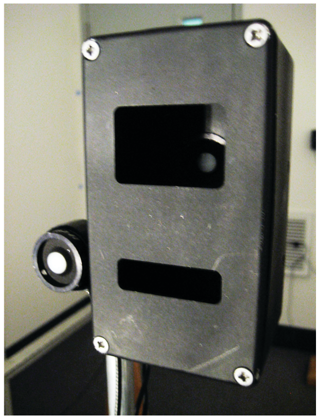


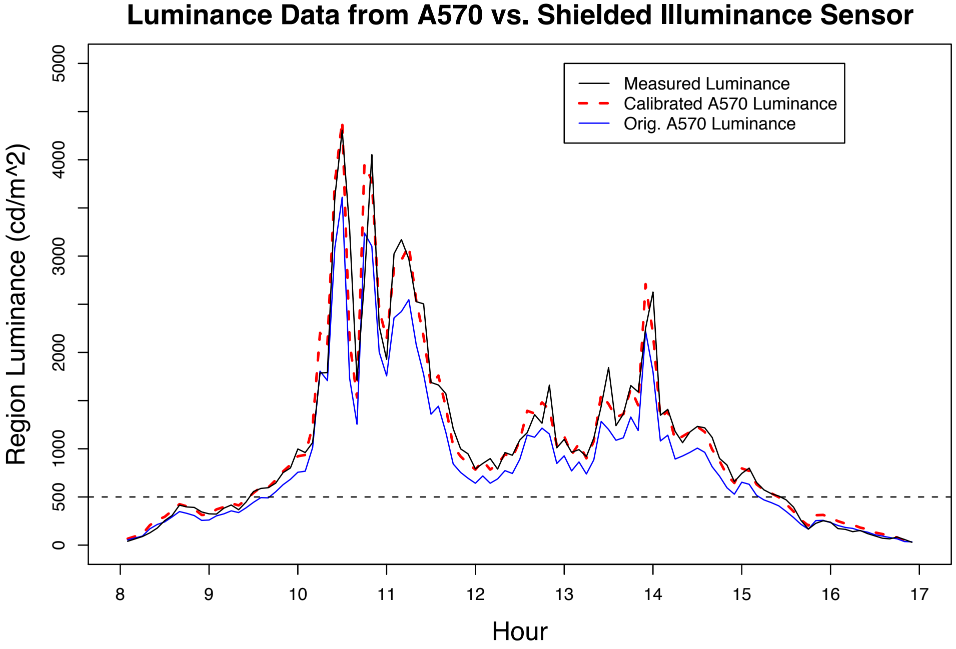
Radiance

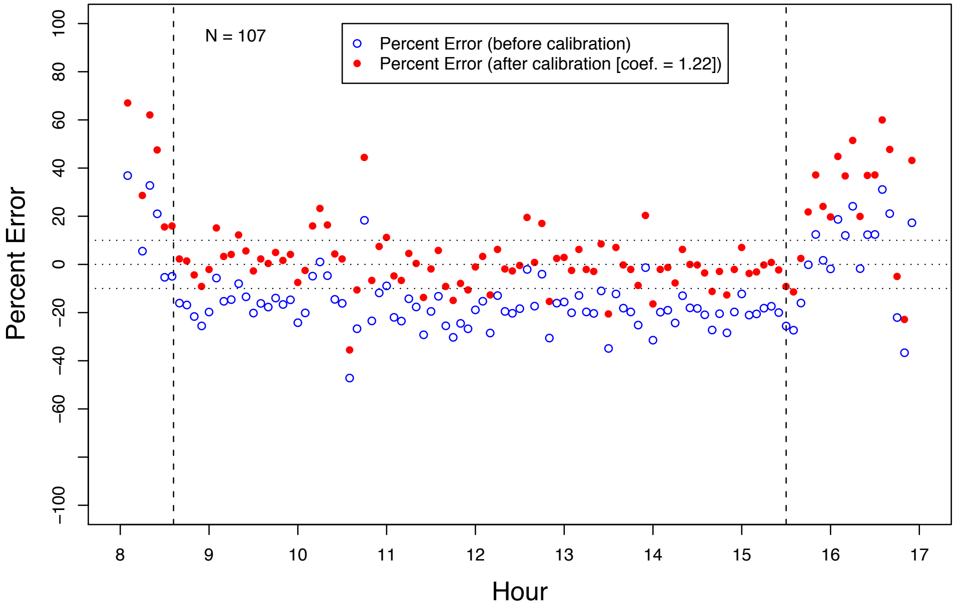
hdrgen





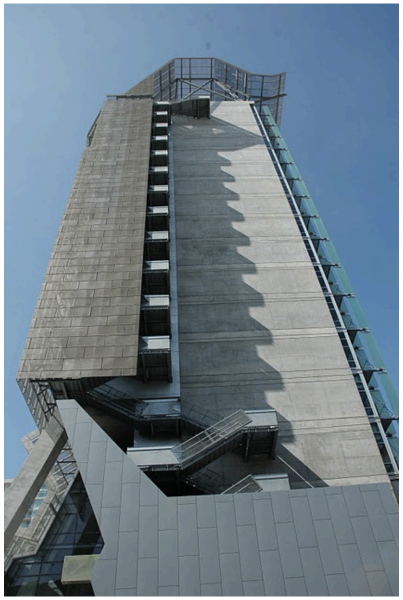




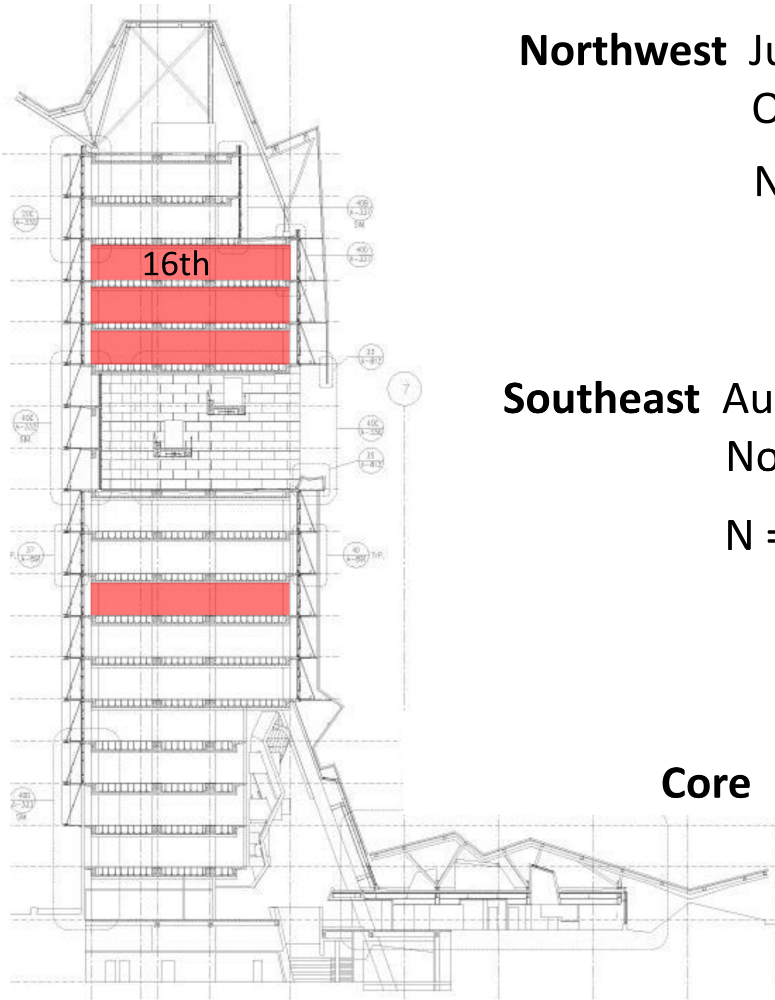


Calibration . . . does it work?

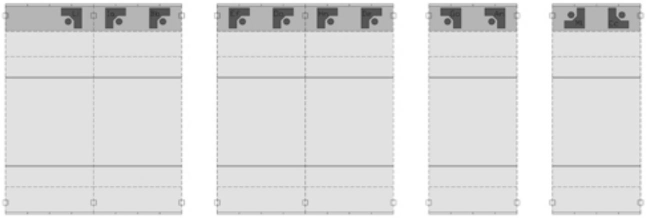
Enter the field . . .



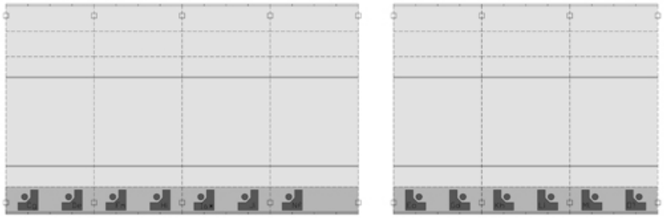
Study design: multi-week phases by zone



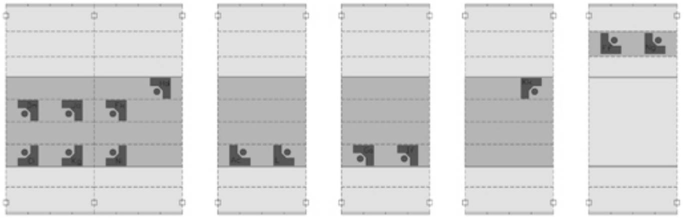
Northwest July 9 – 29
Oct 18 - 29
N = 12


