A Comparison Of Manual Blind Control Algorithms Using Two Methods Of Daylight Harvesting Simulation

Research Project for the degree of Master of Science in Mechanical Engineering

Christopher J. Dyke, M.S. 2013

12th Intl Radiance Workshop - 2013.08.13

INTEGRATED DESIGN LAB
University of Idaho

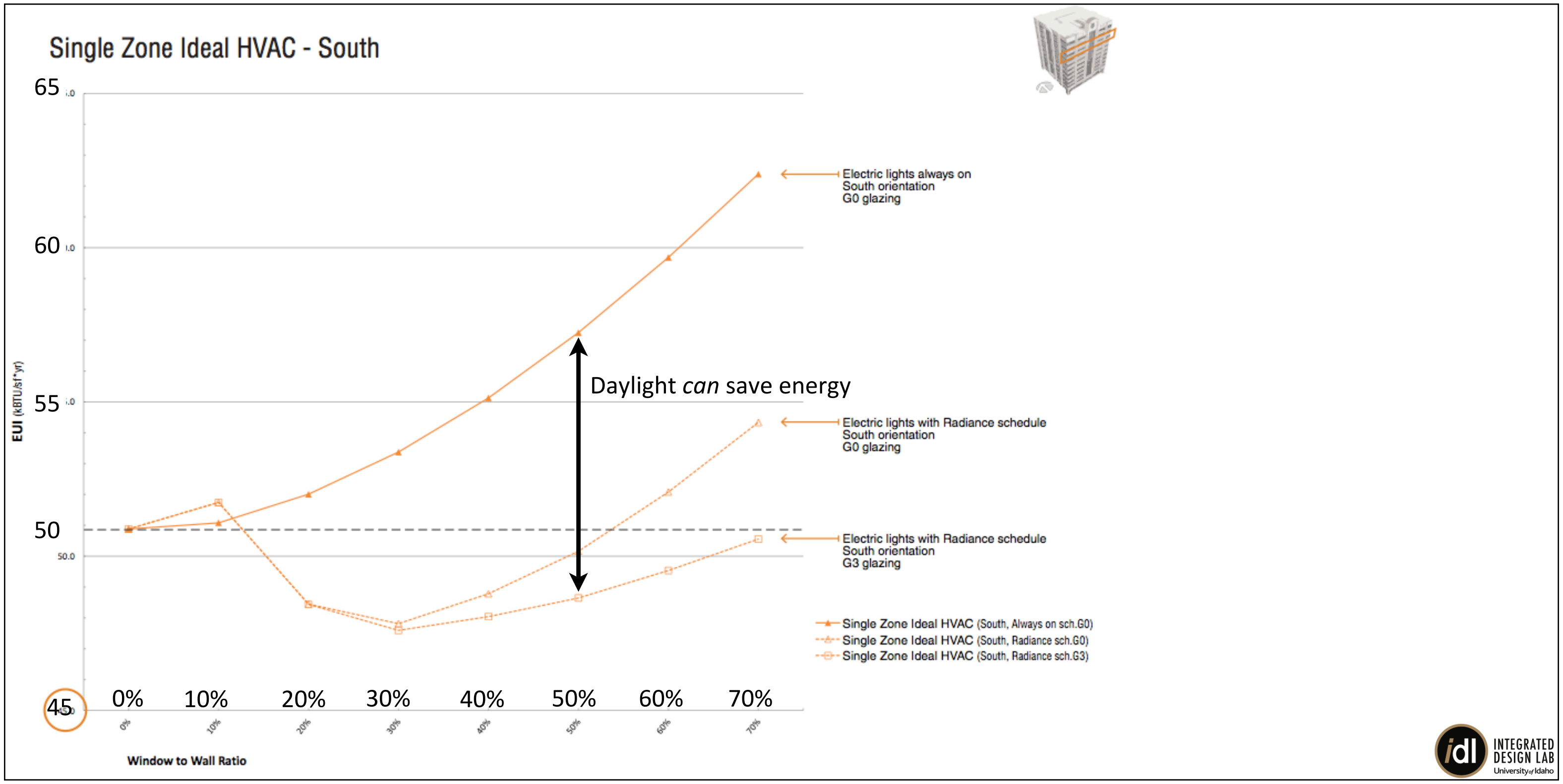
Committee: Staciak, Van Den Wymelenberg, Djunaedy, Budwig
Presenters: Van Den Wymelenberg & Djunaedy

Outline

- Background
- Goals
- Lit. Review
- Methods
- Results
- Future Work

Goals

1. Identify, model, and compare typical manual blind control schemes
2. Compare results from using the EnergyPlus simplified daylight sensing lighting controls to the daylighting engine Radiance
3. Develop framework of fully integrated simulation tool to incorporate Radiance with EnergyPlus for annual whole building energy simulations



Daylight ‘CAN’ save energy

Illuminating
ENGINEERING SOCIETY

IES **LM-83-12**

Approved Method: **IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)**

IES LM-83-12

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IES Spatial Daylight Autonomy (sDA)
and
Annual Sunlight Exposure (ASE)

Publication of this report
has been approved by IES.
Suggestions for revisions
should be directed to IES.

Prepared by:
The Daylight Metrics Committee

IES LM-83-12

Prepared by the IES Daylight Metrics Committee

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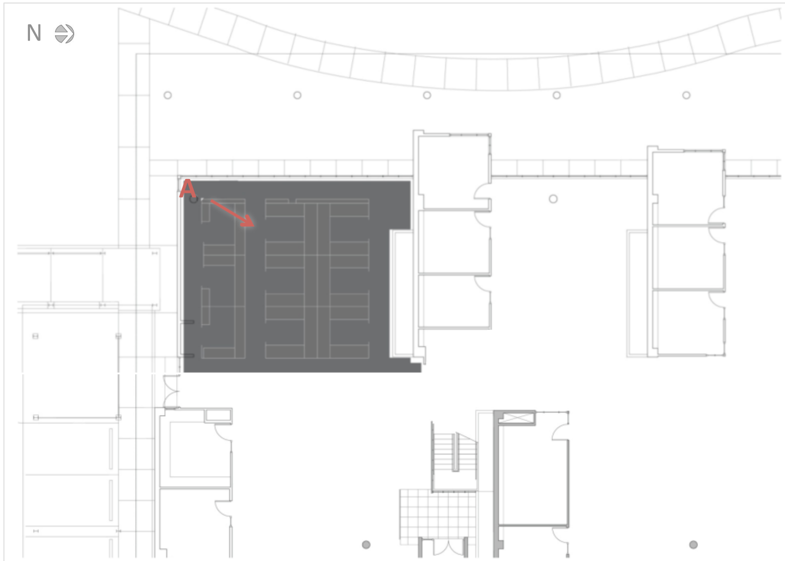
Lighting Measurement – 83 (LM-83)

Spatial Daylight Autonomy (sDA)

