Carleton UNIVERSITY

Hbi Human-Building Interaction Laboratory

Best-practices Guideline on Advanced Occupant Modeling

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Content

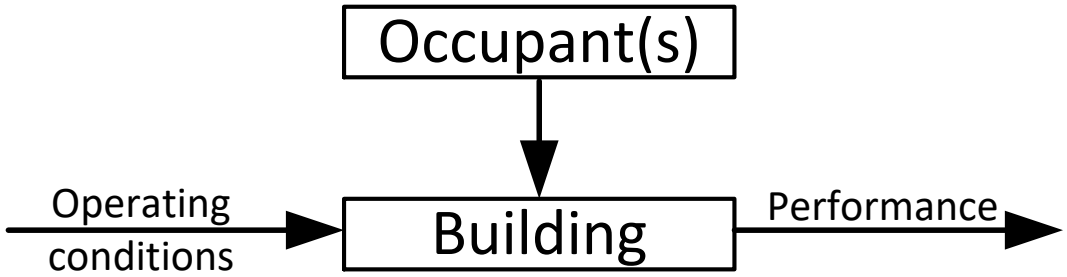
- **Part 1:** Basic theories
- **Part 2:** Implementation of advanced occupant models in EnergyPlus
- **Part 3:** Sensitivity analysis

Part 1:

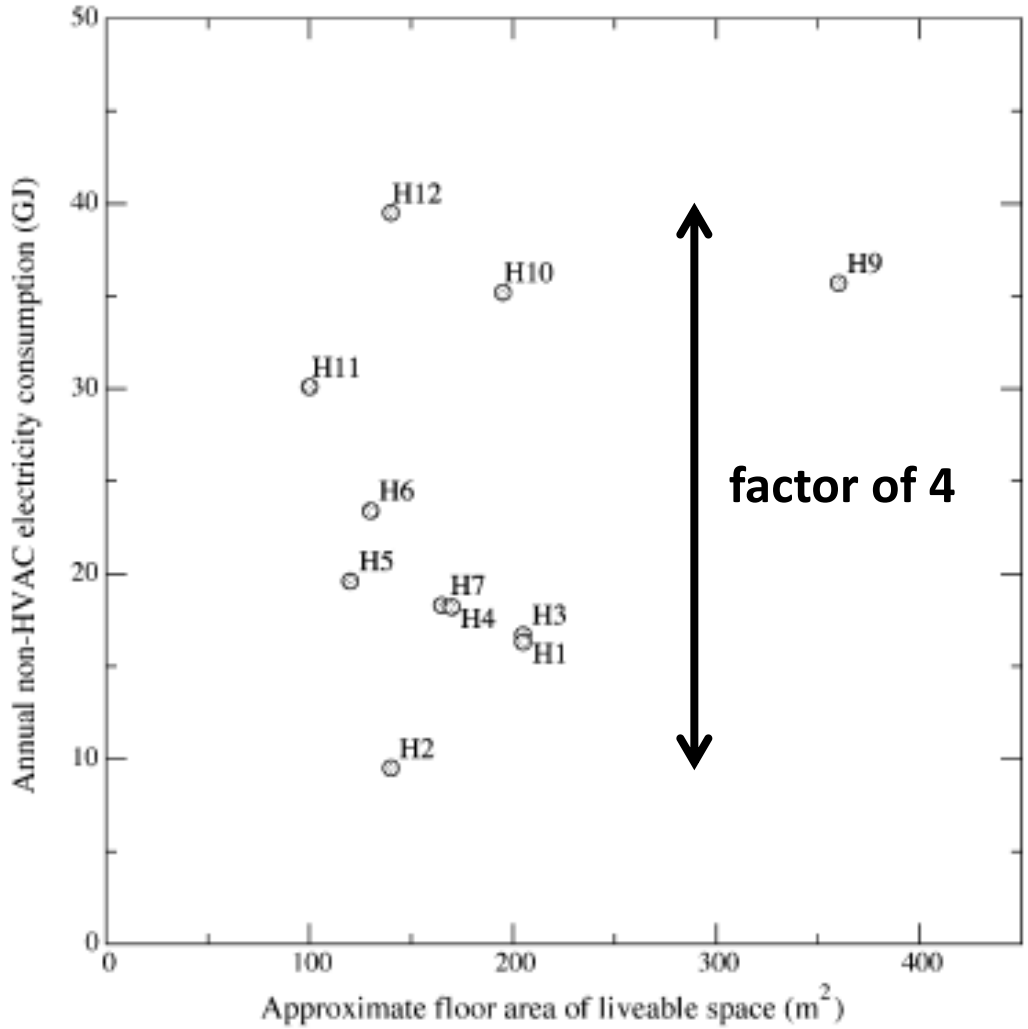
Basic theories

Why do occupants matter in buildings?

- Occupants are not passive recipients of buildings.
- They actively and continually attempt to improve comfort.



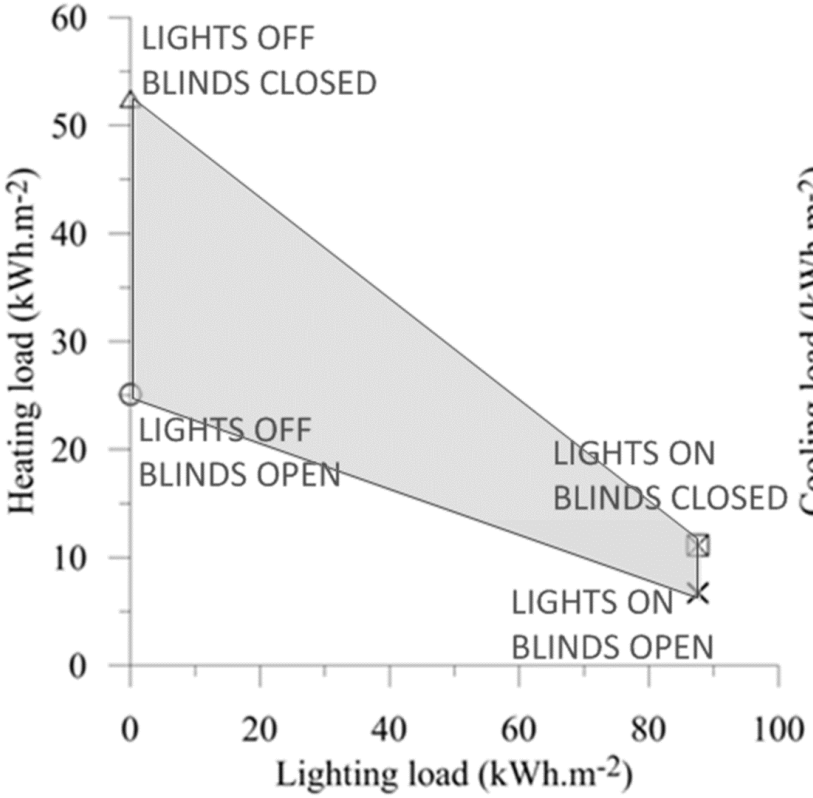
Why do occupants matter in buildings?