Phase 1

Southeast Aug 3 – Sept 3
Nov 8 - 19
N = 18


Phase 2

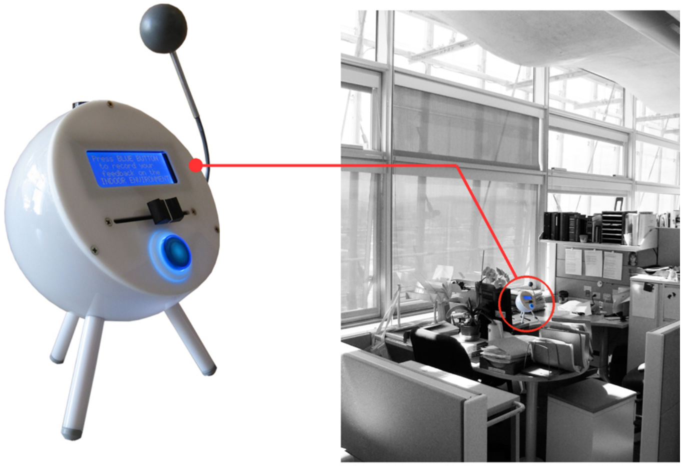
Core Oct 4 – 15
Dec 6 - 17
N = 14


Phase 3

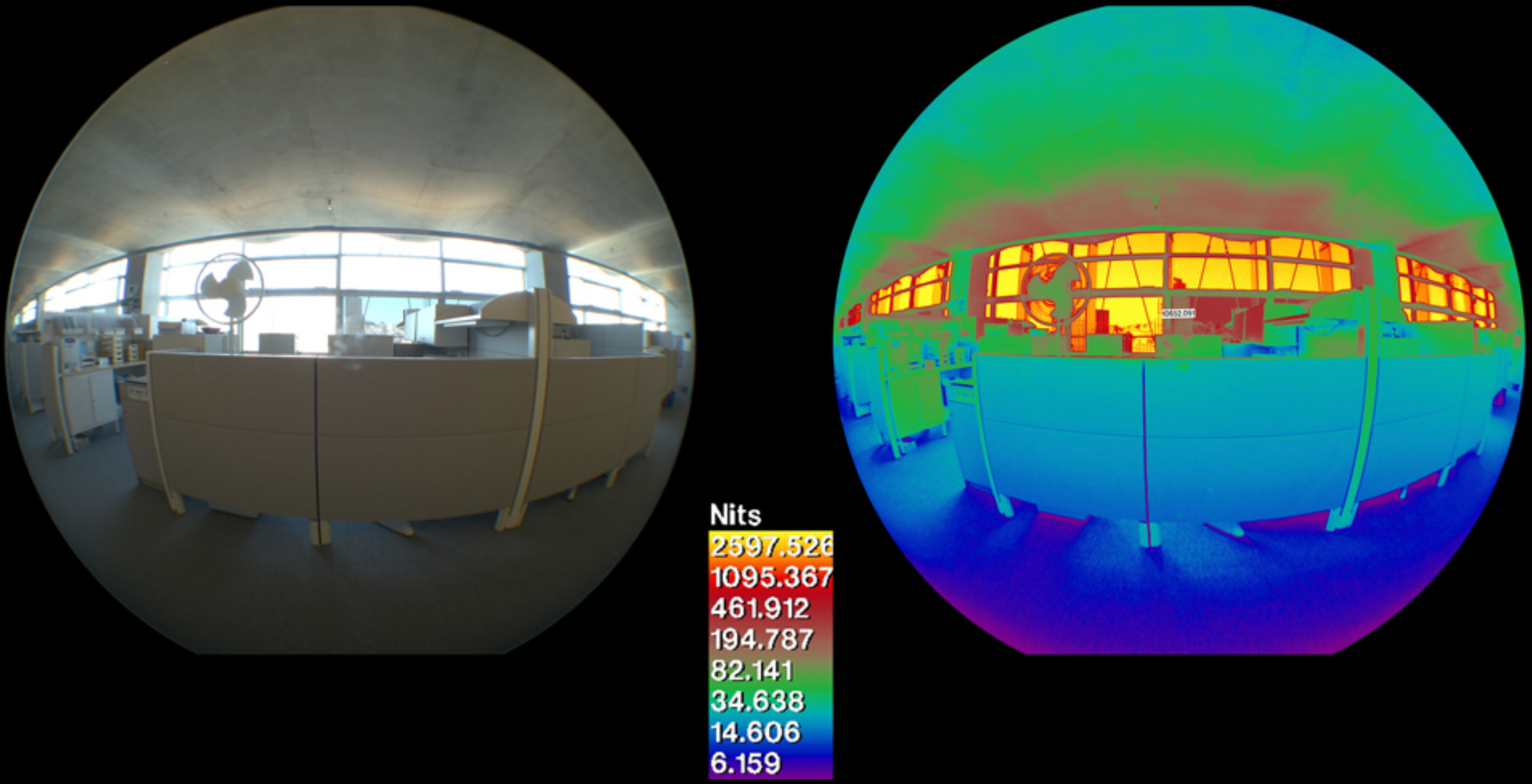
July – December 2010

Measurement protocol

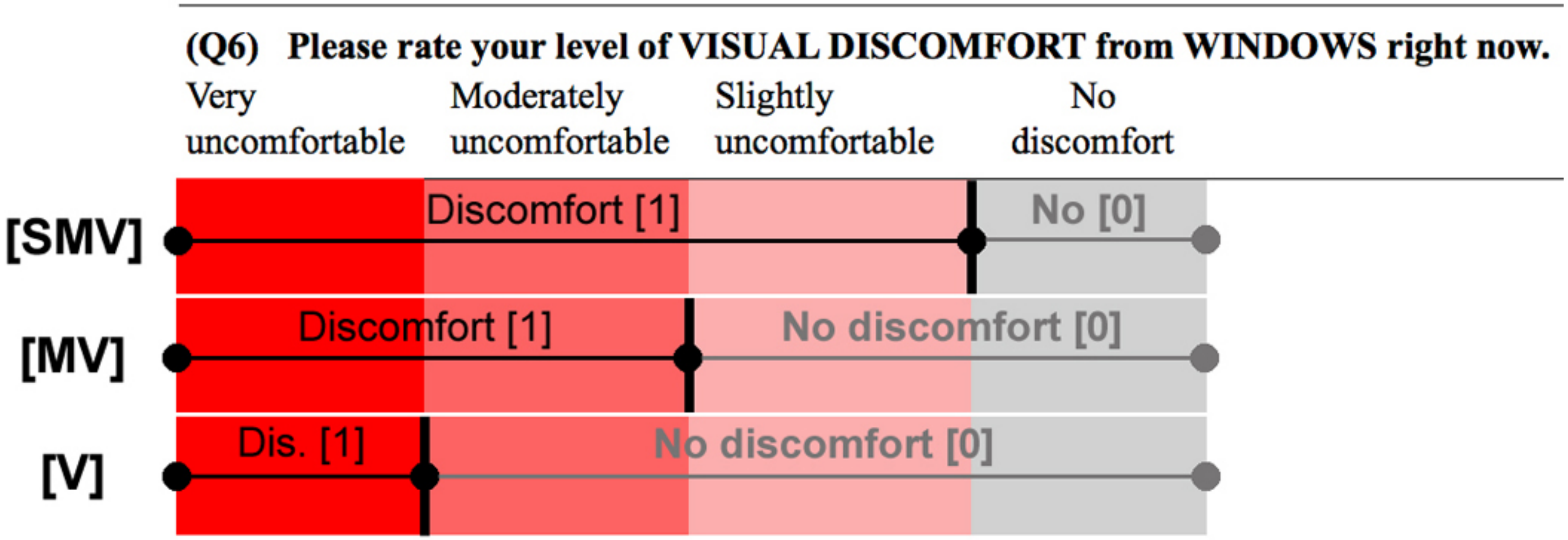
- 1 Camera at each participant workstation
- Image acquisition @ 5min. Intervals 6:00 – 20:00
- Subjective assessments collected using a desktop polling station (participants can record responses at any time)



Example viewpoint from workspace located in “core zone”



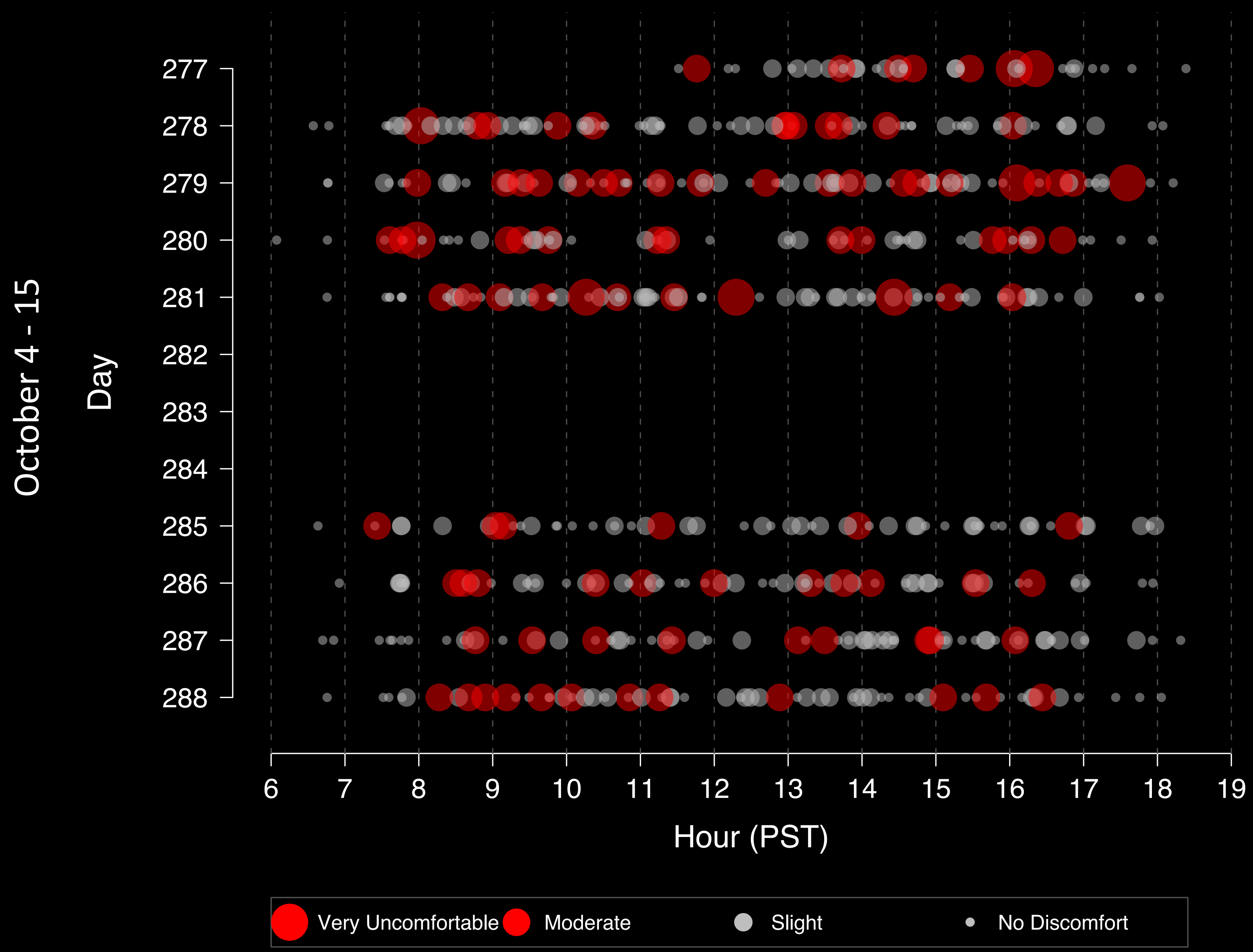
Discomfort scale and binary “bins”



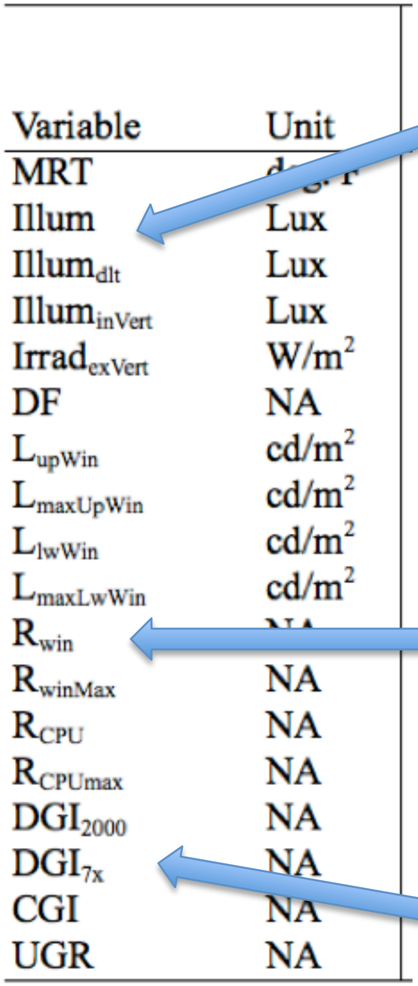
(Q6) Please rate your level of VISUAL DISCOMFORT from WINDOWS right now.

Very uncomfortable | Moderately uncomfortable | Slightly uncomfortable | No discomfort

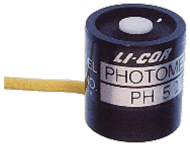
Subjective responses from (N=11) study participants



Subjective responses compared to a number of independent variables . . .



Variable	Unit
MRT	deg. F
Illum	Lux
$\mathrm{Illum}_{\mathrm{dlt}}$	Lux
$\mathrm{Illum}_{\mathrm{inVert}}$	Lux
$\mathrm{Irrad}_{\mathrm{exVert}}$	$\mathrm{W/m^2}$
DF	NA
L_{upWin}	$\mathrm{cd/m^2}$
L_{maxUpWin}	$\mathrm{cd/m^2}$
L_{lwWin}	$\mathrm{cd/m^2}$
L_{maxLwWin}	$\mathrm{cd/m^2}$
R_{win}	NA
R_{winMax}	NA
R_{CPU}	NA
R_{CPUmax}	NA
DGI_{2000}	NA
DGI_{7x}	NA
CGI	NA
UGR	NA



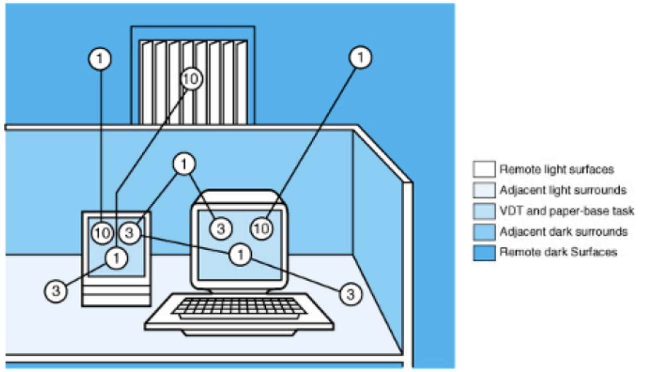
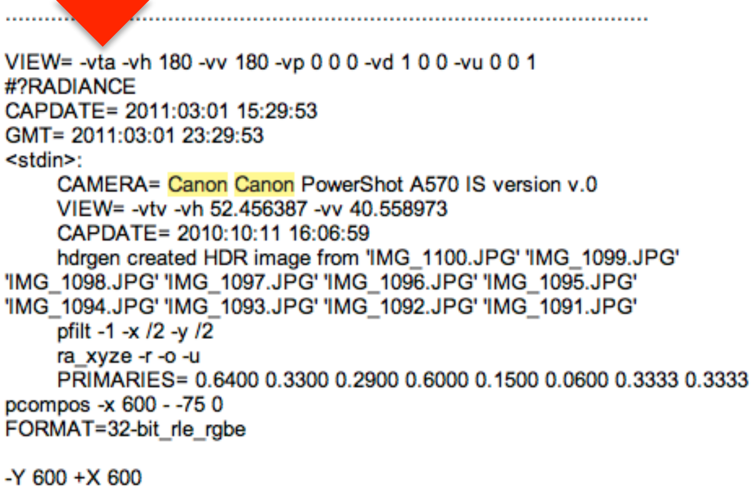