B

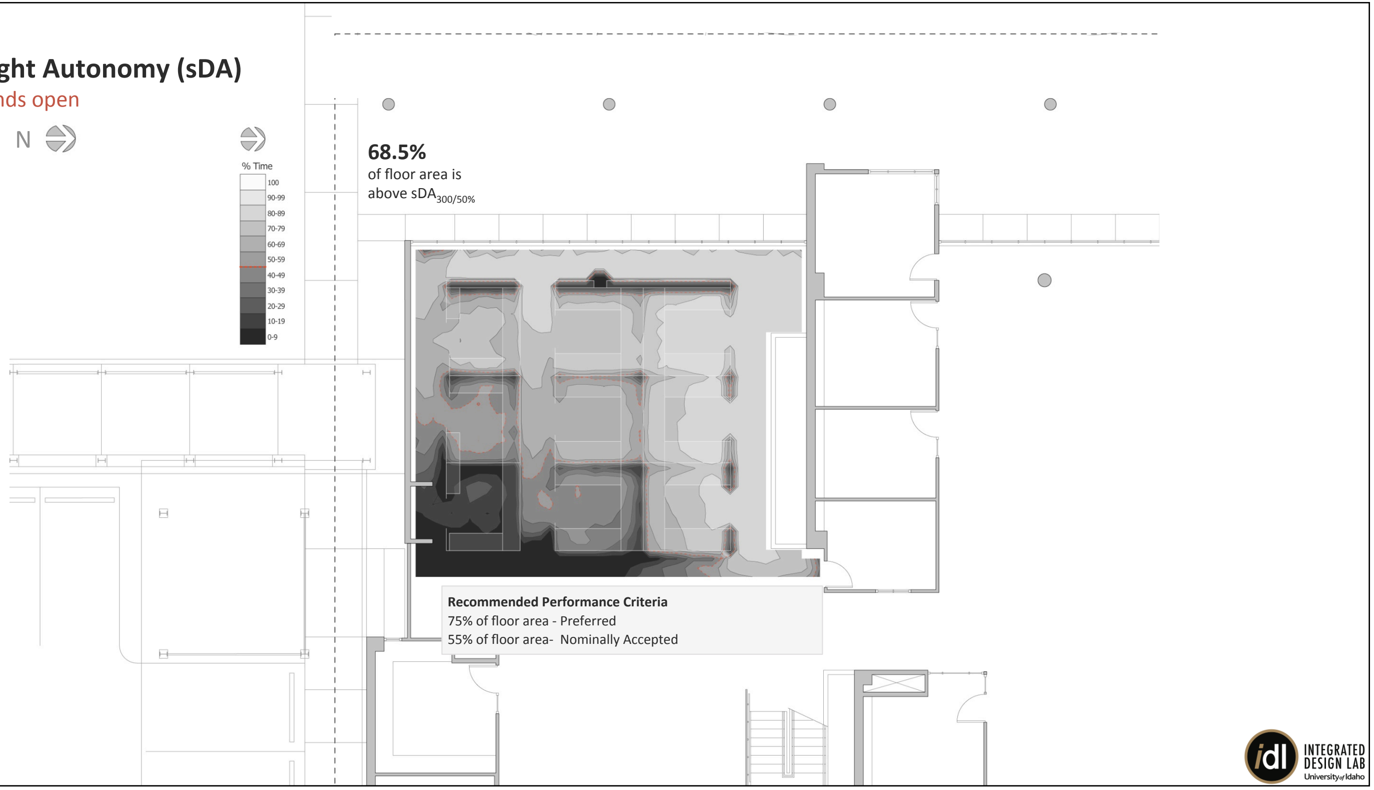


Blind use matters for Daylight!

Spatial Daylight Autonomy (sDA)

50%/300lux, blinds open

sea.06.wk2



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Spatial Daylight Autonomy

50%/300lux, blinds closed

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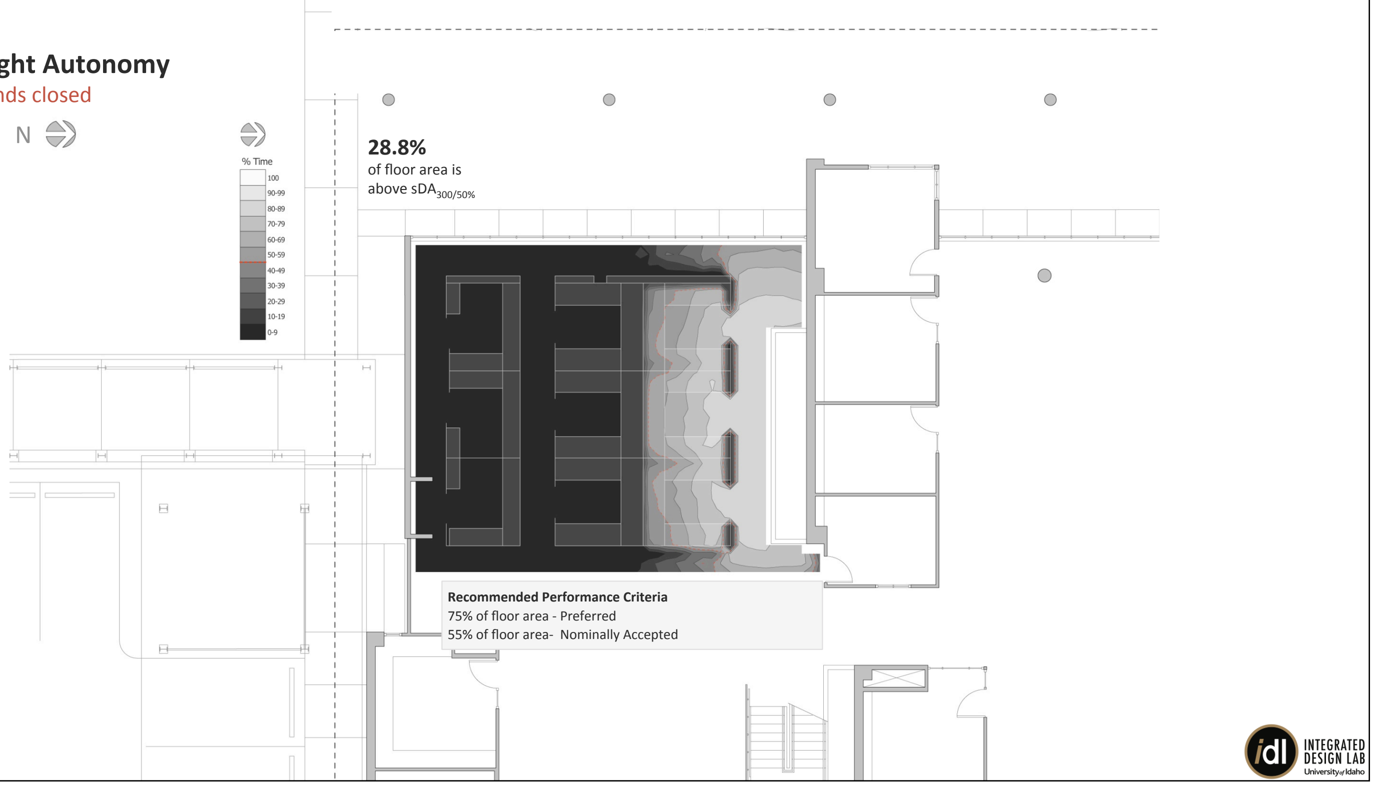