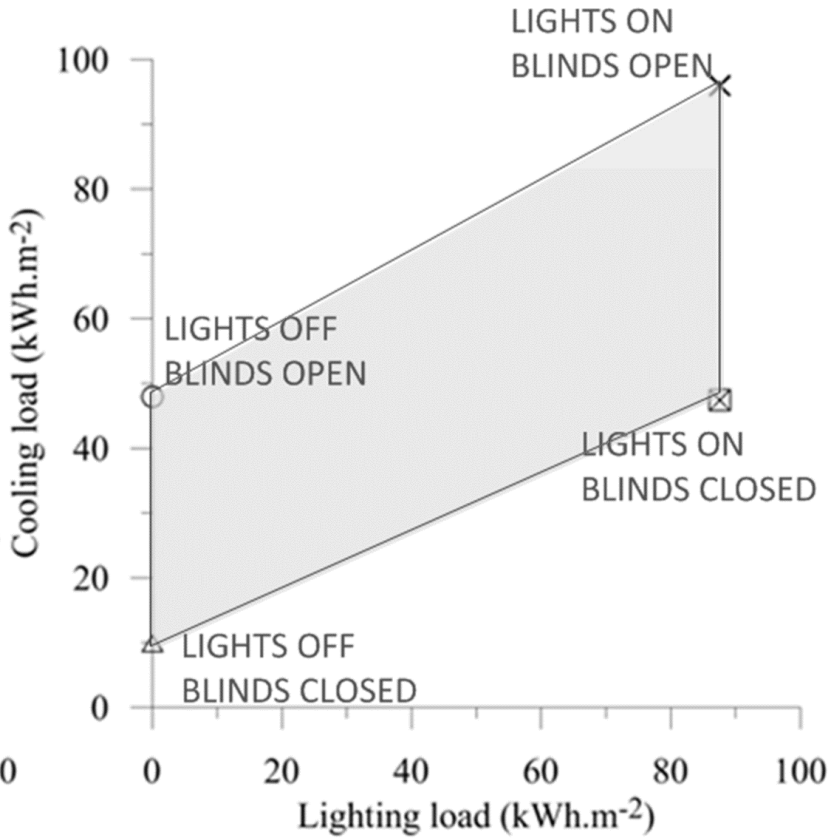


(Saldanha, Beausoleil-Morrison, 2012)

Why do occupants matter in buildings?

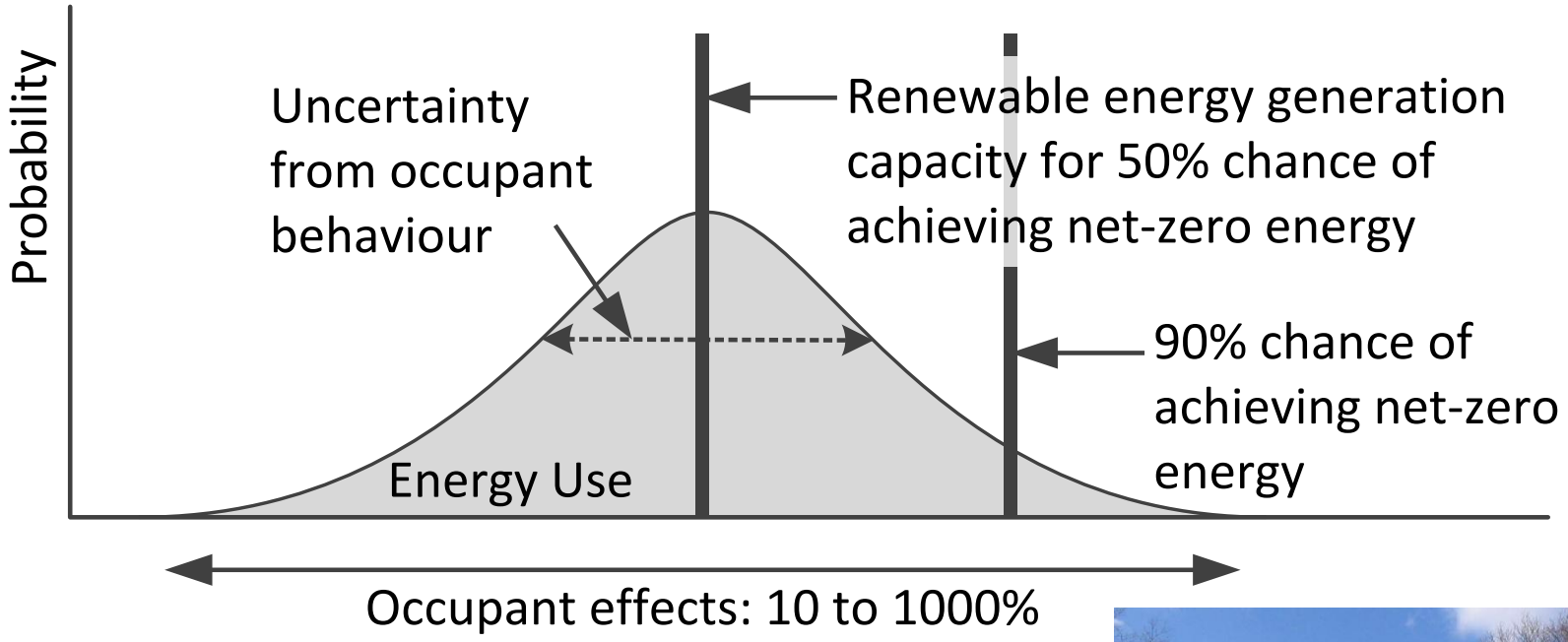
Lights 10 W/m^2
Blinds 10% transmittance
South-facing office in Ottawa