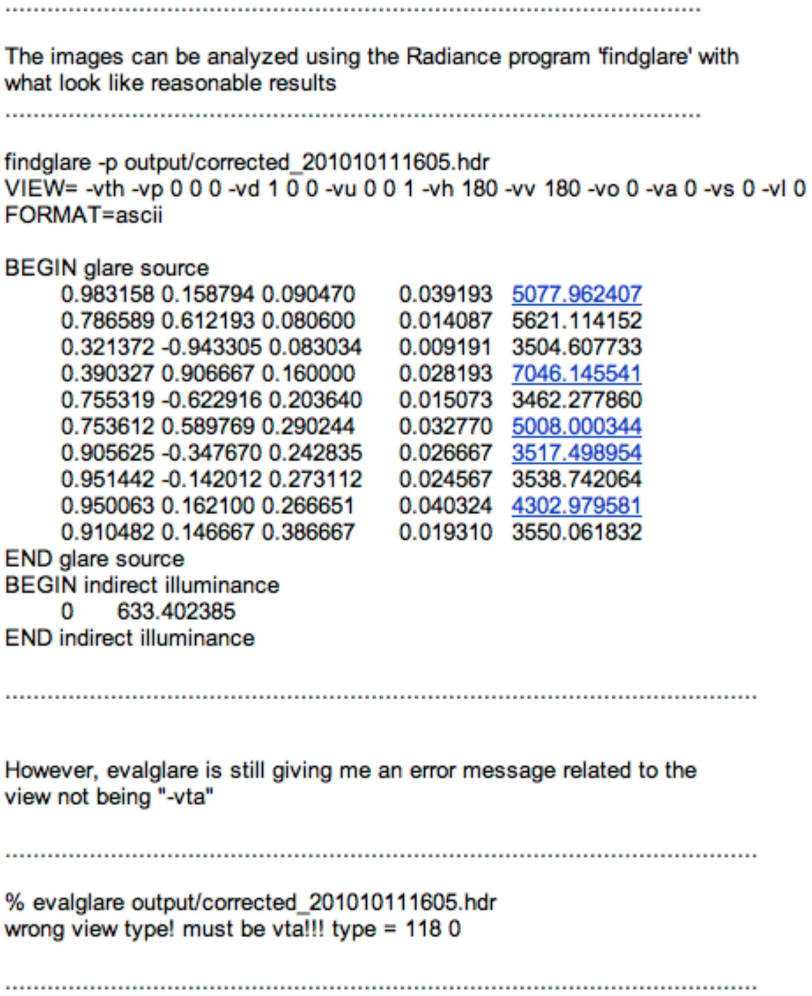
FIGURE 8-2 IESNA Recommended Luminance Ratios for a Typical Office Space
Source: IESNA Lighting Handbook, Ninth Edition
Reproduced by permission of the Illuminating Engineering Society of North America (IESNA)

$$DGI = 10 \log 0.478 \sum_{i=1}^{n} \frac{L_s^{1.6}\,\Omega^{0.8}}{L_b + 0.07\,\omega^{0.5}\,L_s}$$

Unfortunately, not Evalglare . . .



```
VIEW= -vta -vh 180 -vv 180 -vp 0 0 0 -vd 1 0 0 -vu 0 0 1
#?RADIANCE
CAPDATE= 2011:03:01 15:29:53
GMT= 2011:03:01 23:29:53
<stdin>:
        CAMERA= Canon Canon PowerShot A570 IS version v.0
        VIEW= -vtv -vh 52.456387 -vv 40.558973
        CAPDATE= 2010:10:11 16:06:59
        hdrgen created HDR image from 'IMG_1100.JPG' 'IMG_1099.JPG'
'IMG_1098.JPG' 'IMG_1097.JPG' 'IMG_1096.JPG' 'IMG_1095.JPG'
'IMG_1094.JPG' 'IMG_1093.JPG' 'IMG_1092.JPG' 'IMG_1091.JPG'
        pfilt -1 -x /2 -y /2
        ra_xyze -r -o -u
        PRIMARIES= 0.6400 0.3300 0.2900 0.6000 0.1500 0.0600 0.3333 0.3333
pcompos -x 600 - -75 0
FORMAT=32-bit_rle_rgbe

-Y 600 +X 600
```



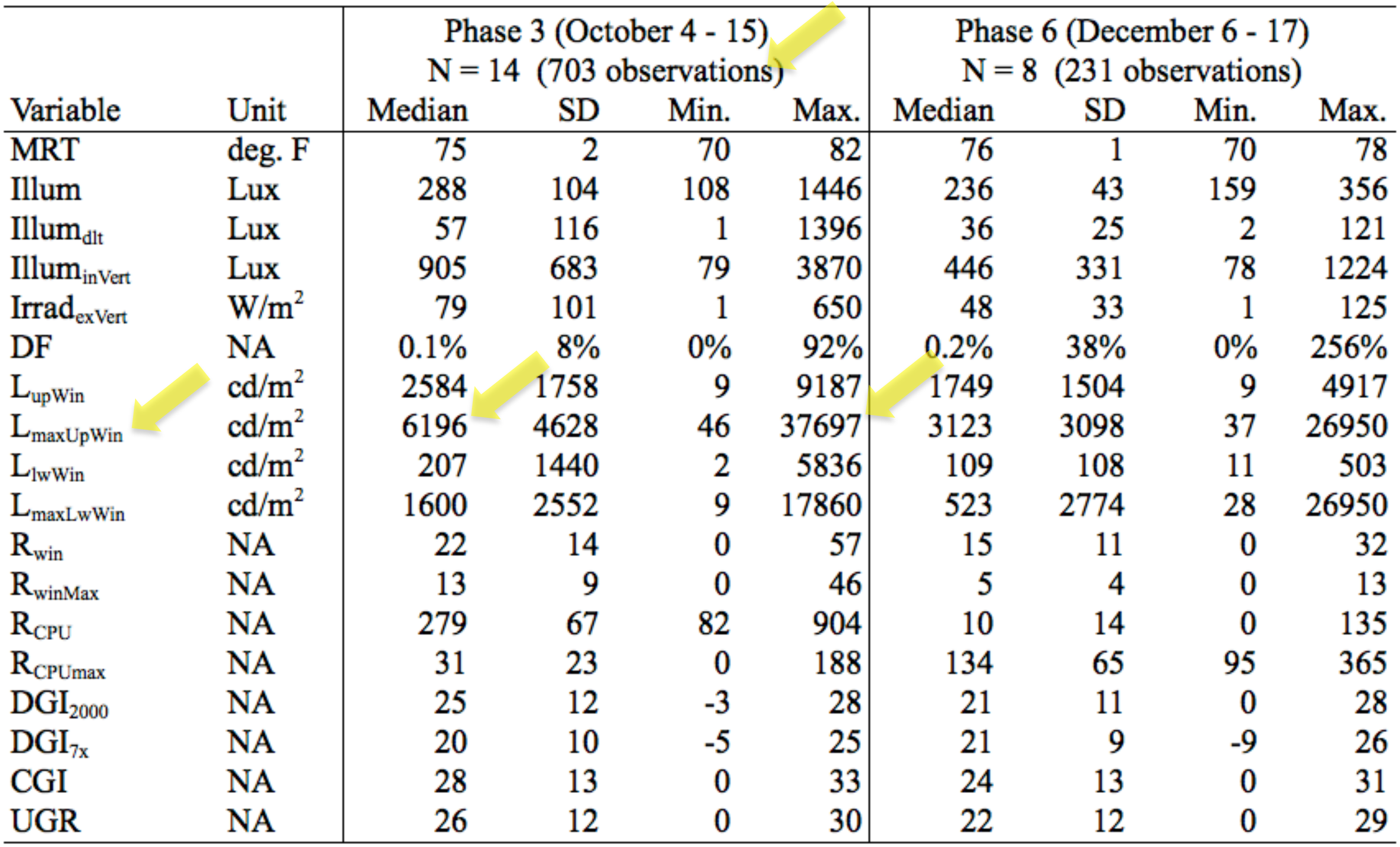
The images can be analyzed using the Radiance program 'findglare' with what look like reasonable results

```
findglare -p output/corrected_201010111605.hdr
VIEW= -vth -vp 0 0 0 -vd 1 0 0 -vu 0 0 1 -vh 180 -vv 180 -vo 0 -va 0 -vs 0 -vl 0
FORMAT=ascii

BEGIN glare source
        0.983158 0.158794 0.090470      0.039193  5077.962407
        0.786589 0.612193 0.080600      0.014087  5621.114152
        0.321372 -0.943305 0.083034     0.009191  3504.607733
        0.390327 0.906667 0.160000      0.028193  7046.145541
        0.755319 -0.622916 0.203640     0.015073  3462.277860
        0.753612 0.589769 0.290244      0.032770  5008.000344
        0.905625 -0.347670 0.242835     0.026667  3517.498954
        0.951442 -0.142012 0.273112     0.024567  3538.742064
        0.950063 0.162100 0.266651      0.040324  4302.979581
        0.910482 0.146667 0.386667      0.019310  3550.061832
END glare source
BEGIN indirect illuminance
        0       633.402385
END indirect illuminance
```

However, evalglare is still giving me an error message related to the view not being "-vta"

```
% evalglare output/corrected_201010111605.hdr
wrong view type! must be vta!!! type = 118 0
```

Descriptive statistics for core zone participants



		Phase 3 (October 4 - 15) N = 14 (703 observations)				Phase 6 (December 6 - 17) N = 8 (231 observations)			
Variable	Unit	Median	SD	Min.	Max.	Median	SD	Min.	Max.
MRT	deg. F	75	2	70	82	76	1	70	78
Illum	Lux	288	104	108	1446	236	43	159	356
Illum_{dlt}	Lux	57	116	1	1396	36	25	2	121
Illum_{inVert}	Lux	905	683	79	3870	446	331	78	1224
Irrad_{exVert}	W/m^2	79	101	1	650	48	33	1	125
DF	NA	0.1%	8%	0%	92%	0.2%	38%	0%	256%
L_{upWin}	cd/m^2	2584	1758	9	9187	1749	1504	9	4917
$L_{maxUpWin}$	cd/m^2	6196	4628	46	37697	3123	3098	37	26950
L_{lwWin}	cd/m^2	207	1440	2	5836	109	108	11	503
$L_{maxLwWin}$	cd/m^2	1600	2552	9	17860	523	2774	28	26950
R_{win}	NA	22	14	0	57	15	11	0	32
R_{winMax}	NA	13	9	0	46	5	4	0	13
R_{CPU}	NA	279	67	82	904	10	14	0	135
R_{CPUmax}	NA	31	23	0	188	134	65	95	365
DGI_{2000}	NA	25	12	-3	28	21	11	0	28
DGI_{7x}	NA	20	10	-5	25	21	9	-9	26
CGI	NA	28	13	0	33	24	13	0	31
UGR	NA	26	12	0	30	22	12	0	29

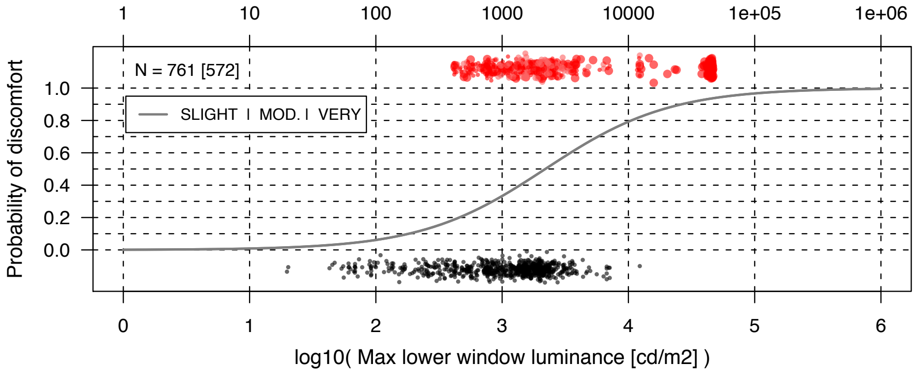
Logistic models fit to predict binary outcomes

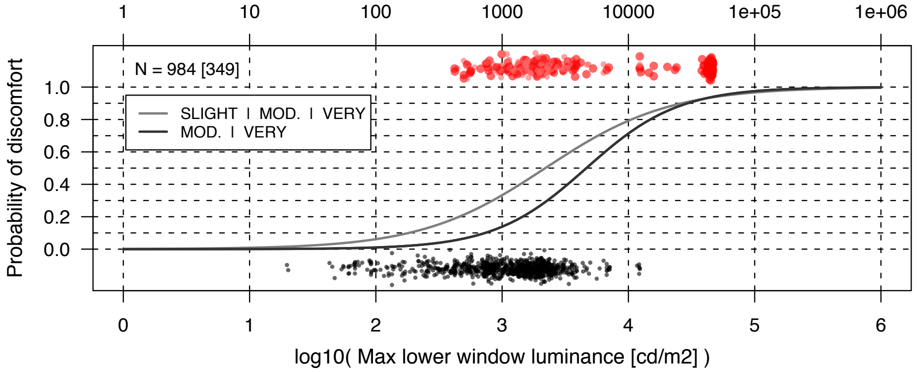
$$f(z) = \frac{e^z}{e^z + 1} = \frac{1}{1 + e^{-z}}$$

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_k x_k,$$

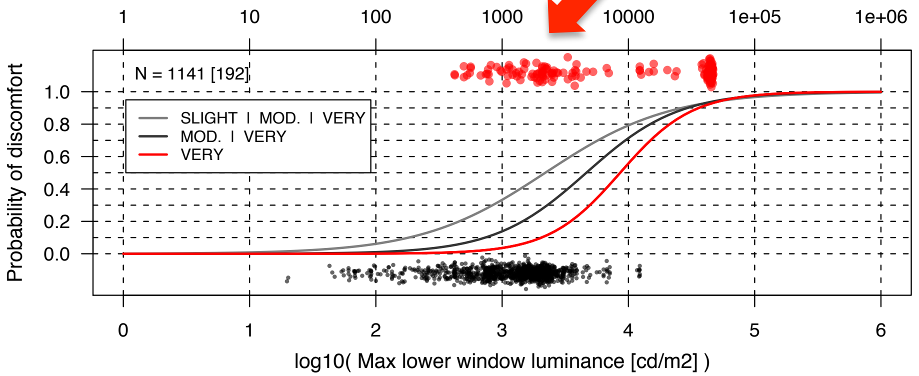
(Q6) Please rate your level of VISUAL DISCOMFORT from WINDOWS right now.