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Spatial Daylight Autonomy

50%/300lux, blinds auto - 2% trigger

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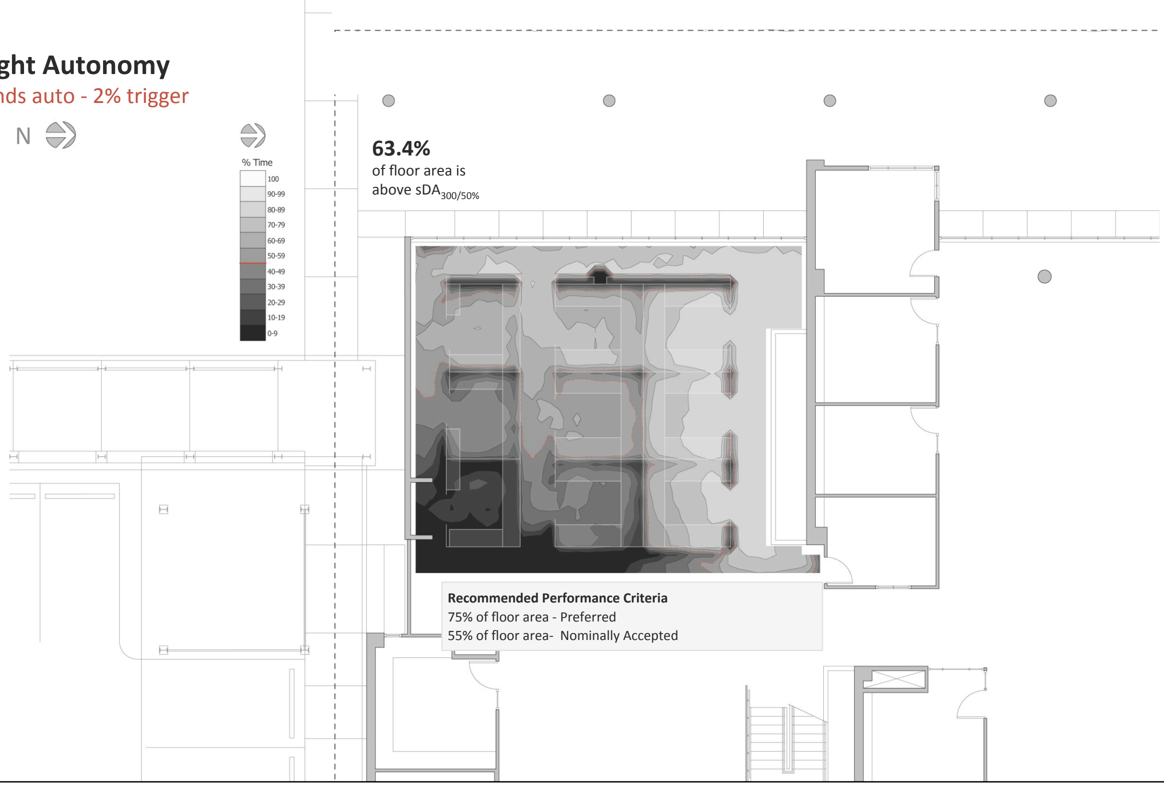

63.4%
of floor area is
above $sDA_{300/50\%}$

Recommended Performance Criteria
75% of floor area - Preferred
55% of floor area- Nominally Accepted

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Reference	Bldg. Location & Count	Duration of Study	Occlusion	Rate of Change	Measured Illuminance	Measured Luminance	Measured Irradiance	POE
(Rubin et al. 1978)	Six in MD, USA	Three months	x	x			x	
(Rea 1984)	One in Ottawa, Canada	Two days	x					
(Inoue et al. 1988)	Four in Tokyo	39 days	x	x	x		x	x
(Pigg et al. 1996)	One in WI, USA	Eleven months	x	x				x
(Lindsay & Littlefair 1992)	Five in England	Nineteen months	x	x			x	
(Foster & Oreszczyn 2001)	Three in England	Nineteen days	x				x	
(Reinhart & Voss 2003)	One in Germany	Nine months	x	x	x		x	
(Inkarojrit 2005)	Two in CA, USA	Nine days	x	x	x	x	x	x
(Mahdavi 2009)	Five in Austria	33 months	x	x	x		x	
(Sutter et al. 2006)	One in France	Nine months	x	x	x	x	x	x
(Nicol et al. 2006)	26 in Europe	Three years	x	x	x		x	x
(Kim et al. 2009)	One in Korea	Four days	x	x	x	x	x	
(Sze 2009)	Nine in New York	Three months	x		x			x
(Haldi & Robinson 2009)	One in Switezerland	Six years	x	x	x		x	
(Day et al. 2012)	One in WA, USA	Two weeks	x	x				x

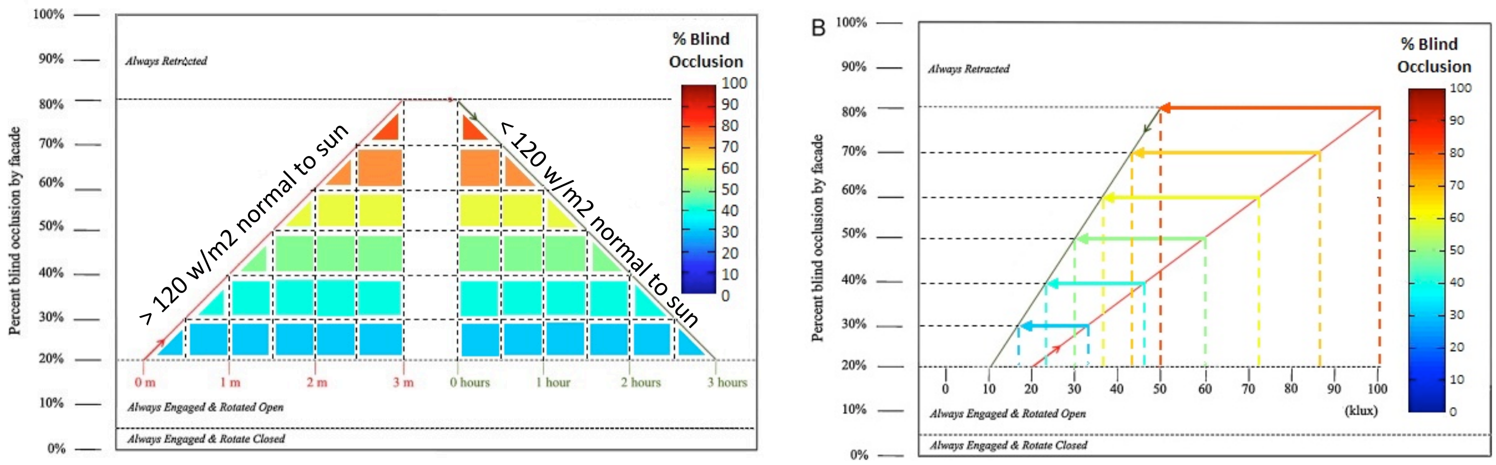
Blind use data available for about 20 buildings

- 50 w/m2 (Inoue and Reinhart)
    - Inoue measured vertically at window interior, Reinhart measured global horizontal
    - Lightswitch 2002 uses 50 w/m2 'hitting workplane' as blind trigger
- Data from just the 'moving blinds' were applied to all the blinds in simulation