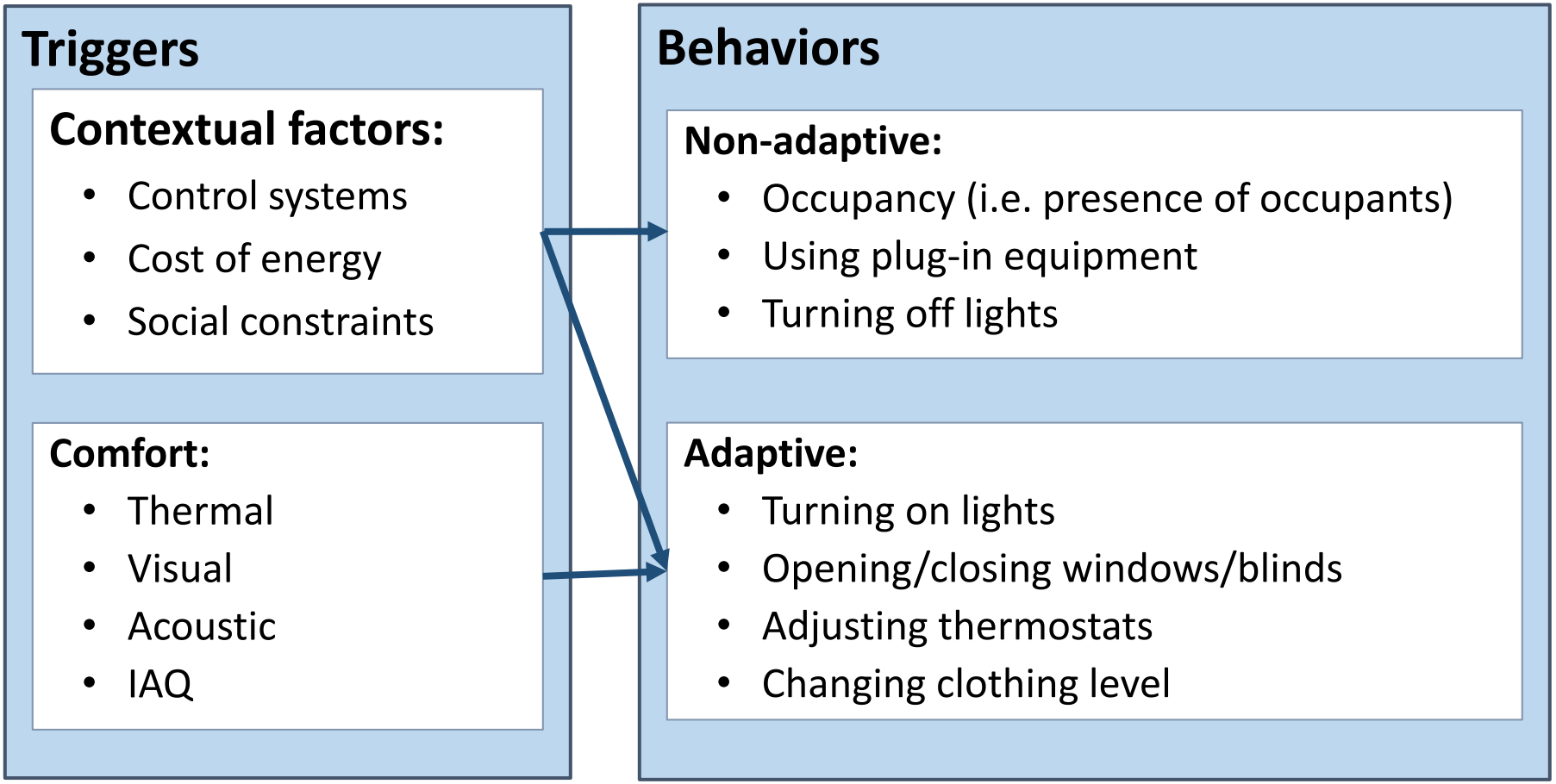


(Burak Gunay)

Why do occupants matter in buildings?

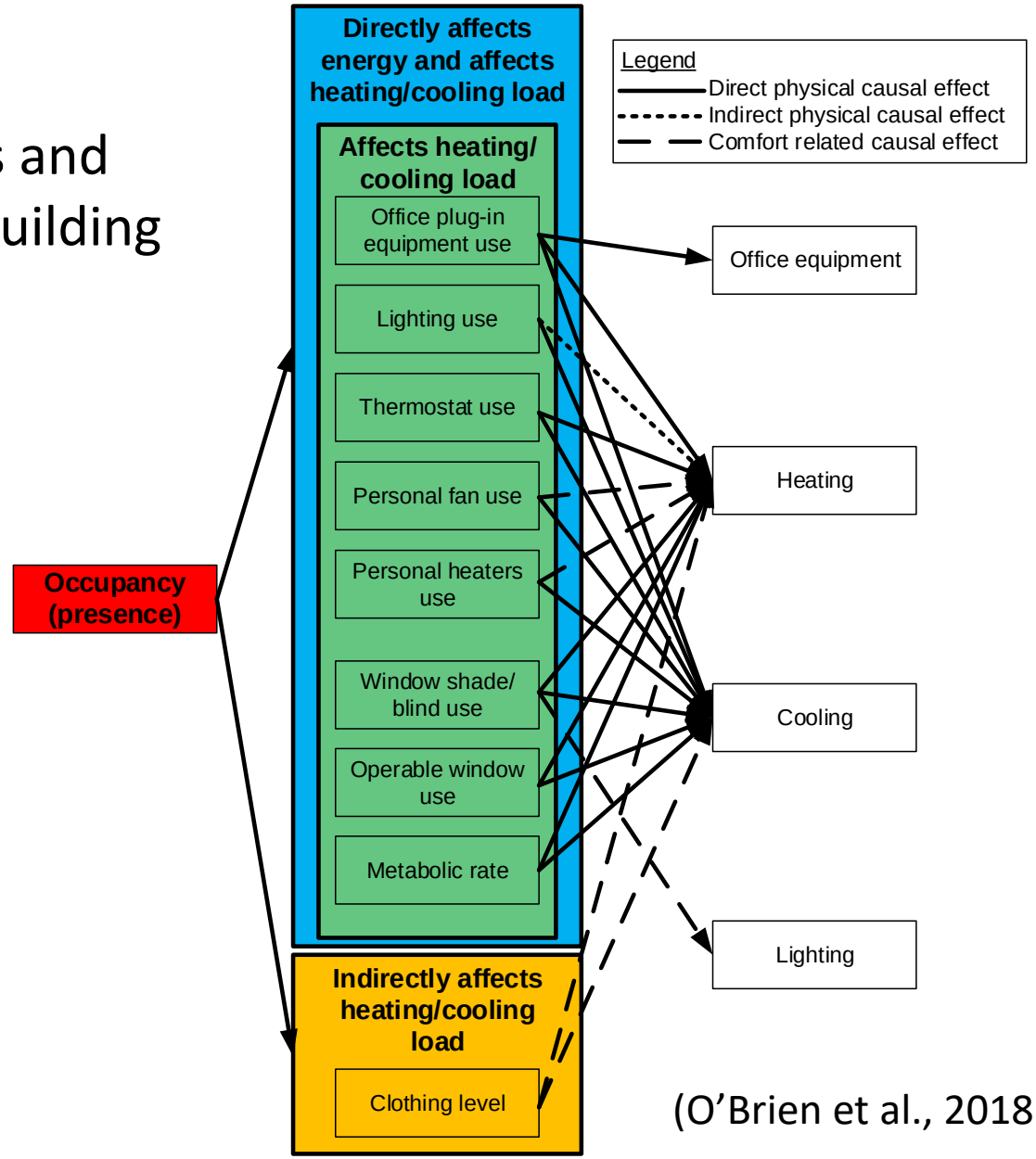


What are occupant behaviors?



What are occupant behaviors?