Very uncomfortable	Moderately uncomfortable	Slightly uncomfortable	No discomfort

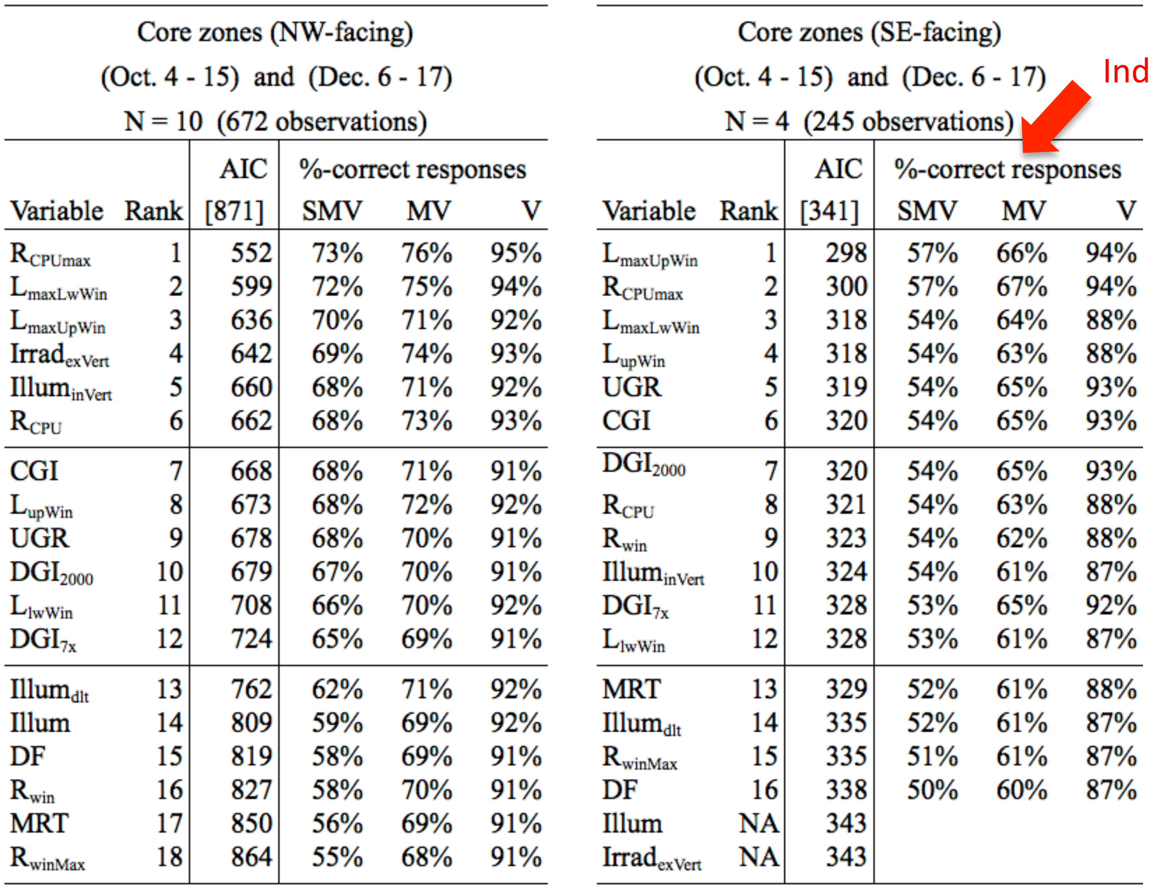




Discomfort responses



Ranking of logistic regression models



Core zones (NW-facing)
(Oct. 4 - 15) and (Dec. 6 - 17)
N = 10 (672 observations)

		AIC	%-correct responses		
Variable	Rank	[871]	SMV	MV	V
R_{CPUmax}	1	552	73%	76%	95%
$L_{maxLwWin}$	2	599	72%	75%	94%
$L_{maxUpWin}$	3	636	70%	71%	92%
$Irrad_{exVert}$	4	642	69%	74%	93%
$Illum_{inVert}$	5	660	68%	71%	92%
R_{CPU}	6	662	68%	73%	93%
CGI	7	668	68%	71%	91%
L_{upWin}	8	673	68%	72%	92%
UGR	9	678	68%	70%	91%
DGI_{2000}	10	679	67%	70%	91%
L_{lwWin}	11	708	66%	70%	92%
DGI_{7x}	12	724	65%	69%	91%
$Illum_{dlt}$	13	762	62%	71%	92%
Illum	14	809	59%	69%	92%
DF	15	819	58%	69%	91%
R_{win}	16	827	58%	70%	91%
MRT	17	850	56%	69%	91%
R_{winMax}	18	864	55%	68%	91%

Core zones (SE-facing)
(Oct. 4 - 15) and (Dec. 6 - 17)
N = 4 (245 observations)

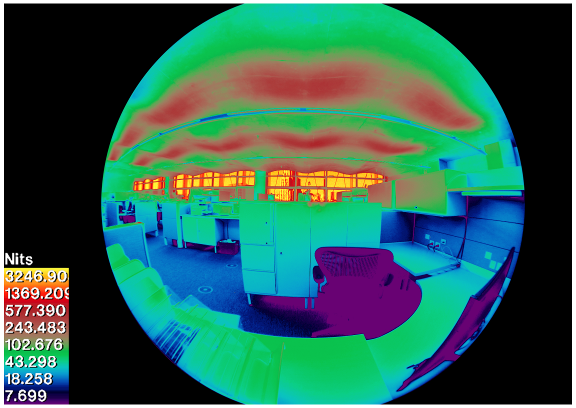
		AIC	%-correct responses		
Variable	Rank	[341]	SMV	MV	V
$L_{maxUpWin}$	1	298	57%	66%	94%
R_{CPUmax}	2	300	57%	67%	94%
$L_{maxLwWin}$	3	318	54%	64%	88%
L_{upWin}	4	318	54%	63%	88%
UGR	5	319	54%	65%	93%
CGI	6	320	54%	65%	93%
DGI_{2000}	7	320	54%	65%	93%
R_{CPU}	8	321	54%	63%	88%
R_{win}	9	323	54%	62%	88%
$Illum_{inVert}$	10	324	54%	61%	87%
DGI_{7x}	11	328	53%	65%	92%
L_{lwWin}	12	328	53%	61%	87%
MRT	13	329	52%	61%	88%
$Illum_{dlt}$	14	335	52%	61%	87%
R_{winMax}	15	335	51%	61%	87%
DF	16	338	50%	60%	87%
Illum	NA	343			
$Irrad_{exVert}$	NA	343			

Best model

Indicator of “accuracy”

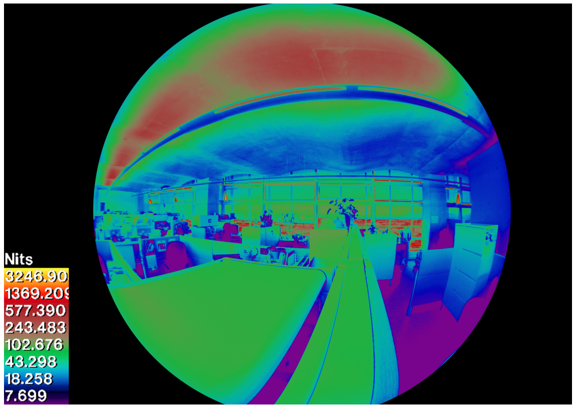
Absolute measures of window luminance (max, average) and luminance ratios found to be best predictors

Resulting models



Core zones (NW-facing) (Oct. 4 - 15) and (Dec. 6 - 17)

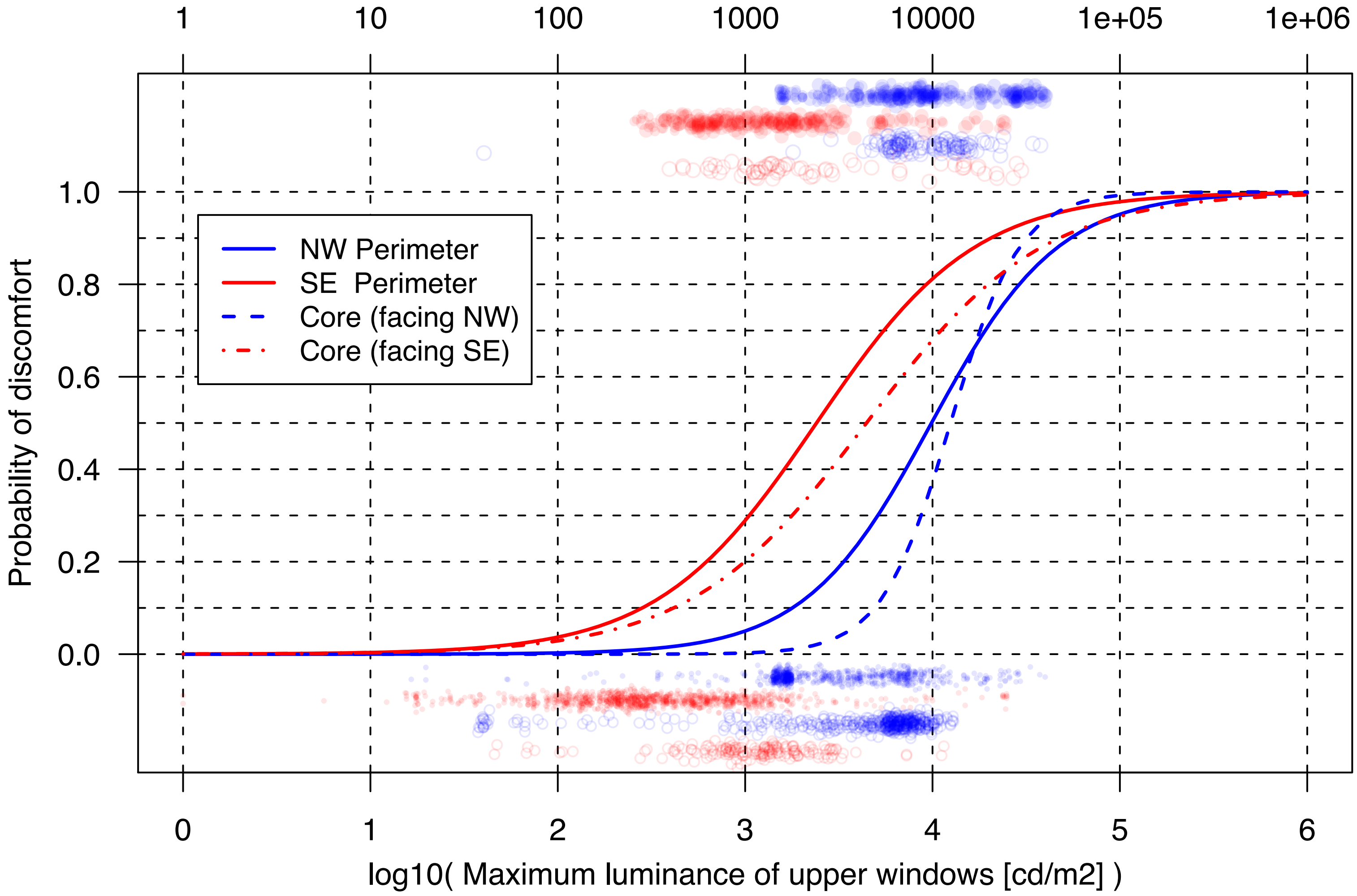
N = 10 (672)		[871]		SMV			MV			V	
Variable	Rank	AIC	(B_0)	(B_1)	%-cor.	(B_0)	(B_1)	%-cor.	(B_0)	(B_1)	%-cor.
R_{CPUmax}	1	552	-3.32	0.14	73%	-4.22	0.08	76%	-8.02	0.11	95%
$L_{maxUpWin}$	2	599	-20.84	5.78	72%	-22.15	5.41	75%	-37.15	8.70	94%
$L_{maxLwWin}$	3	636	-7.56	2.58	70%	-7.98	1.96	71%	-15.72	3.68	92%
R_{CPU}	6	662	-2.49	0.24	68%	-3.43	0.13	73%	-5.63	0.15	93%
L_{upWin}	8	673	-15.50	4.79	68%	-15.70	4.13	72%	-18.34	4.39	92%
L_{lwWin}	11*	708	-3.74	1.82	66%	-4.34	1.13	70%	-7.52	1.66	92%