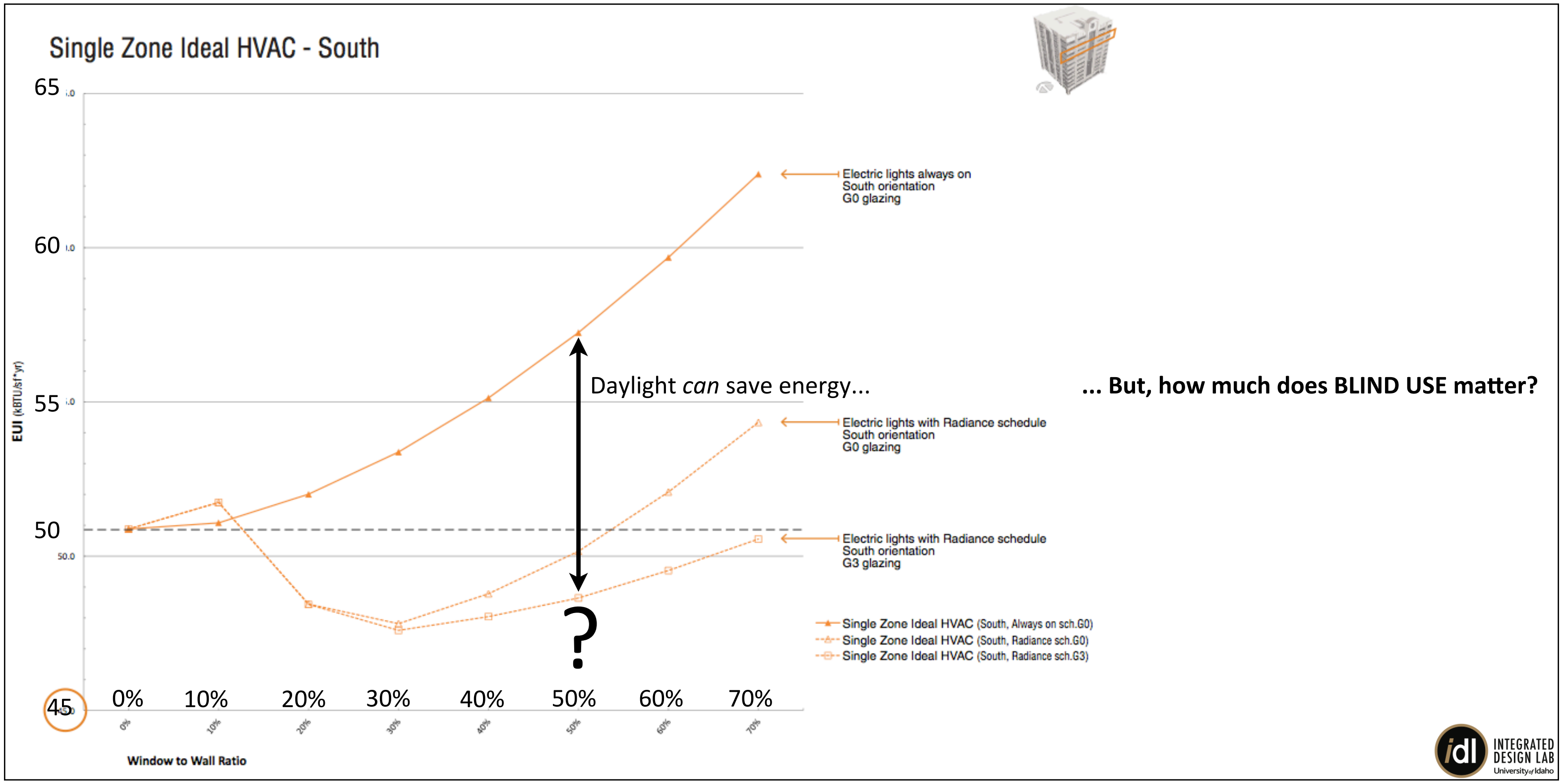
Blind use data available from more than 50 buildings

- No agreed upon manual blind use model
- VDW proposed two models from field study data

With LM-83, DMC agreed that as improved research became available, the blind control trigger could become less or more stringent.



Van Den Wymelenberg, K., 2012, **Patterns of occupant interaction with window blinds: a literature review** , Energy & Buildings.



Daylight 'CAN' save energy

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Literature Review

Five models were researched and compared:

- Always engaged
- Always retracted
- Daylight Glare Index$_{20}$ (Correia da Silva et al. 2012)
- Blindswitch-2012A (Van Den Wymelenberg 2012)
- Blindswitch-2012B (Van Den Wymelenberg 2012)
- Why not sDA 2% (1000 lux - 0 bounce) blind trigger?

  ....No available script yet.

Control Algorithm	Description
Always Engaged	Window blinds are always engaged
Always Retracted	Window blinds are always retracted
Daylight Glare Index$_{20}$	Window blinds are engaged if DGI is above 20
Blindswitch-2012 A	Increased occlusion with increased penetration depth and exterior irradiance > 120 W/m^2
Blindswitch-2012 B	Increased occlusion following increased vertical exterior illuminance on façade

Explain “engaged” and “retracted”

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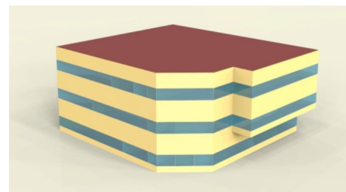
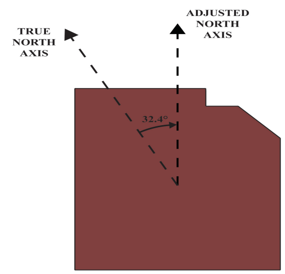
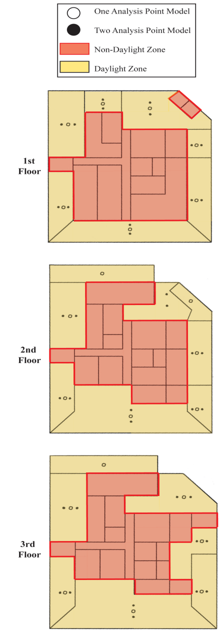
Case Study Building

Capital Gateway Plaza Building II

- Three-story medium sized office bldg. located in downtown Boise, ID
- Standard double pane ribbon windows
- 32,000 ft² w/ EUI of 63.4 kBtu/ ft²-yr
- Built up heat pump system
  - Boiler (89% efficient)
  - Cooling tower
  - DOAS
- No blinds modeled







U value- 2.67 W/m2K (.47)
SHGC of .5
VLT of .5

Oriented 32.4 degrees counterclockwise - Using definitive directions allows for improved generalization of occlusion based on specific façade orientation

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Simulations were performed using the three following programs:

1. EnergyPlus
2. Radiance
3. Building Controls Virtual Test Bed (BCVTB)

EnergyPlus

1. Whole building energy simulation modeling program
2. Model the performance of buildings which allows users to optimize building design before construction
3. Standalone simulation program that reads input data files and writes outputs as text files

Radiance

1. Backwards ray-tracing daylight analysis tool
2. Extremely accurate means of lighting analysis
3. Standalone simulation program

BCVTB

1. Single platform designed to connect multiple programs
2. Coordinates real time data exchange

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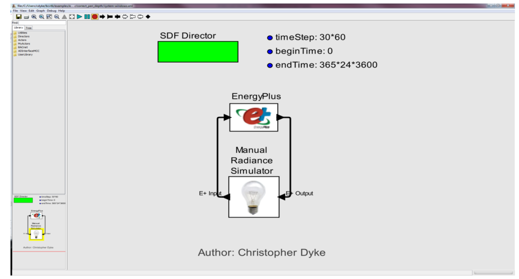
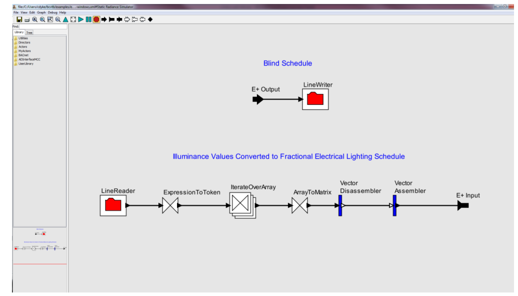
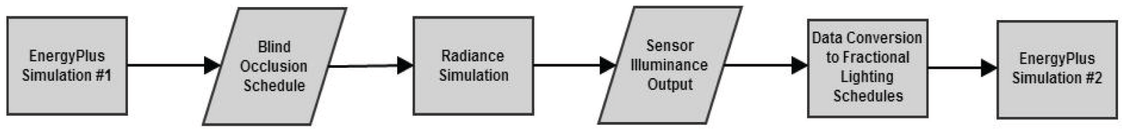
Co-Simulation