Key occupant behaviors and how they may impact building energy performance:

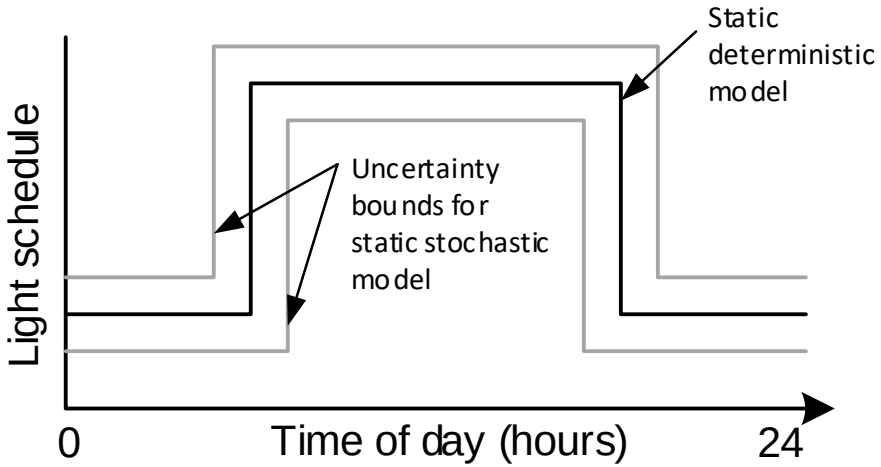


(O'Brien et al., 2018)

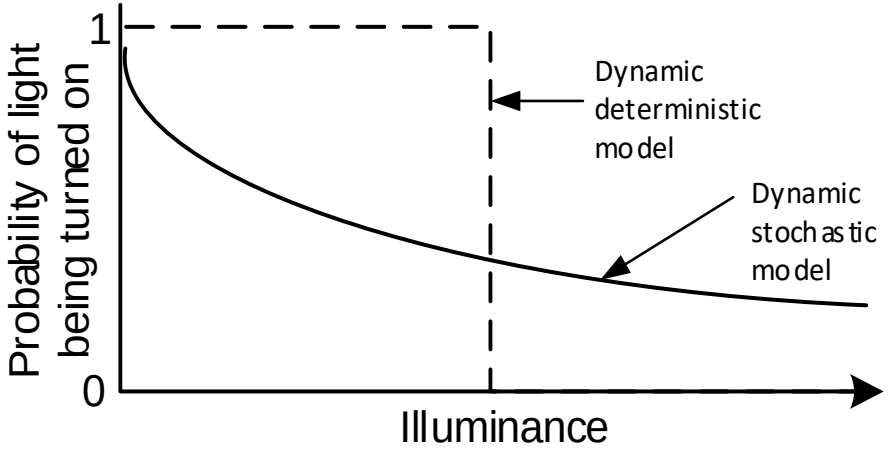
What are occupant modeling approaches?

Two main occupant modeling approaches:

- Standard-based models



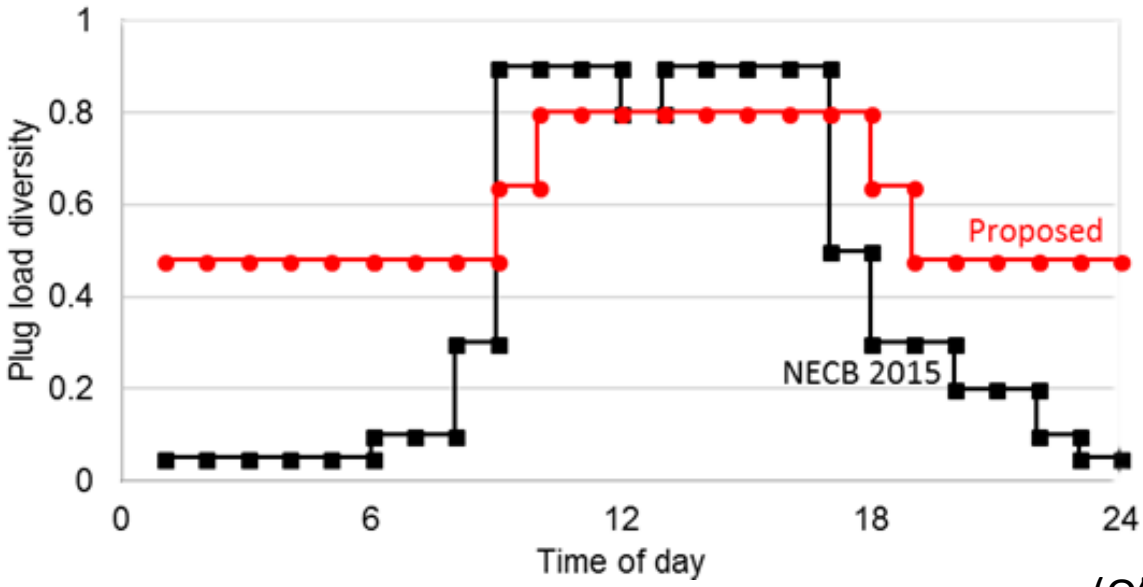
- Advanced occupant models



(O'Brien et al., 2018)

What are occupant modeling approaches?

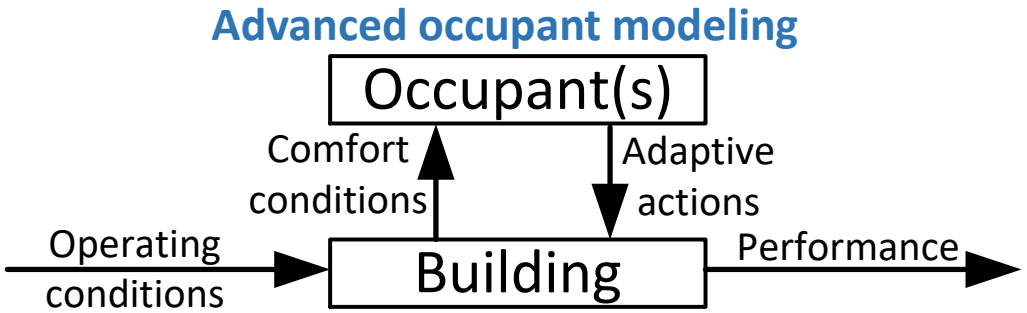
- Standard-based models are the current practices in modeling occupant in buildings.
- Limitations:
  - Inaccurate prediction of building performance
  - Poor design decision-making based on the inaccurate simulation results



(O'Brien et al., 2018)

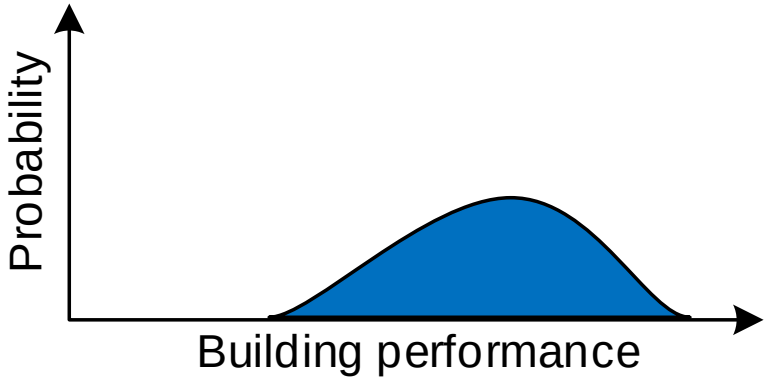
What are advanced models?

1. Dynamic



(O'Brien, Gunay, 2015)

2. Stochastic



(O'Brien et al., 2018)

3. Agent-based

4. Data-driven

What are advanced model forms?

1. Markov chain:

This model form predicts whether an occupant takes an action in the next timestep or next event:

1. Discrete-time
2. Discrete-event

2. Bernoulli:

This model from predicts the state of a building system or component.

3. Survival

This model form predicts the duration of a state right before an event happens.

Which occupant models to use?