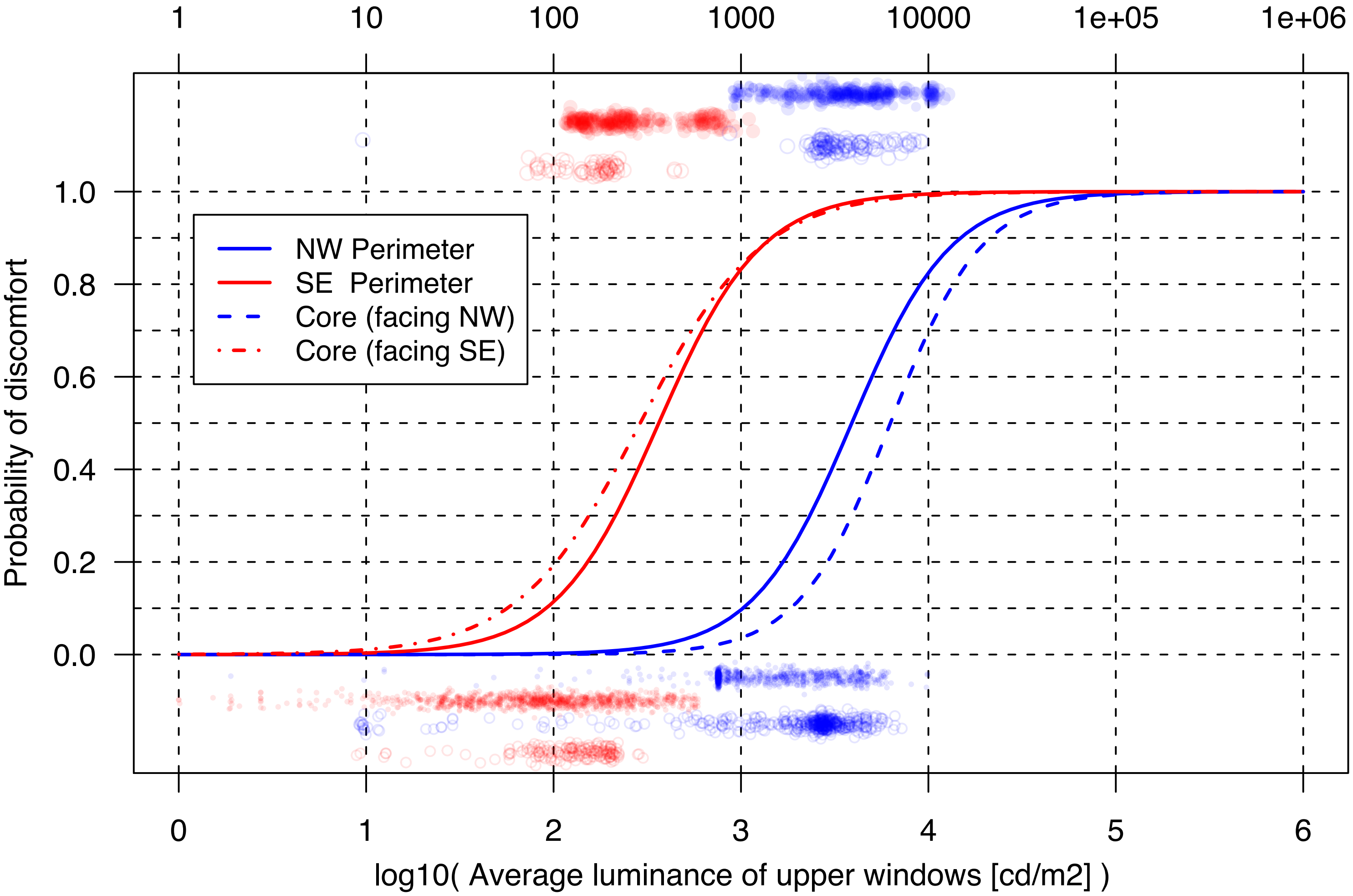
Core zones (SE-facing) (Oct. 4 - 15) and (Dec. 6 - 17)

N = 4 (245)		[341]		SMV			MV			V	
Variable	Rank	AIC	(B_0)	(B_1)	%-cor.	(B_0)	(B_1)	%-cor.	(B_0)	(B_1)	%-cor.
$L_{maxUpWin}$	1	298	-7.83	2.49	57%	-7.79	2.14	66%	-19.78	4.91	94%
R_{CPUmax}	2	300	-1.05	0.12	57%	-1.62	0.05	67%	-4.49	0.07	94%
$L_{maxLwWin}$	3	318	-5.63	1.79	54%	-7.36	2.01	64%	-10.45	2.40	88%
L_{upWin}	4	318	-6.89	3.22	54%	-7.63	3.10	63%	-15.42	5.81	88%
R_{CPU}	8*	321	-1.59	2.11	54%	-2.41	1.88	63%	-4.58	2.35	88%
L_{lwWin}	12*	328	-5.04	2.32	53%	-5.27	1.98	61%	-5.22	1.21	87%