Building Controls Virtual Test Bed

- Single platform that supports co-simulation of multiple programs by coordinating real time data exchange
  - Can be used with BACnet controllers
  - Works on all platforms
  - Can connect programs such as: Matlab, Simulink, Radiance, EnergyPlus, Dymola







Flow chart shows manual interaction between EnergyPlus and Radiance

- Includes three separate simulations
- Includes two instances of data conversion externally

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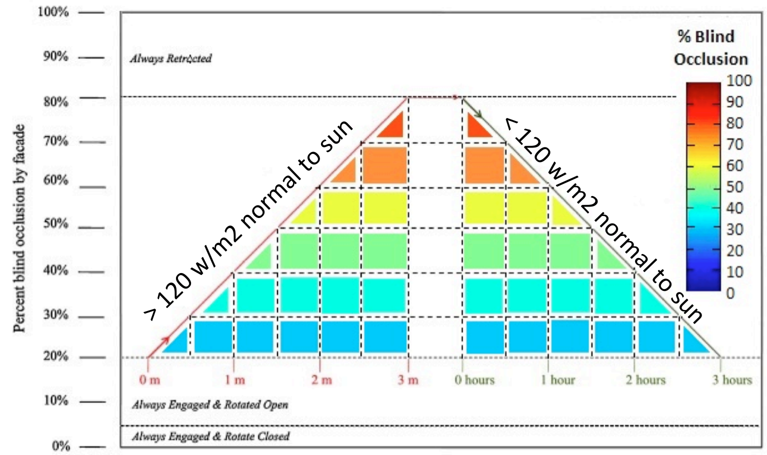
Blindswitch-2012A

- Blinds retract if:
  - Direct solar falls below 120 W/m² on the window
  - OR penetration depth falls below respective trigger for specified duration
- Control algorithm assumes that of all blinds per façade and floor:
  - 20% are retracted
  - 15% are engaged and rotated open (slat angle of 0° below the horizontal)
  - 5% are engaged and rotated closed (slat angle of 75° below the horizontal)



5% always engaged and rotated closed; 15% always engaged and rotated open; 60% Operable; 20% always retracted

$$\%\ Occlusion\ (Blindswitch\ Models) = \underbrace{\left(0.05 * \frac{5}{5} * \frac{3}{3}\right)}_{\text{5\% always engaged and rotated closed}} + \underbrace{\left(0.15 * \frac{5}{5} * \frac{1}{3}\right)}_{\text{15\% always engaged and rotated open}} + \underbrace{\left(0.1 * \frac{5}{5} * \frac{3}{3} * \#\ engaged\ blinds\right)}_{\text{60\% Operable}} + \underbrace{\left(0.20 * \frac{0}{5} * \frac{1}{3}\right)}_{\text{20\% always retracted}}$$

*Minimum % = 10%
*Maximum % = 70%

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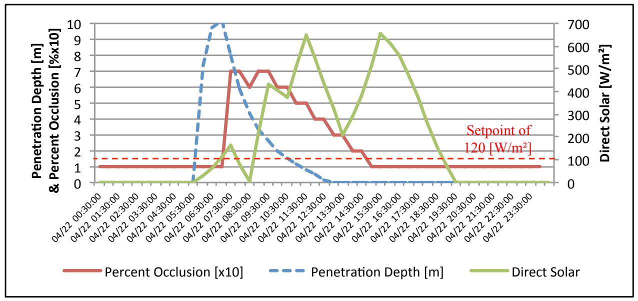
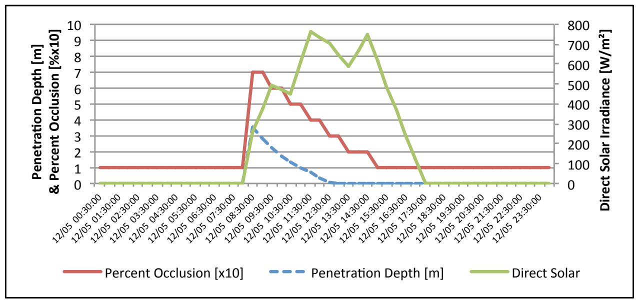
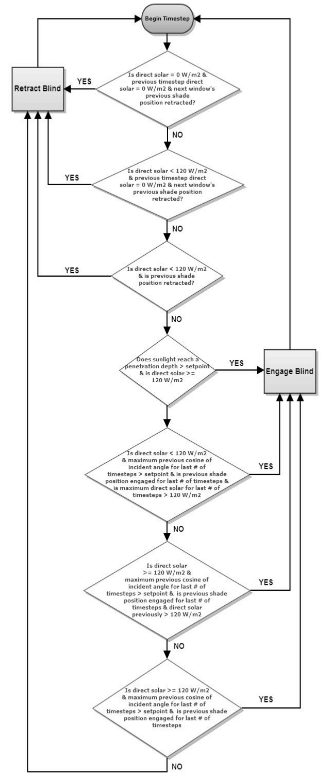
Blindswitch-2012A: Validation

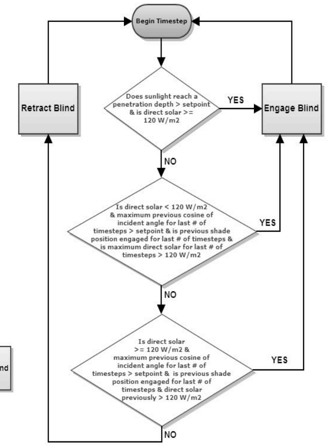
April 22nd East façade 1st floor



December 5th East façade 1st floor







April 22nd shows variability of algorithm

December 5th shows typical blind operation of Blindswitch A model

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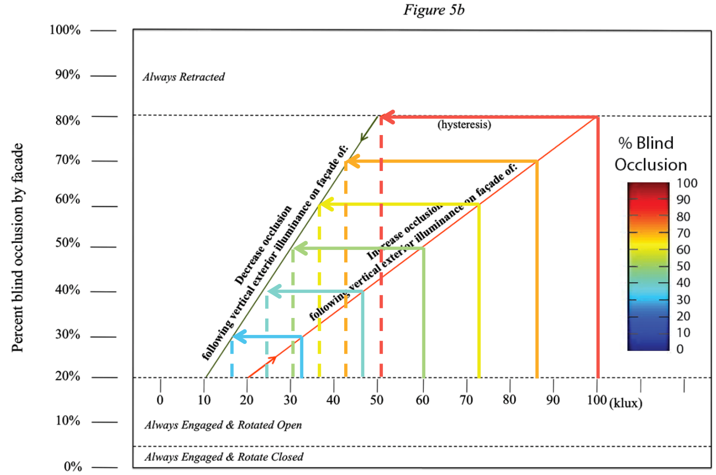
Blindswitch-2012B

- Blinds engage if vertical exterior illuminance per façade and floor is above a certain trigger limit
  - Hourly vertical exterior illuminance values were gathered using Radiance results.
  - Analysis points located 1’ outside the middle of each floor and façade at the work plane level (2.5’ above floor)
- Hysteresis effect controls retraction points for each window
  - 10 windows per façade and floor