Occupant modeling strategies vary for different applications:

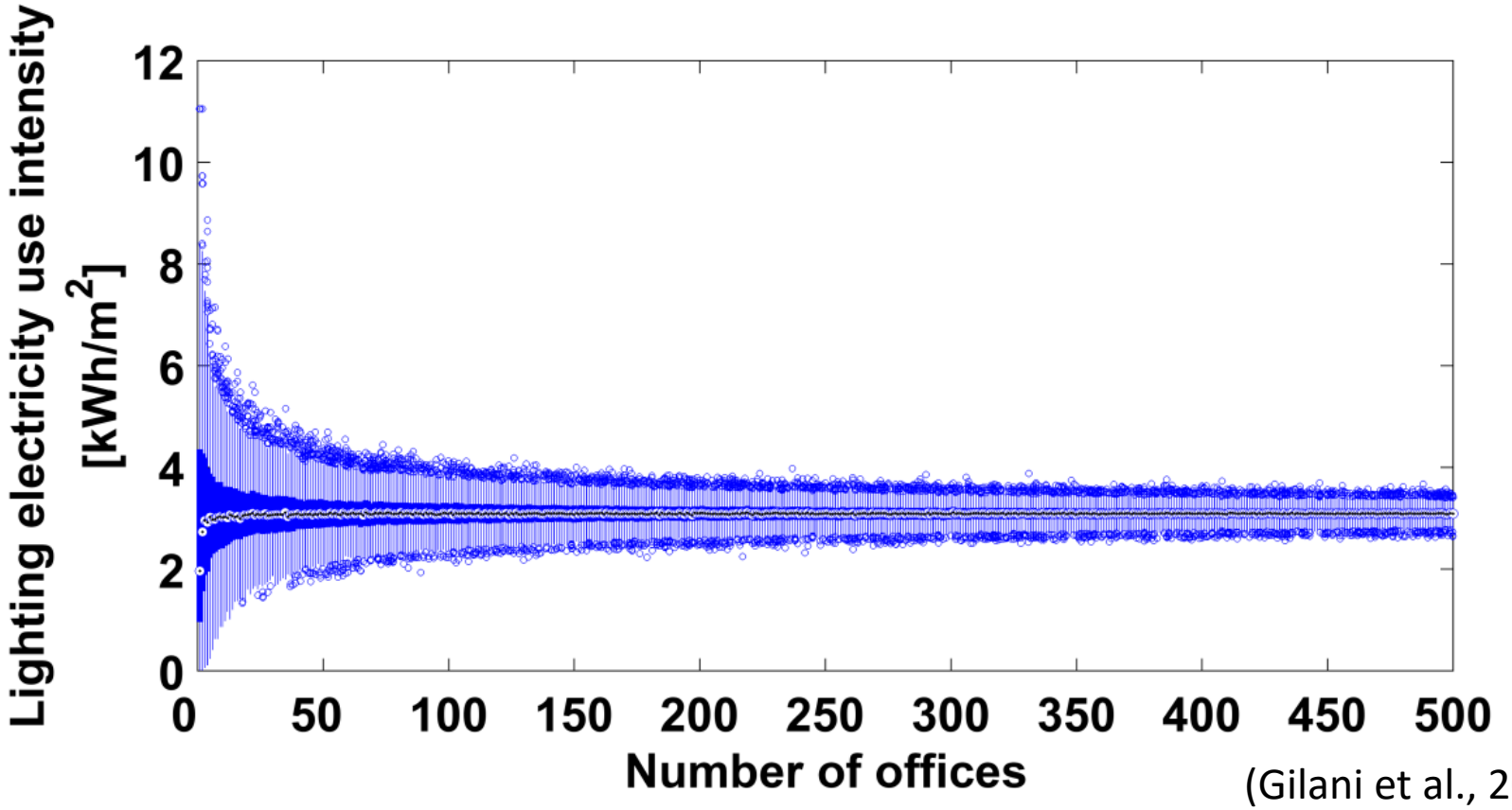
- What is our aim from simulating a building or a room-level model?
- How big is the building we simulate?
- What type of building we simulate?

What is our aim from simulating a building or a room-level model?

- Code compliance
- HVAC design
- Net-zero energy design
- Comfort assessment
- Façade design

How big is the building we simulate?

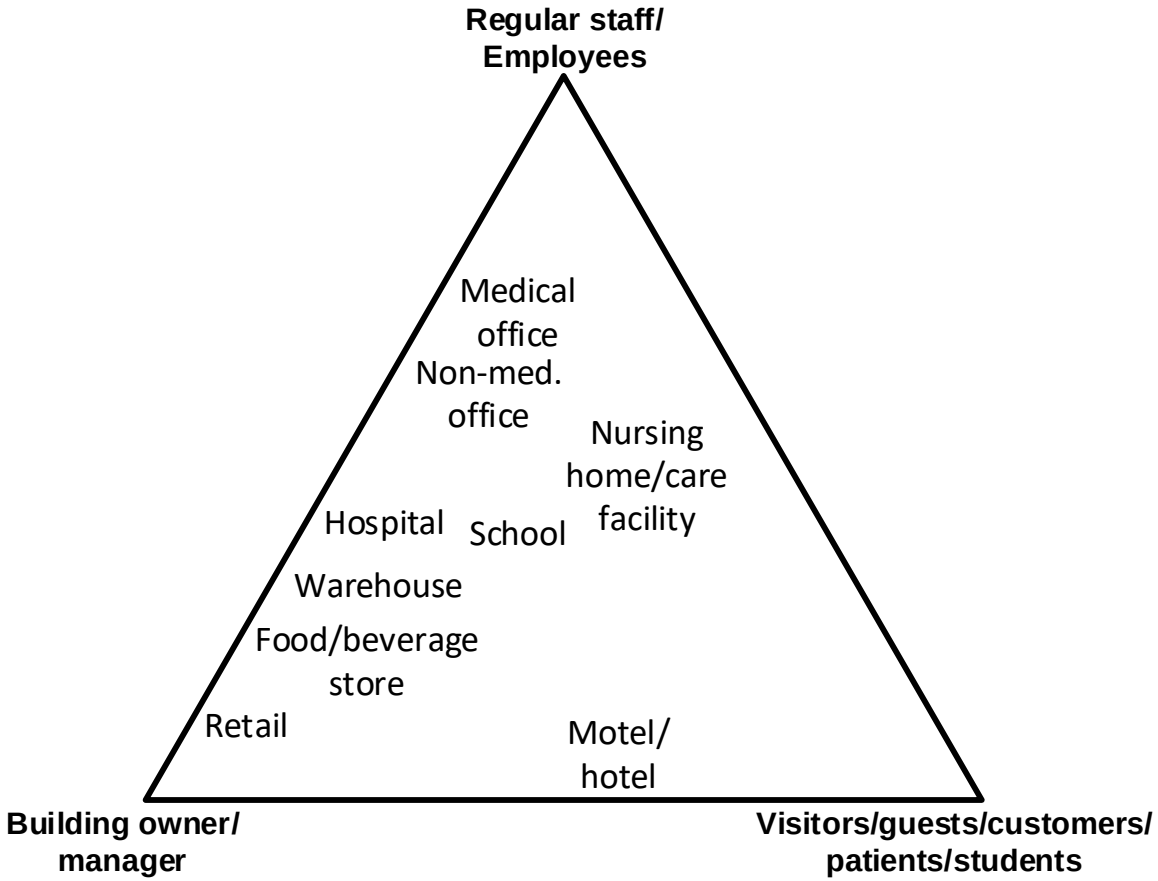
- The larger the building size, the lower the uncertainty in the predicted whole-building energy use



(Gilani et al., 2018)

What type of building we simulate?