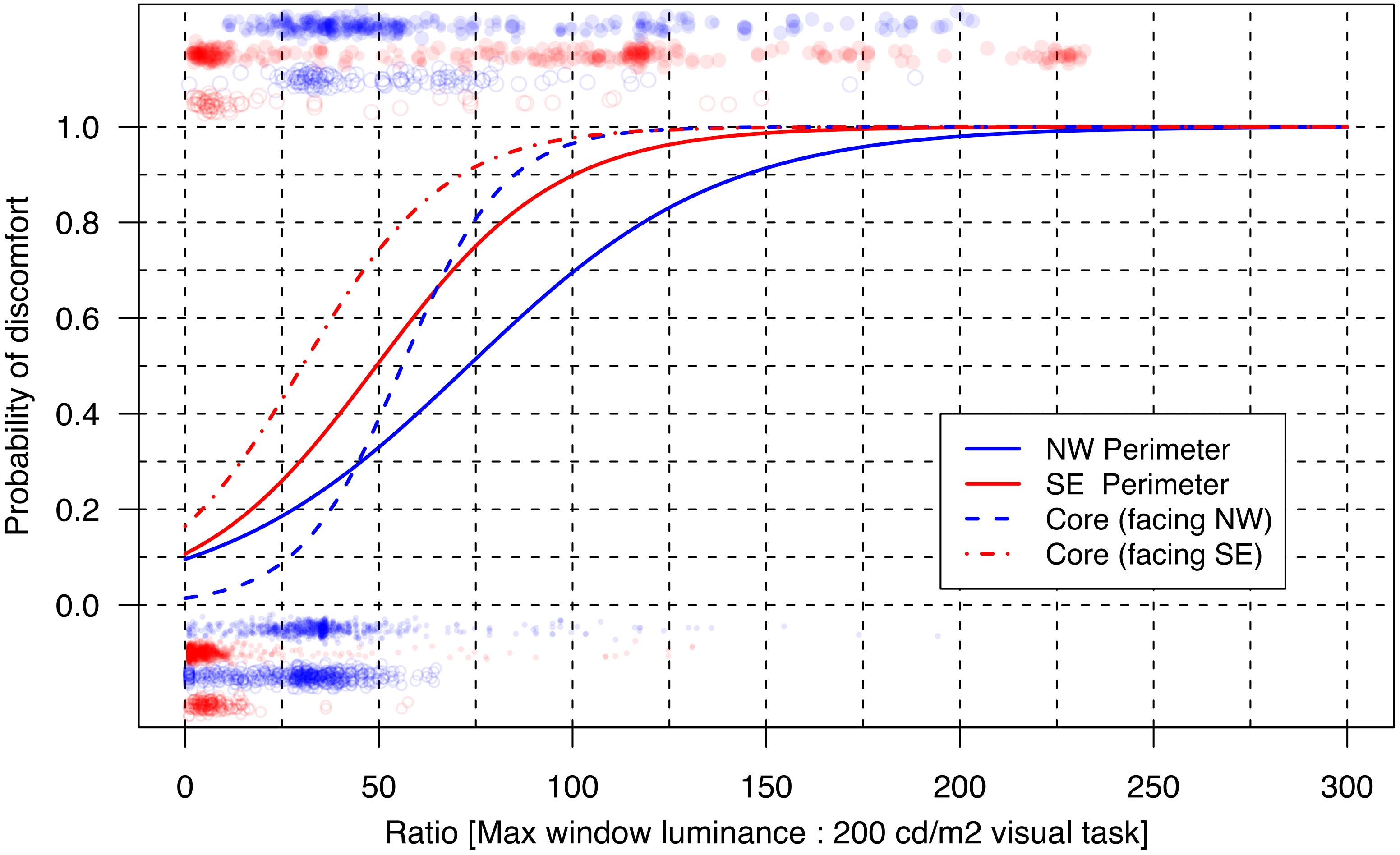
Max luminance of upper windows



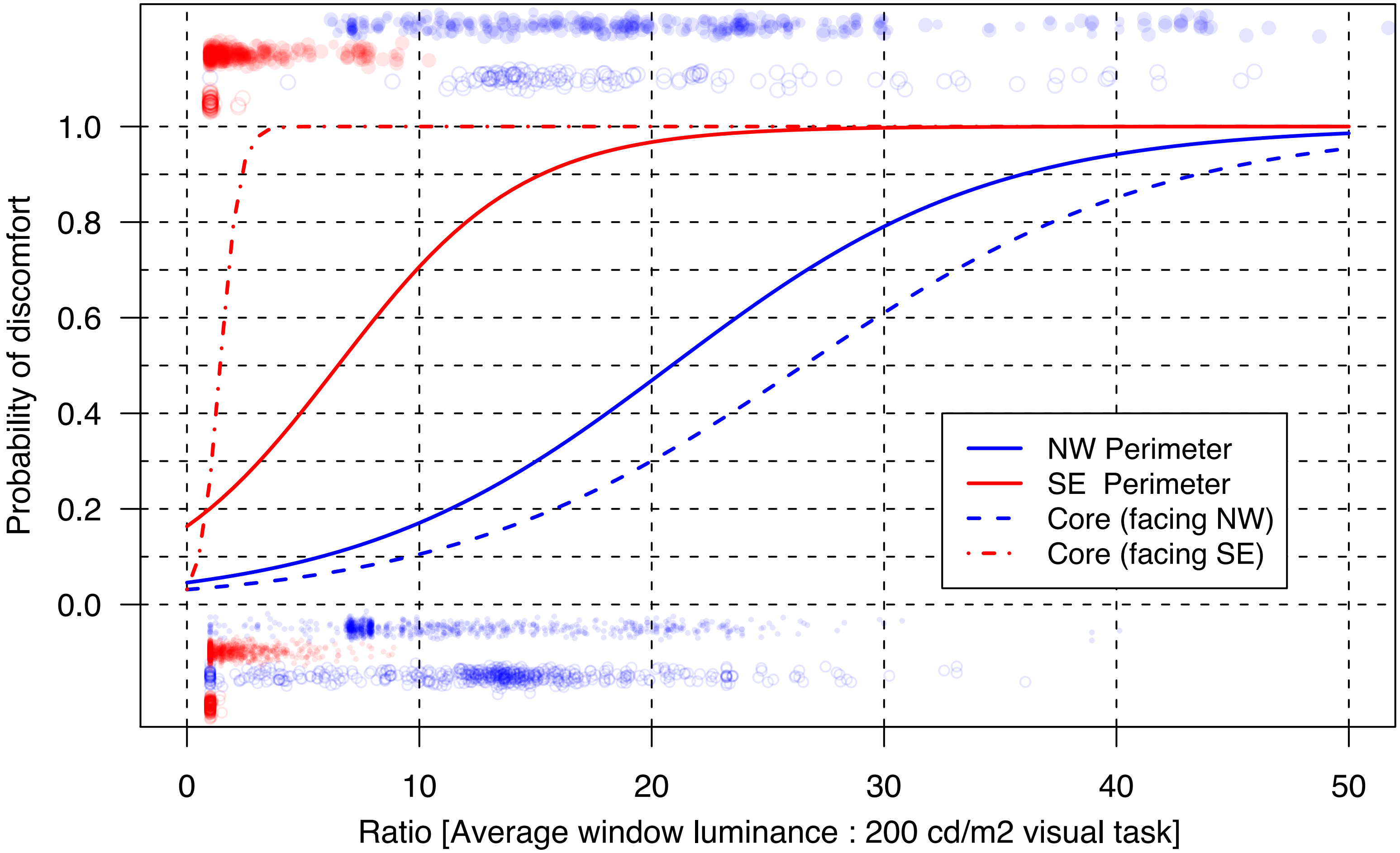
Average luminance of upper windows



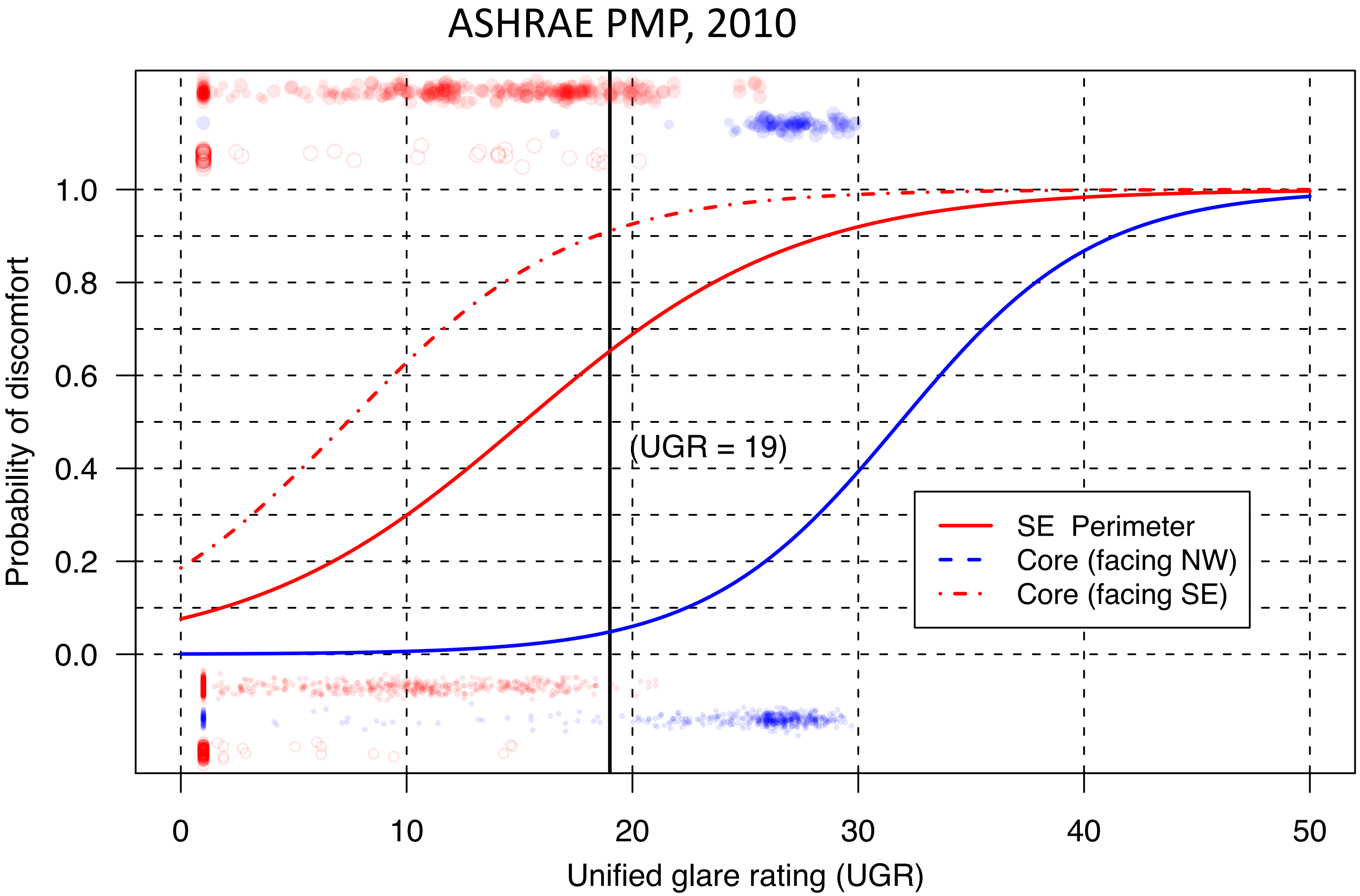
Ratio [max window luminance : 200 cd/m^2 visual task]

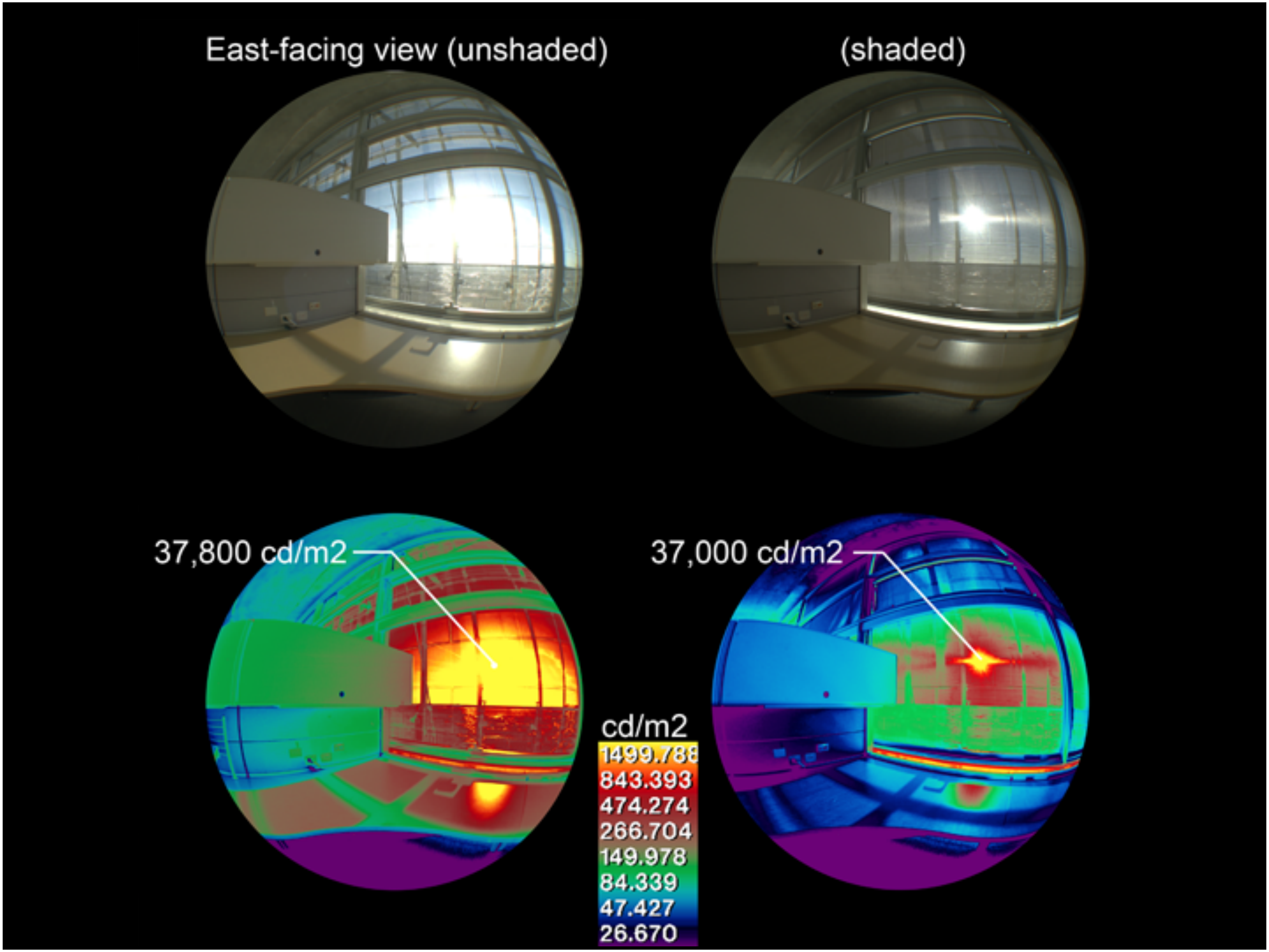


Ratio [avg. window luminance : 200 cd/m^2 visual task]

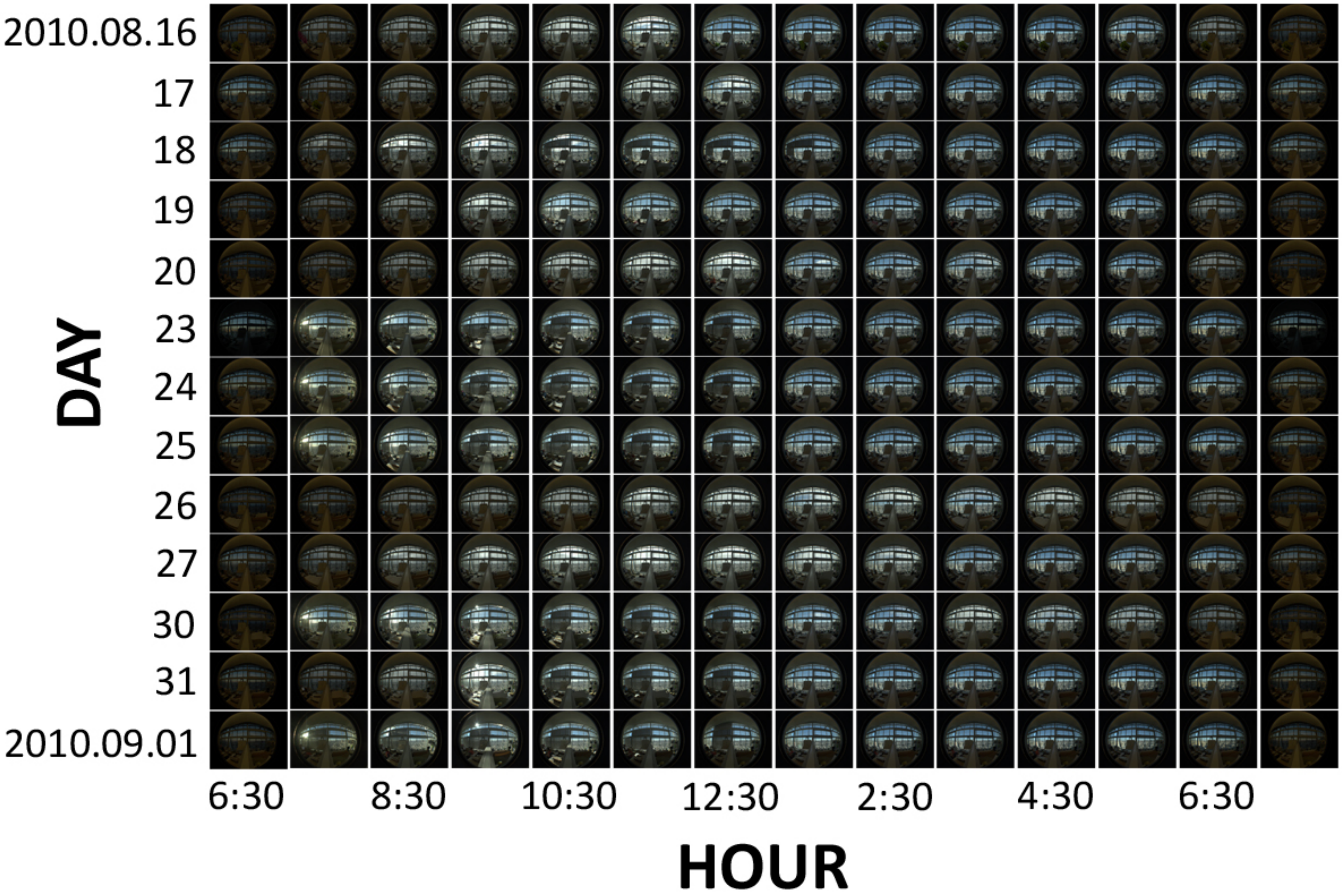


Unified Glare Rating (UGR)

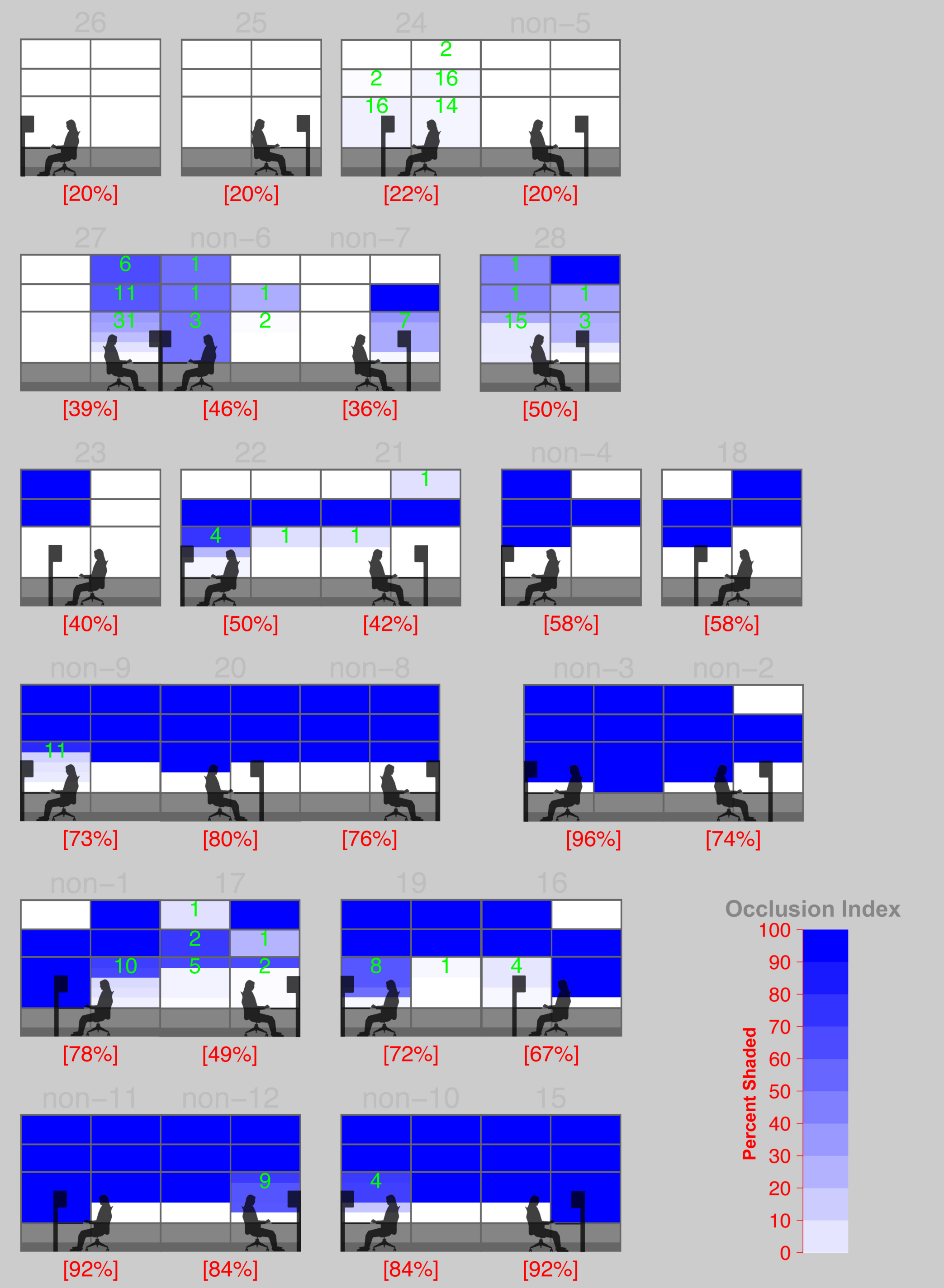



East-facing view (unshaded)
(shaded)
37,800 cd/m2
37,000 cd/m2
cd/m2
1499.788
843.393
474.274
266.704
149.978
84.339
47.427
26.670