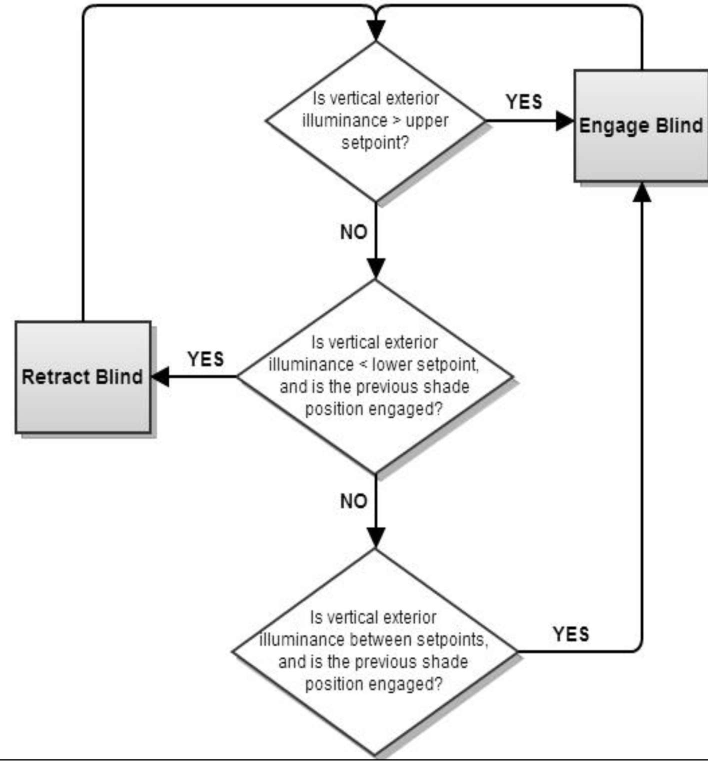
Figure 5b



Hysteresis affect (or delay)

* Same randomization of windows used in Blindswitch A

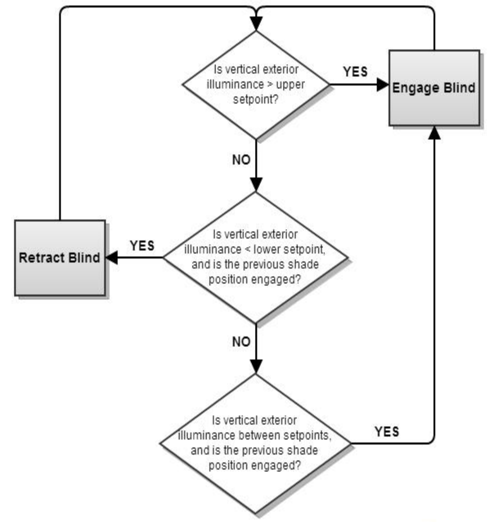
Blindswitch-2012B



Outline

EnergyPlus Control Code

- Energy Management System (EMS)
  - Advanced EnergyPlus feature that allows users to create customizable computer programs
  - Provides high-level control of basic control schemes
  - Simplified programming language
- Stacked decision scheme
  - Uses conditional programming
  - Trend variables are used to collect and analyze stored variables for a specific duration of time



*ERL programming language

*trend variables used extensively in advanced models

*Blindswitch A & B only models to used EMS system

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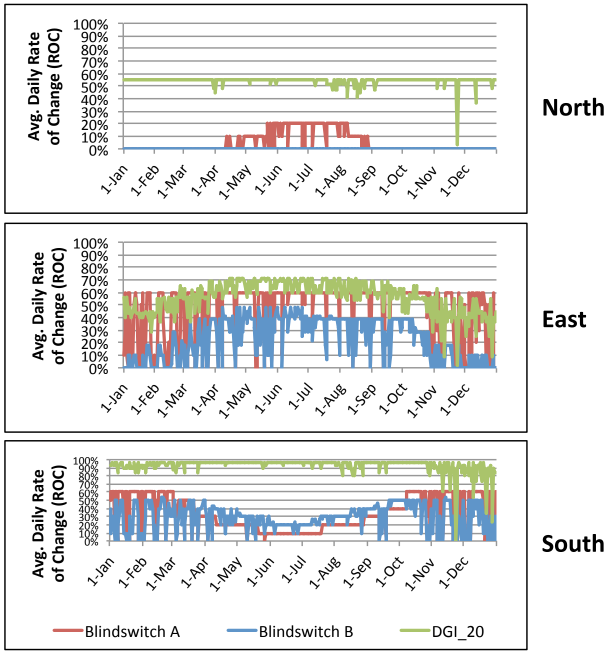
Results

Control algorithms were compared and contrasted using the following metrics:

1. Blind rate of change
   - Defined as the percentage of blinds that move at least once per day per facade

$$ROC = \frac{\sum_{n=1}^{\#\ of\ blinds\ per\ facade} \begin{Bmatrix} 1 & if\ blind\ moves\ at\ least\ once\ per\ day \\ 0 & if\ there\ is\ no\ blind\ movement \end{Bmatrix}}{Total\ \#\ of\ windows\ per\ facade}$$

Annual ROC Values



North (top), East (middle), and South (bottom)

- in all three facades DGI_20 shows the most active response to ROC
- notice the dip in the summer months for Blindswitch A & B, whereas DGI stays consistent across the entire year

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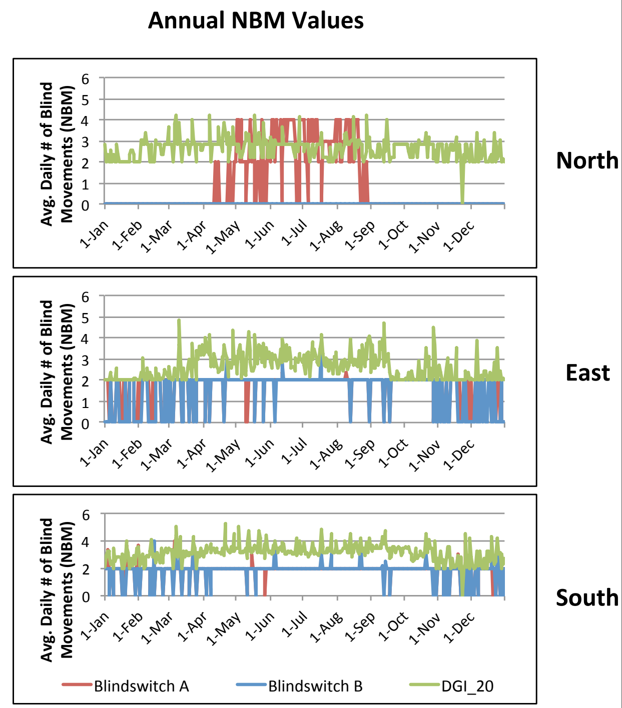
Results

Control algorithms were compared and contrasted using the following metrics:

1. Blind rate of change
2. Number of blind movements
   - Defined as the ratio of the number of blinds that move per day to the total number of blinds per facade

$$NBM = \frac{\sum_{n=1}^{\#\ of\ blinds\ per\ facade}(\#\ of\ blind\ movements\ per\ day)}{Total\ \#\ of\ blinds\ that\ moved\ per\ day}$$



NORTH SOUTH and EAST façade responses seen here for three advanced blind control algorithms

DGI_20 results in highest NBM throughout entire year

- Blindswitch A&B show a consistent value of NBM=2
  - due to blinds engaging early in the day, and retracting in the afternoon