- Energy uses of various building types have different sensitivities to occupant behaviors.



(O'Brien et al., 2018)

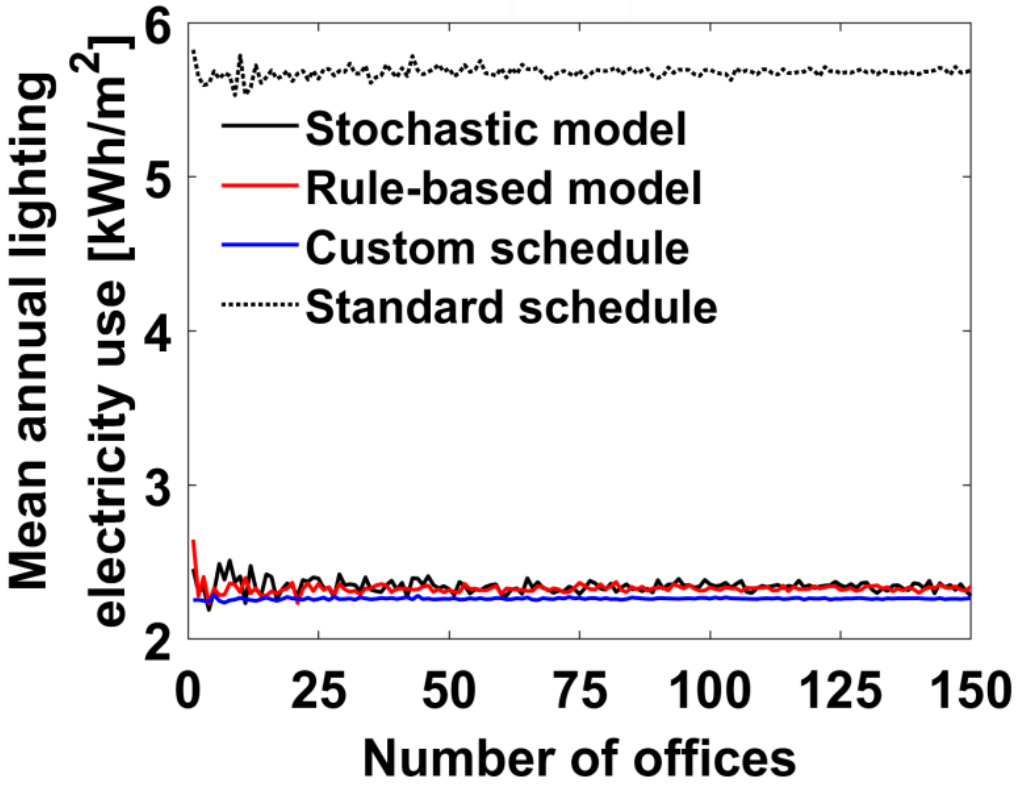
Which occupant models to use?

Use cases:

- Whole-building energy prediction
- Building system and plant equipment sizing
- Net-zero energy buildings
- Occupant comfort
- Façade design

Whole-building energy prediction

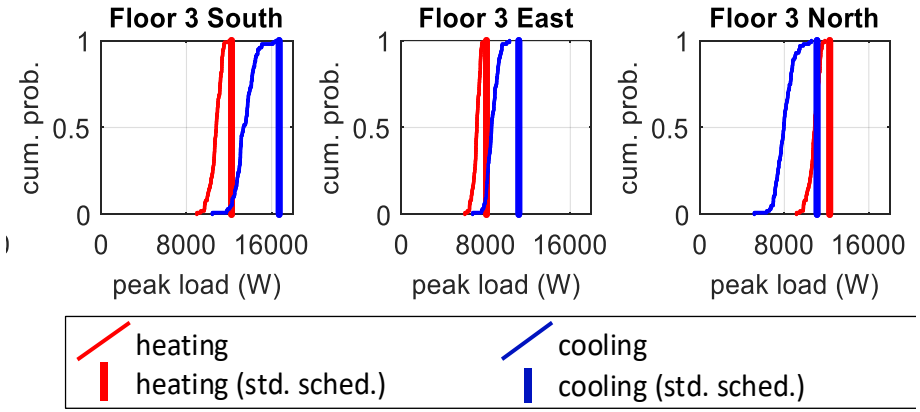
- Current method:
  - Standard schedules
- Proposed method:
  - Small buildings:
    - Agent-based models
  - Medium to large buildings:
    - Static-deterministic models for non-adaptive behaviors and dynamic-deterministic models for adaptive behaviors

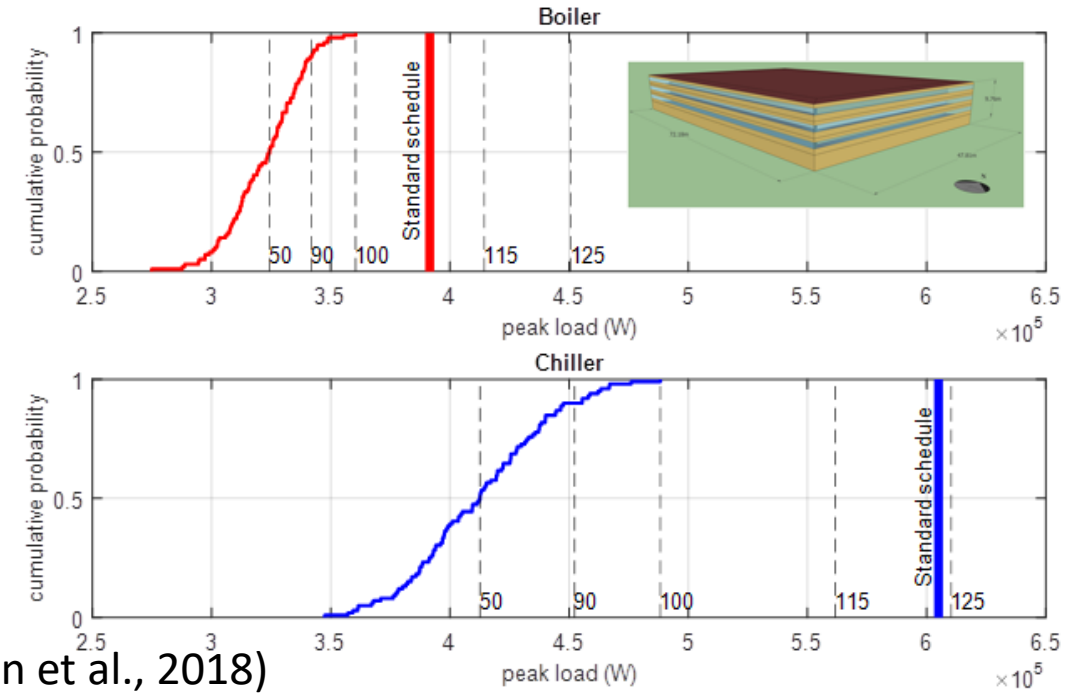


(Gilani et al., 2018)

Building system and plant equipment sizing

- Current method:
  - Standard schedules
    - Lack of potential to evaluate the risk of downsized building system and plant equipment
- Proposed method:
  - Zone-level:
    - Static-deterministic (i.e. standard schedules)
  - Building level:
    - Static-stochastic models