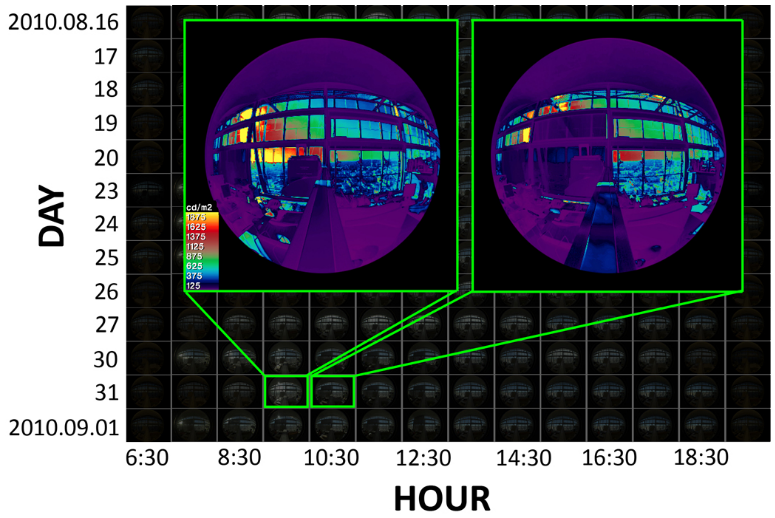
Other applications . . .


2010.08.16
17
18
19
20
23
24
25
26
27
30
31
2010.09.01
DAY
6:30
8:30
10:30
12:30
2:30
4:30
6:30
HOUR

Summary of time-lapse Observation of the SE façade Aug. 3 – Sept. 3



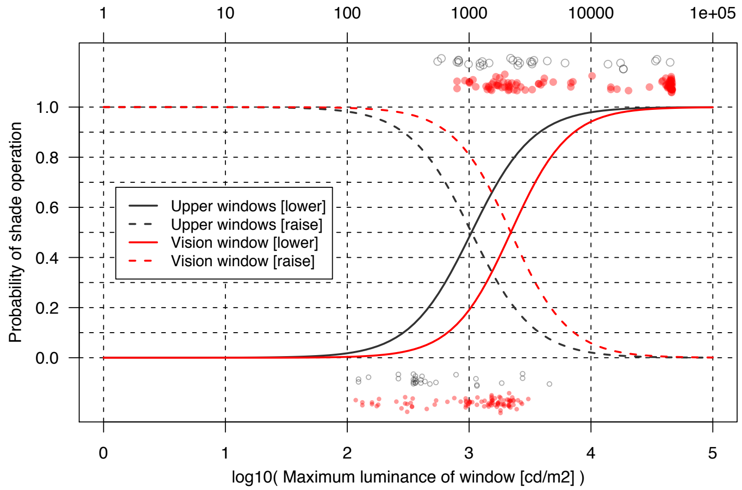
Shade control behavioral models

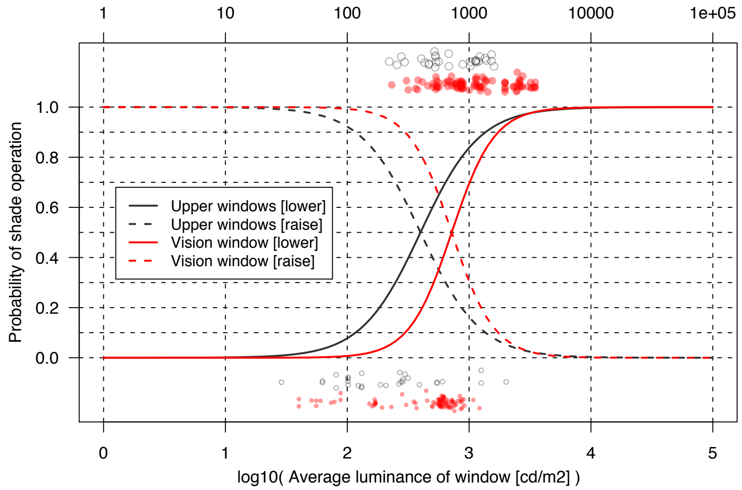


N = 186 operations among 14 participants

N = 14 (186 observations)

Variable	Units	Rank	AIC [260]	(B_0)	(B_1)	%-cor.
$L_{maxLwWin}$	cd/m^2	1	158	-14.14	4.23	71%
R_{CPU}	NA	4	179	-3.20	5.75	69%
L_{lwWin}	cd/m^2	6	186	-16.44	5.75	67%
$Illum_{inVert}$	lux	3	178	-14.19	5.09	69%
$Irrad_{inVert}$	W/m^2	5	182	-3.17	3.60	69%
UGR	NA	8	200	-1.62	0.17	64%
$Illum_{dlt}$	lux	13	236	-4.10	1.48	56%





Feedback on existing indicators of successful daylighting performance . . .

U.S. GREEN BUILDING COUNCIL
LEED PLATINUM
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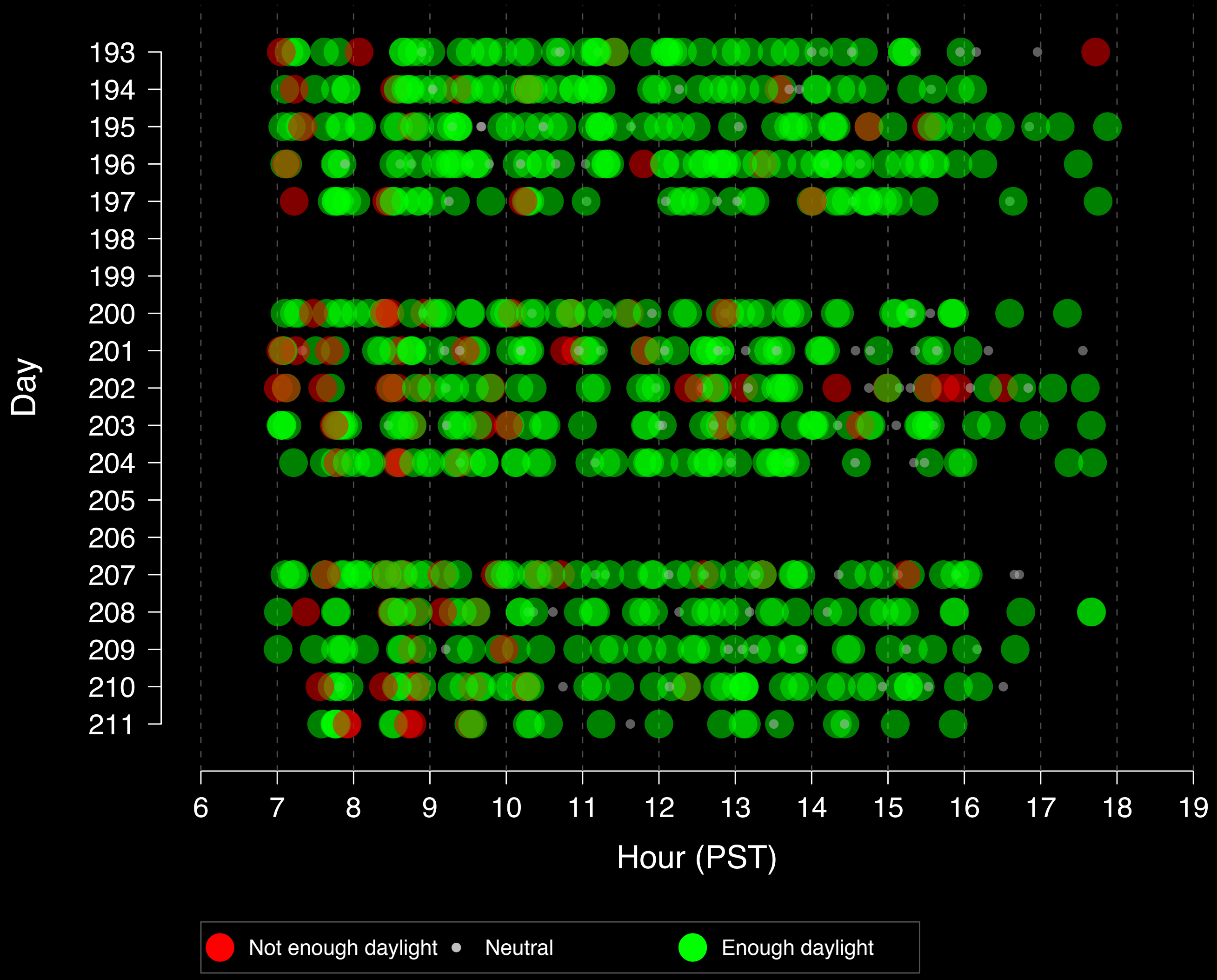
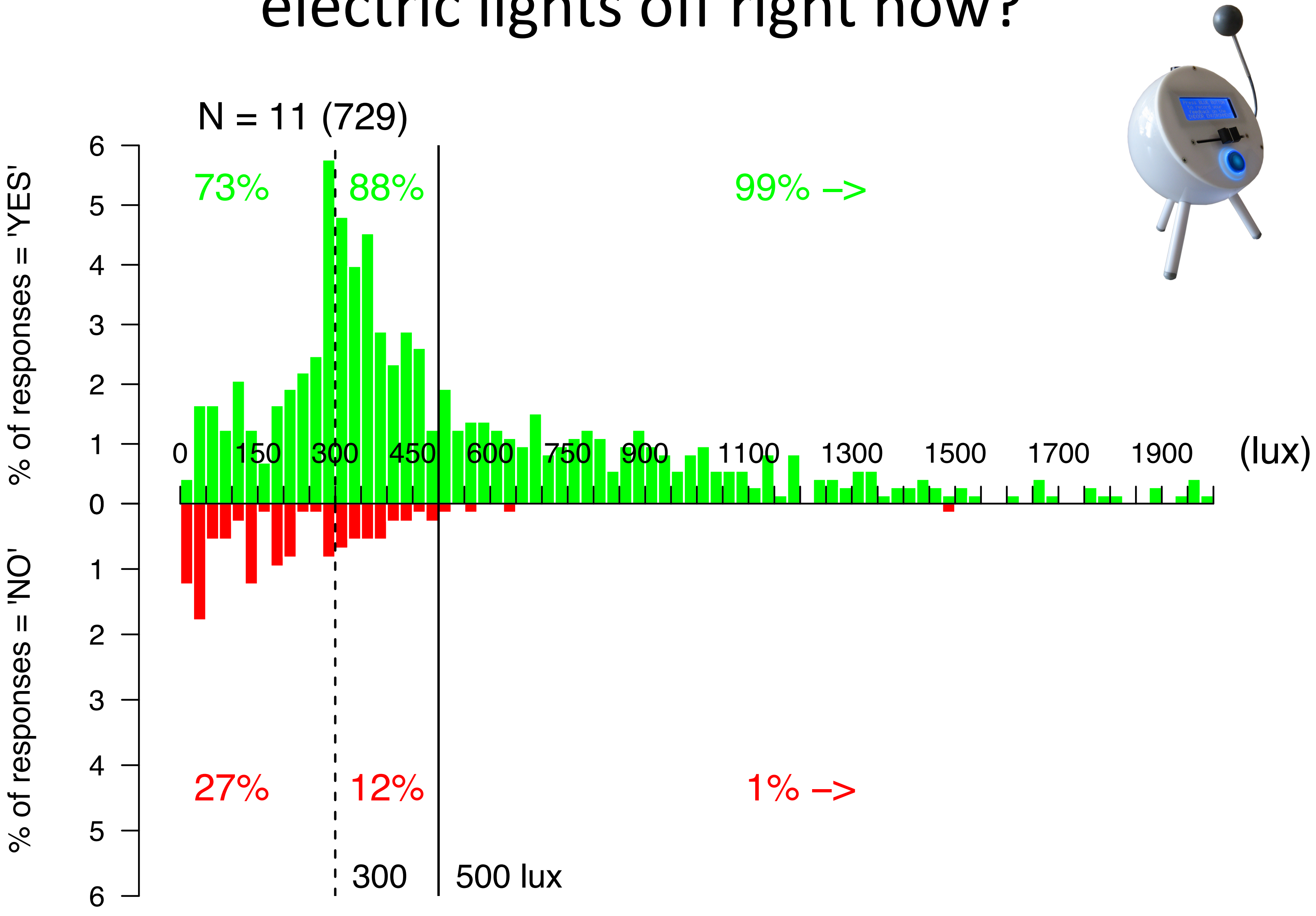
Demonstrate through computer simulations that at least 75% of all regularly occupied spaces achieve a minimum DA value of 50%, based on an annual illuminance of ***300*** *lux when blinds are operated to block direct sunlight.*