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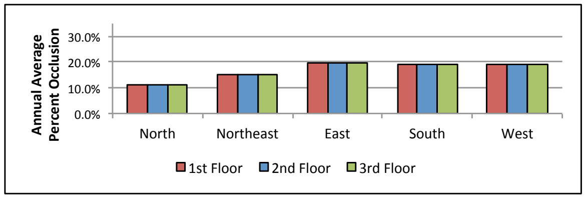
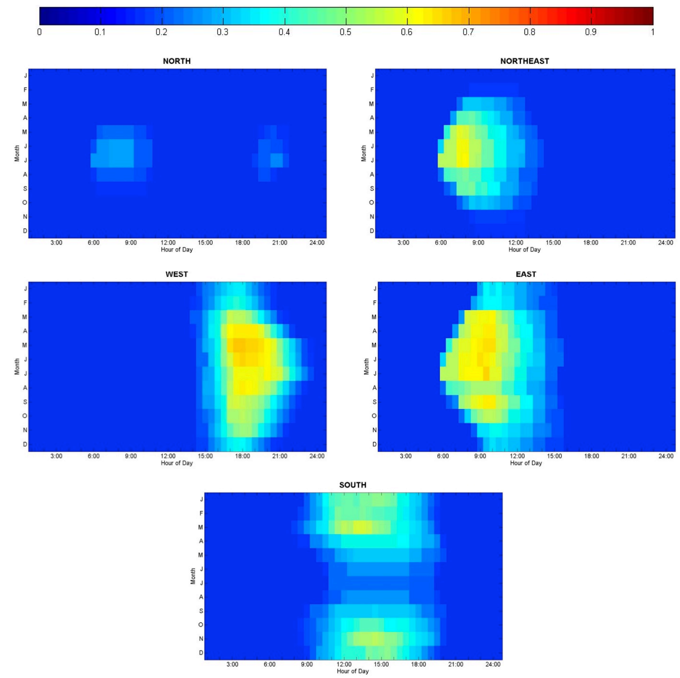
Results

Control algorithms were compared and contrasted using the following metrics:

1. Blind rate of change
2. Number of blind movements
3. Lighting Demand
4. Annual & hourly average percent occlusion



Blindswitch-2012A



- north results in the least occluded façade
- east, south, and west facades show relatively similar annual avg % occlusion values of 20%
- color maps were used to show hourly average percent occlusion for each month of the year
- Blindswitch A shows an interesting response on the north façade where blinds engage and retract in the morning and afternoon hours of summer
- east and west facades show a mimicked response
    - east engages earlier in the day due to sun position, and west engages later in the day
- south results in peak occlusion occurs during winter months as the sun rises and falls later in the day
    * as expected

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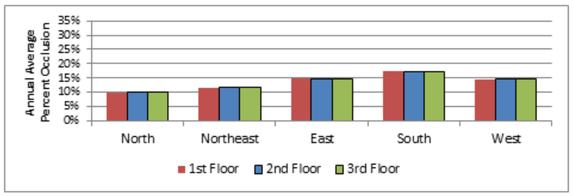
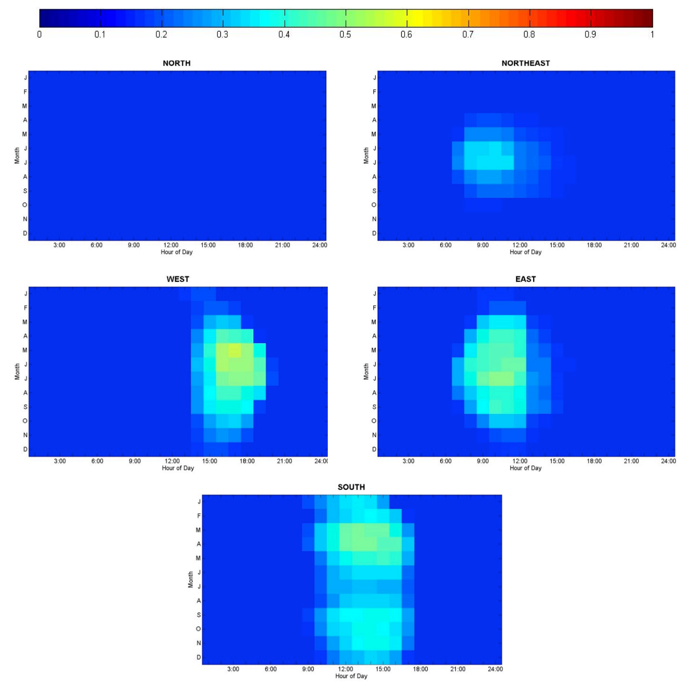


Blindswitch-2012B



-South façade results in the largest annual average percent occlusion of 16.5%

- north façade never results in occlusion (constantly retracted)
    - due to façade never seeing minimum vertical exterior illuminance
- similar response for the east and west façade as with Blindswitch A.
    - smaller scale