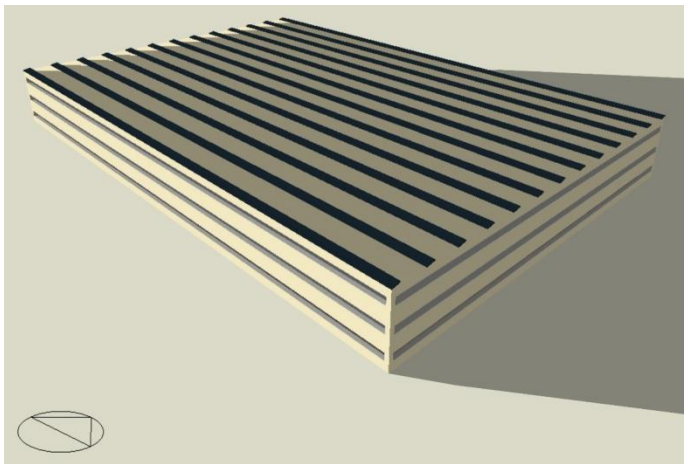


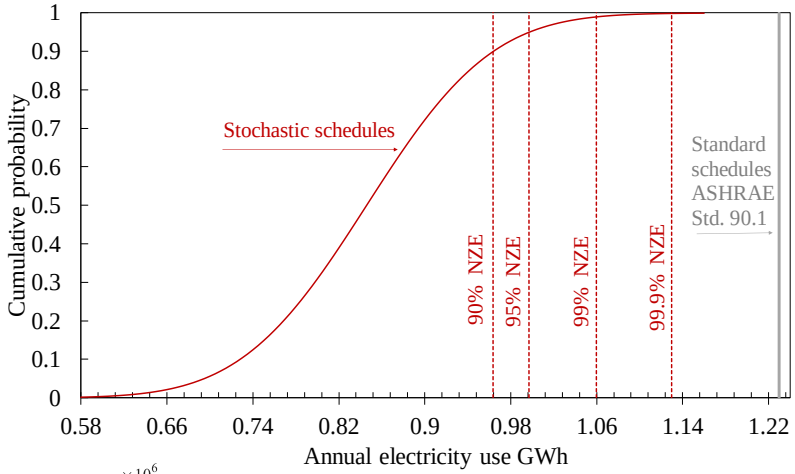


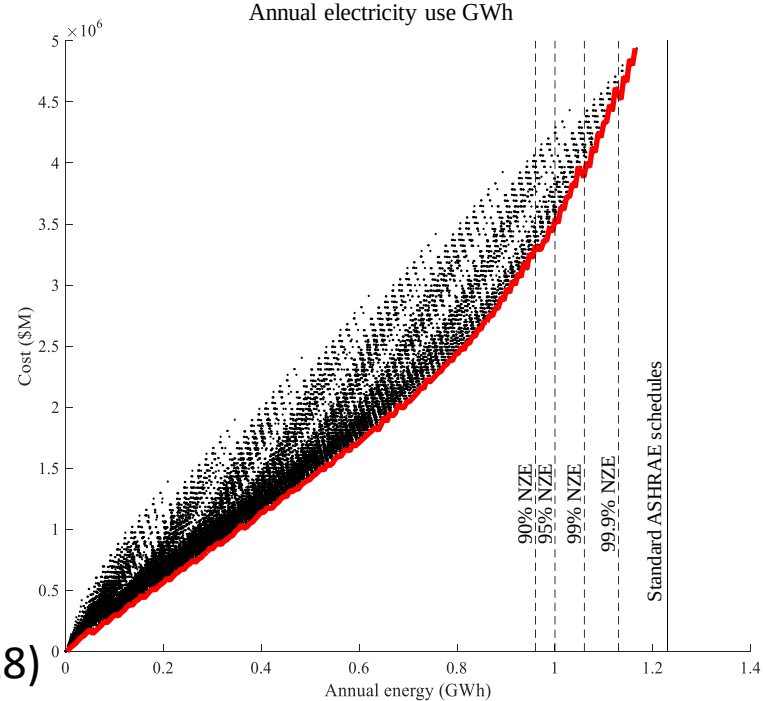
(O'Brien et al., 2018)

Net-zero energy buildings

- Current method:
  - Standard schedules
    - Lack of accurate predicted building energy use
- Proposed method:
  - static-stochastic or dynamic-stochastic models
    - Provide an insight into the impact of occupant-related uncertainties on building energy use



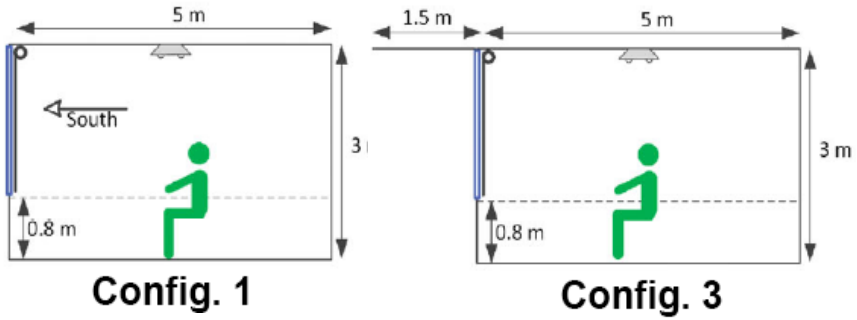


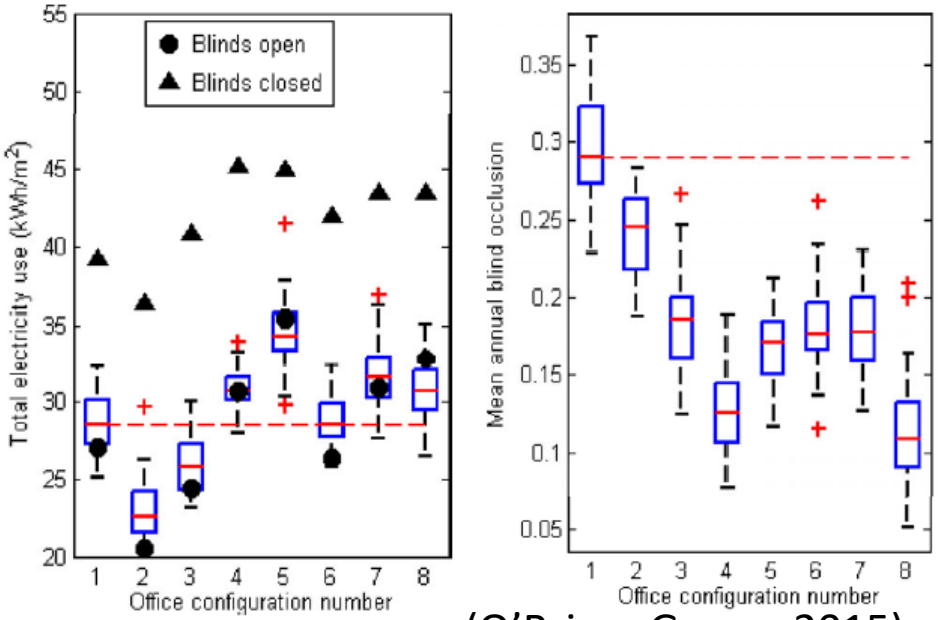


(Abdelalim, O'Brien, 2018)