500 lux a common threshold setpoint for photocontrolled electrical lighting

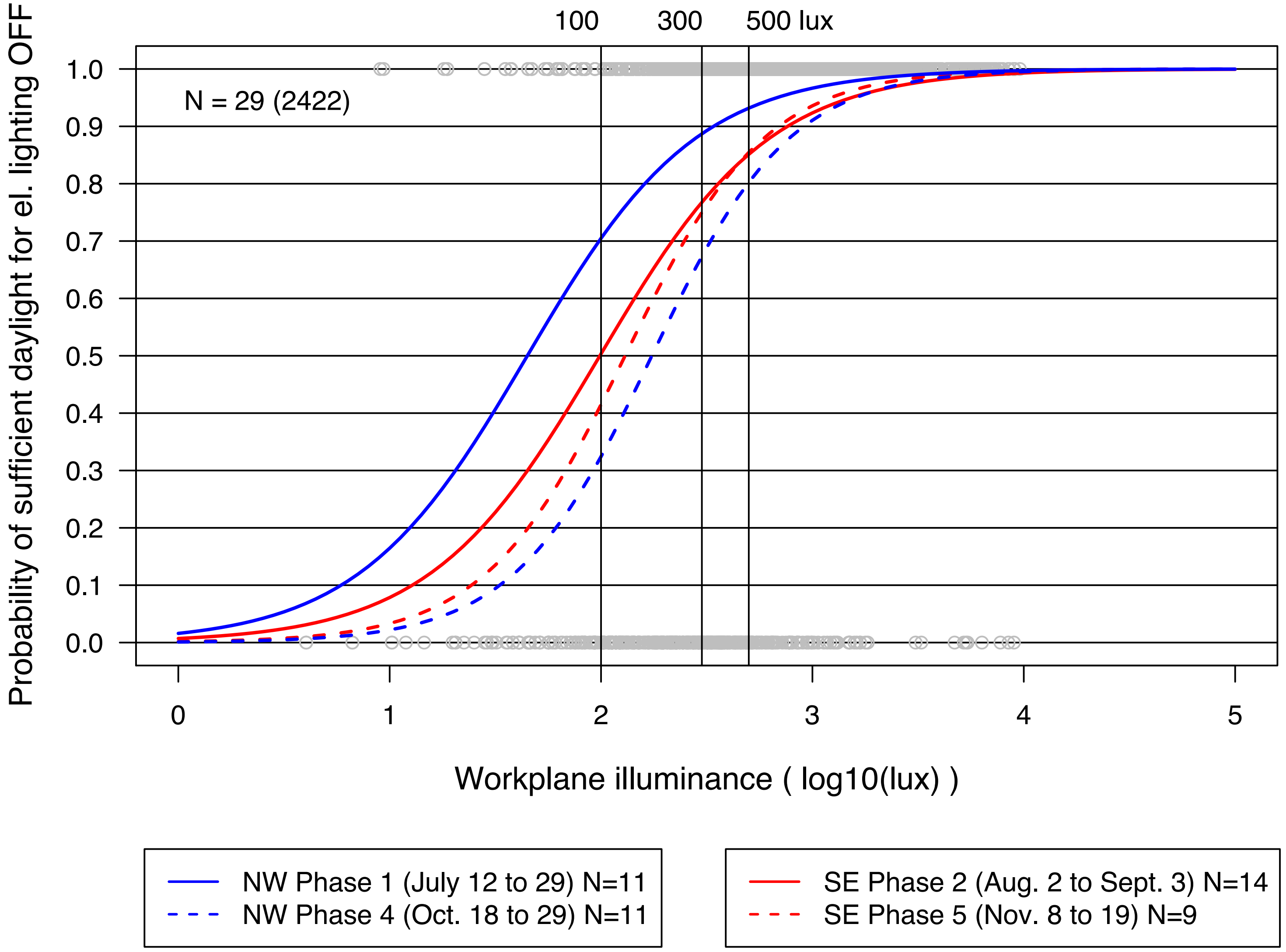
(q7) “Could you work comfortably with the electric lights off right now?”



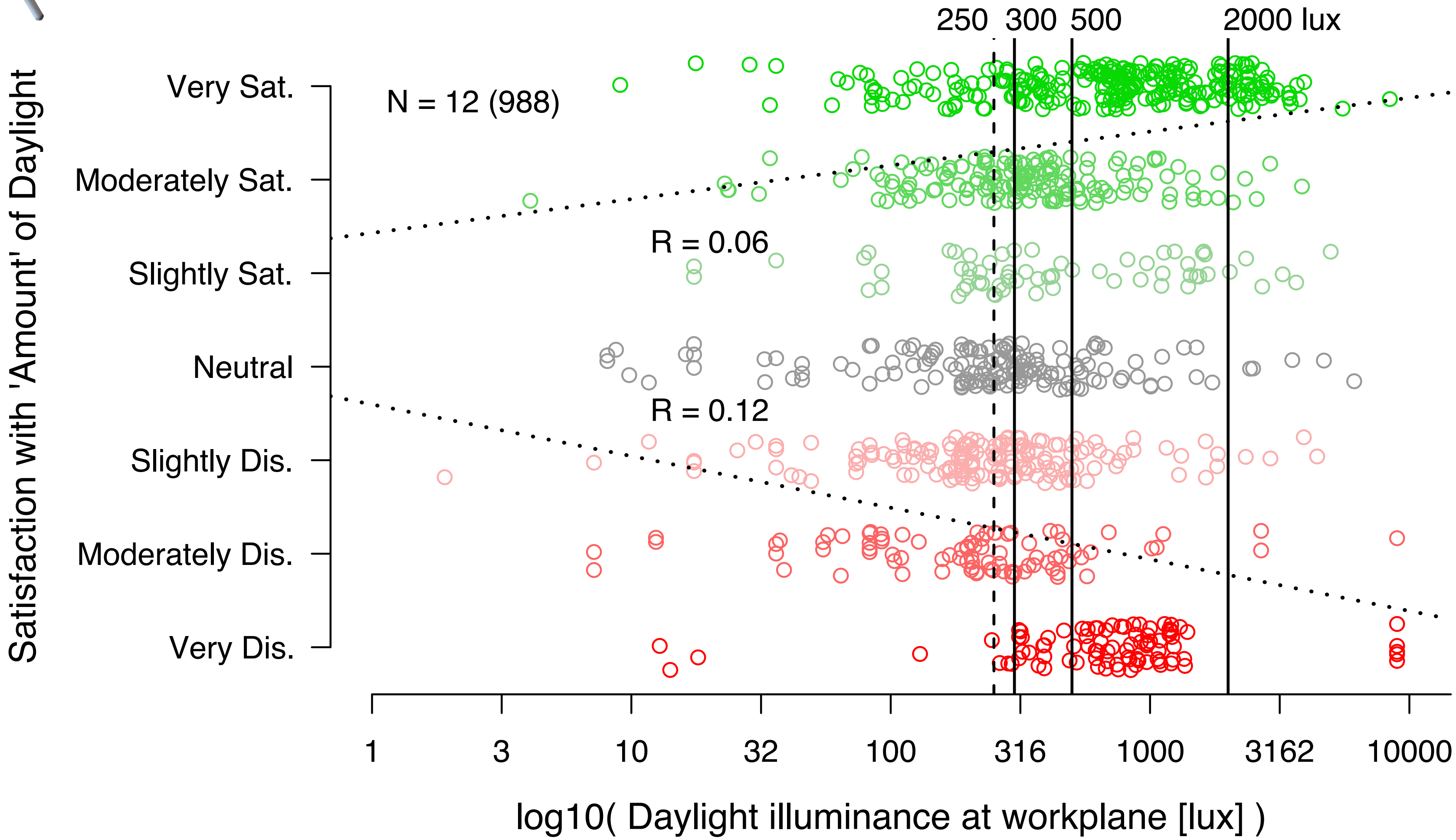
(q7) "Could you work comfortably with the electric lights off right now?"



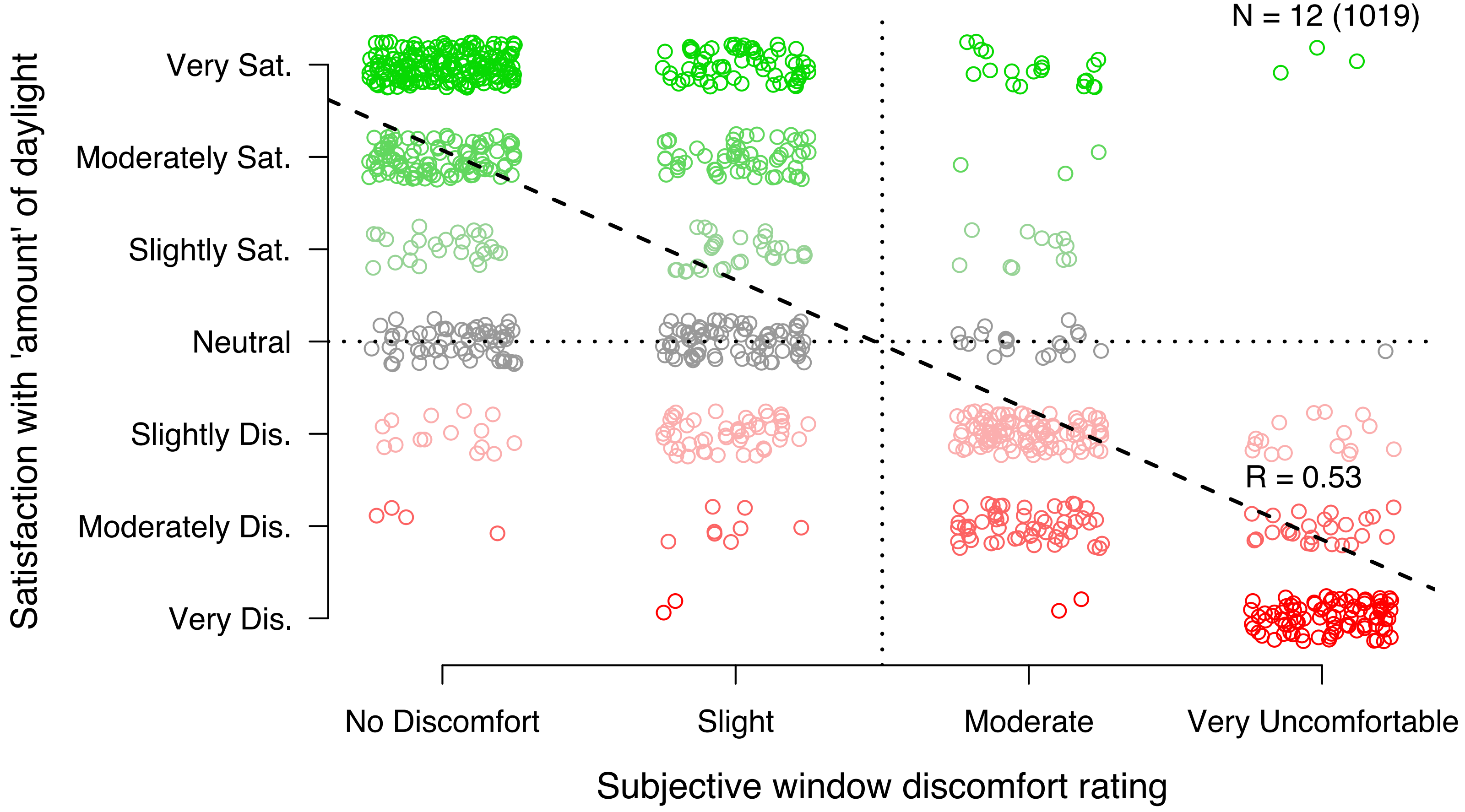
Probability electric lights can be off. . .



(q3) "How satisfied are you with the amount of daylight in your workspace right now?"



Visual discomfort trumps illuminance



Distribution of subjective responses to (Q3) by subjective window discomfort rating (Q4) for Phase 1 and Phase 4 combined.

Conclusions

- Need to examine existing assumptions for daylight sufficiency, shade control behavior and visual discomfort in the field.
  - Horizontal illuminance found to be a poor predictor of occupant satisfaction with amount of daylight and visual discomfort

- Absolute measures from HDR images found to be better predictors for discomfort than more complex glare metrics and more "basic" indicators (e.g. vertical/horiz. illuminance).

THANK YOU

Kyle Konis
CBE

Lawrence Berkeley National Laboratory

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Center for the Built Environment (CBE)
http://www.cbe.berkeley.edu/

kskonis@gmail.com