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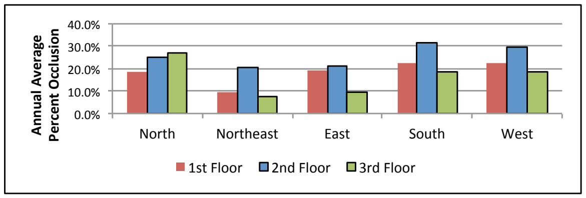
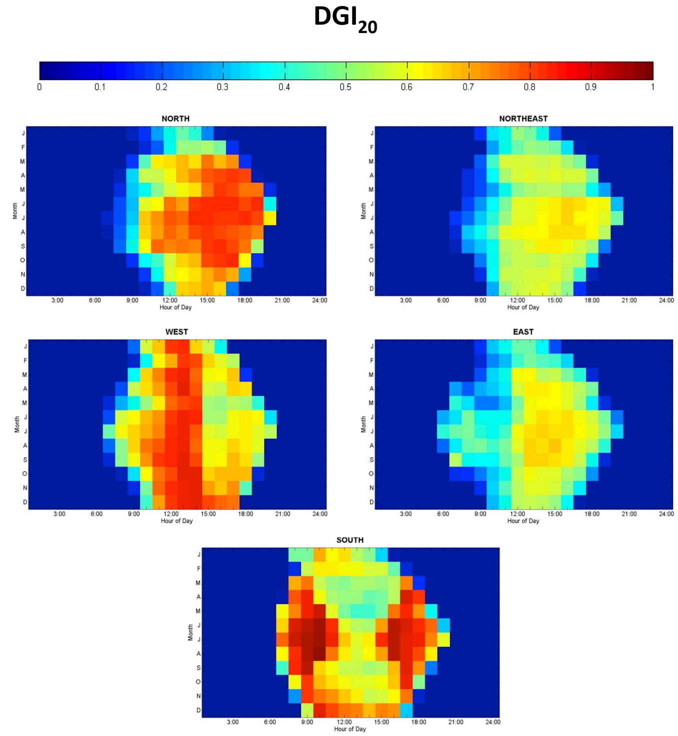
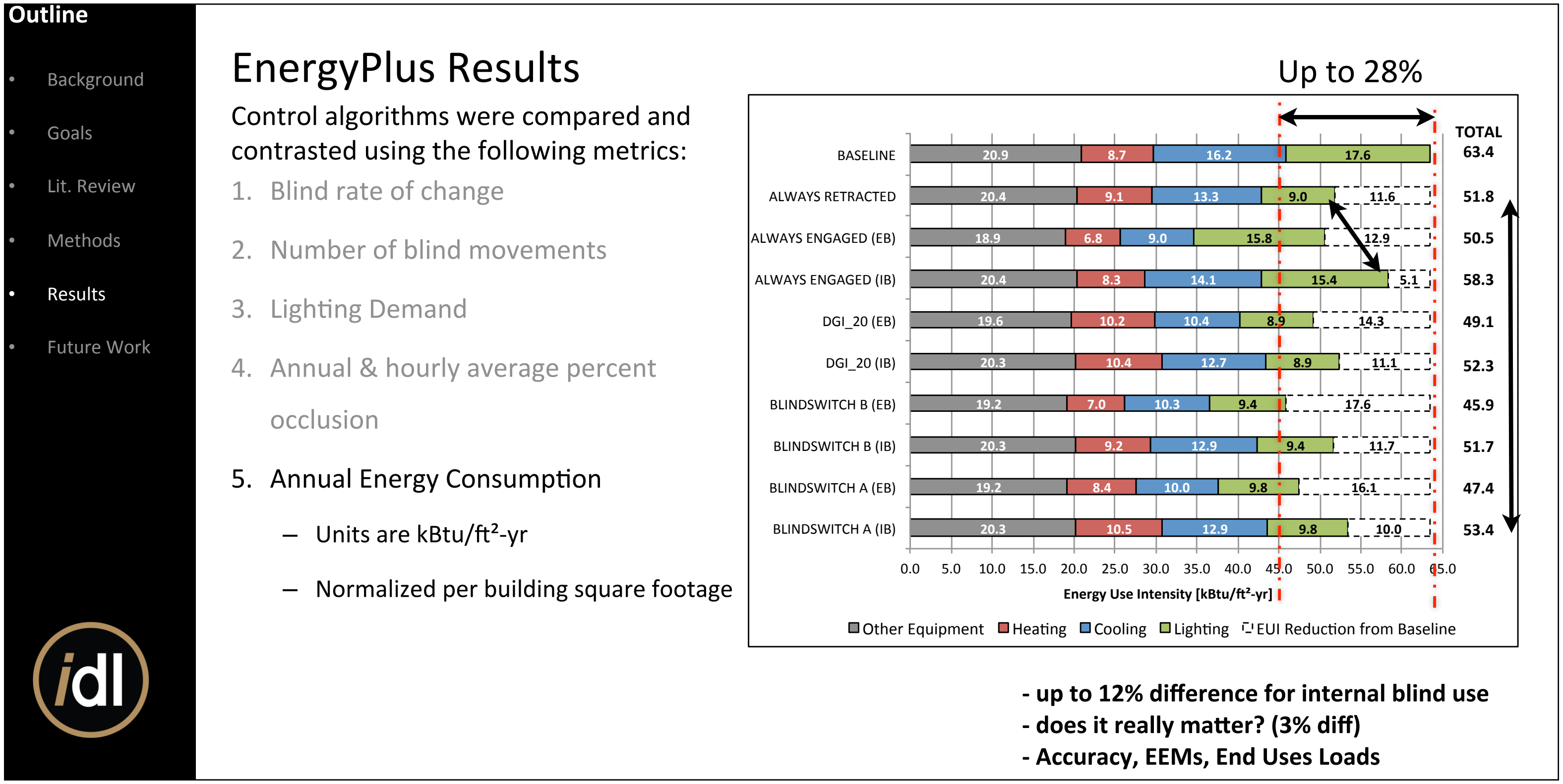




-percent occlusion results for the glare index model were much more sporadic

- South façade again shows the most occlusion throughout the year
  - south and west have similar response

- hourly occlusion graphs show much higher average values of occlusion.
  - north results in the the most consistent peak average of occlusion
    - due to view angle of glare controllers
    - north and northeast façade shows similar response due to relatively similar view angle



Dyke coined Van Den Wymelenberg's algorithms "Blindswitch 2012A" and "Blindswitch 2012B". Applying these manual blind control and daylight sensing electric lighting control resulted in as much as 18.5% annual energy difference compared to the baseline for internal blinds, and 27.6% for external blinds. Considering a baseline with daylighting sensing electric lighting controls and always retracted blinds, applying the proposed manual blind controls resulted in 12.5% difference in annual energy consumption for internal blinds and 11.5% for external blinds. It is important to consider manual blind control parameters in studies such as these because they implicate peak HVAC sizing decisions as well as the choices made regarding design alternatives for daylighting and energy optimization.

- values given in EUI (kBtu/ft2-yr)
- including a manual blind control algorithm result in up to 18.5% differences in energy consumption
  - shows that blind usage matters!
- reductions are based off of baseline model which employs blinds always retracted w/o lighting controls to reduce electric lights (lights always on during occupied hours)

- exterior blinds were also modeled to show energy savings potential of 6.1-13.3% or 3.2-7.8 EUI
- Best way to reduce solar heat gain is to stop it before it hits the window (i.e. exterior louvers))

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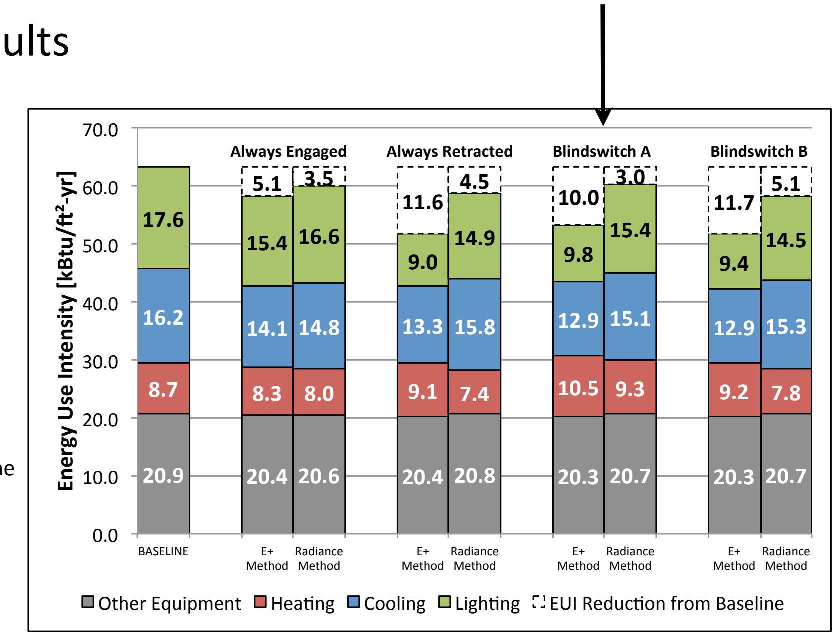
EnergyPlus v Radiance Results

Control algorithms were compared and contrasted using the following metrics:

1. Daylight Metrics
2. Interior Illuminance
3. Lighting Demand
4. Annual Consumption
    1. Comparison of four control models using one analysis point per zone



- Difference between E+ & Radiance substantial
- Blindswitch-A E+ = 53.4 vs Rad = 60 ~ 11% difference

- always retracted model results in the largest percent differences of 18.9, 15.4, and 39.5% for heating, cooling, and lighting respectively
- the largest difference with respect to end use consumption is with heating and lighting
- as you use less electric light, you need more heating for the space

- consequently, as you use more electric light, you need less supplemental heat for the space
- results show from the always retracted model 48.7 and 15.3% for EnergyPlus and Radiance relative differences in lighting consumption to the baseline model

Questions?