Occupant comfort

- Current method:
  - Standard schedules
    - Lack of distribution of energy use and number of occupants' interactions with buildings
- Proposed method:
  - Dynamic-deterministic or dynamic-stochastic models
    - Potential for robust design by reducing occupants' interactions with buildings

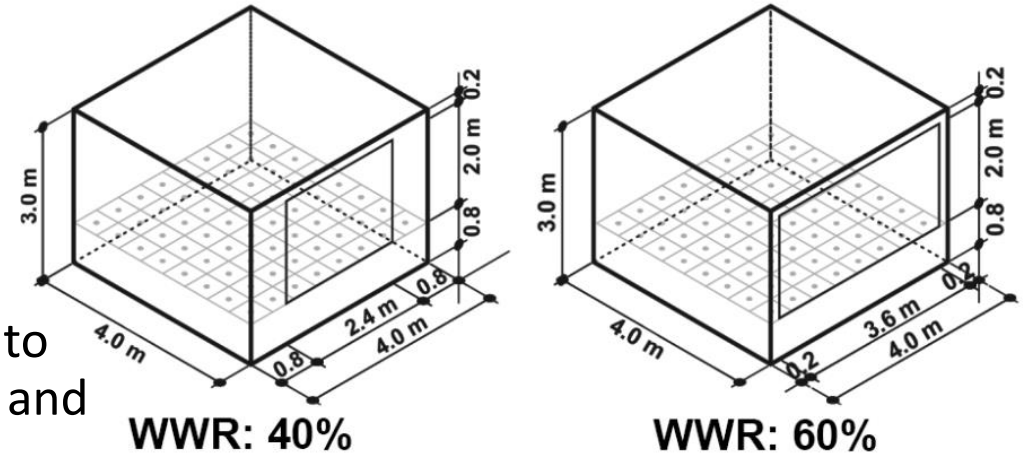


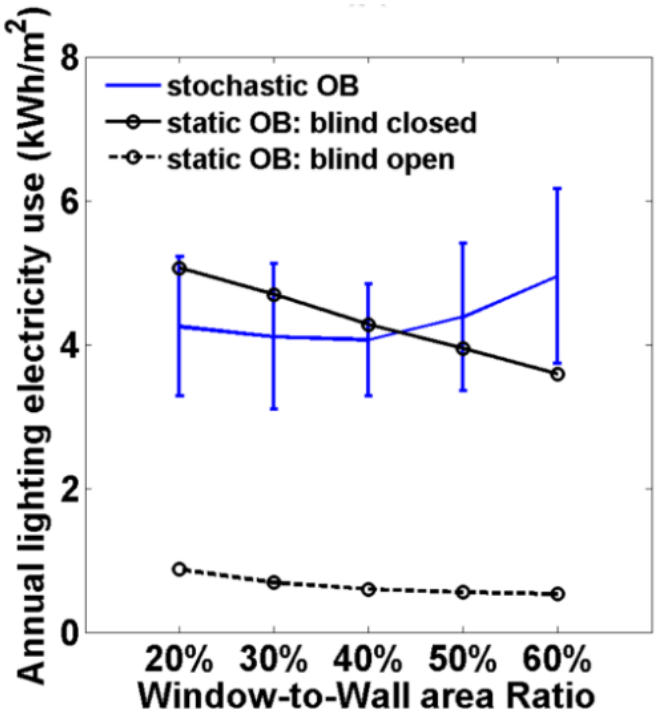


(O'Brien, Gunay, 2015)

Façade design

- Current method:
  - Standard schedules
    - Lack of providing an insight into occupant-related uncertainty and occupants' interactions with facades' components
- Proposed method:
  - Dynamic-deterministic or dynamic-stochastic models
    - Potential for optimal design



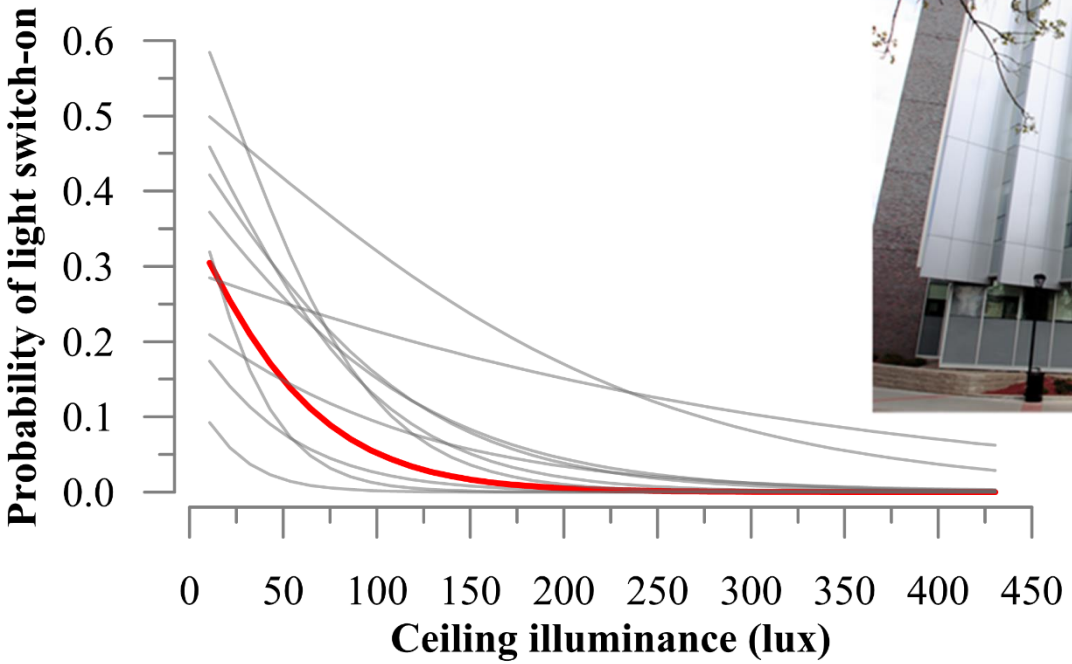


(Gilani et al., 2016)

Part 2:

Implementation of advanced models in EnergyPlus

Discrete-time Markov chain models



(Burak Gunay)

$$p(switch\ on|off) = \frac{Number\ of\ timesteps\ with\ a\ light\ switch\ on}{Number\ of\ occupied\ timestpe\ when\ lights\ were\ off}$$

$$p = \frac{e^{\beta_0 + \sum_{i=1}^{n} \beta_i x_i}}{1 + e^{\beta_0 + \sum_{i=1}^{n} \beta_i x_i}}$$

Advanced occupant models from literature

Taylor & Francis
Taylor & Francis Group

Journal of Building Performance Simulation

ISSN: 1940-1493 (Print) 1940-1507 (Online) Journal homepage: http://www.tandfonline.com/loi/tbps20

Implementation and comparison of existing occupant behaviour models in EnergyPlus

H. Burak Gunay, William O'Brien & Ian Beausoleil-Morrison

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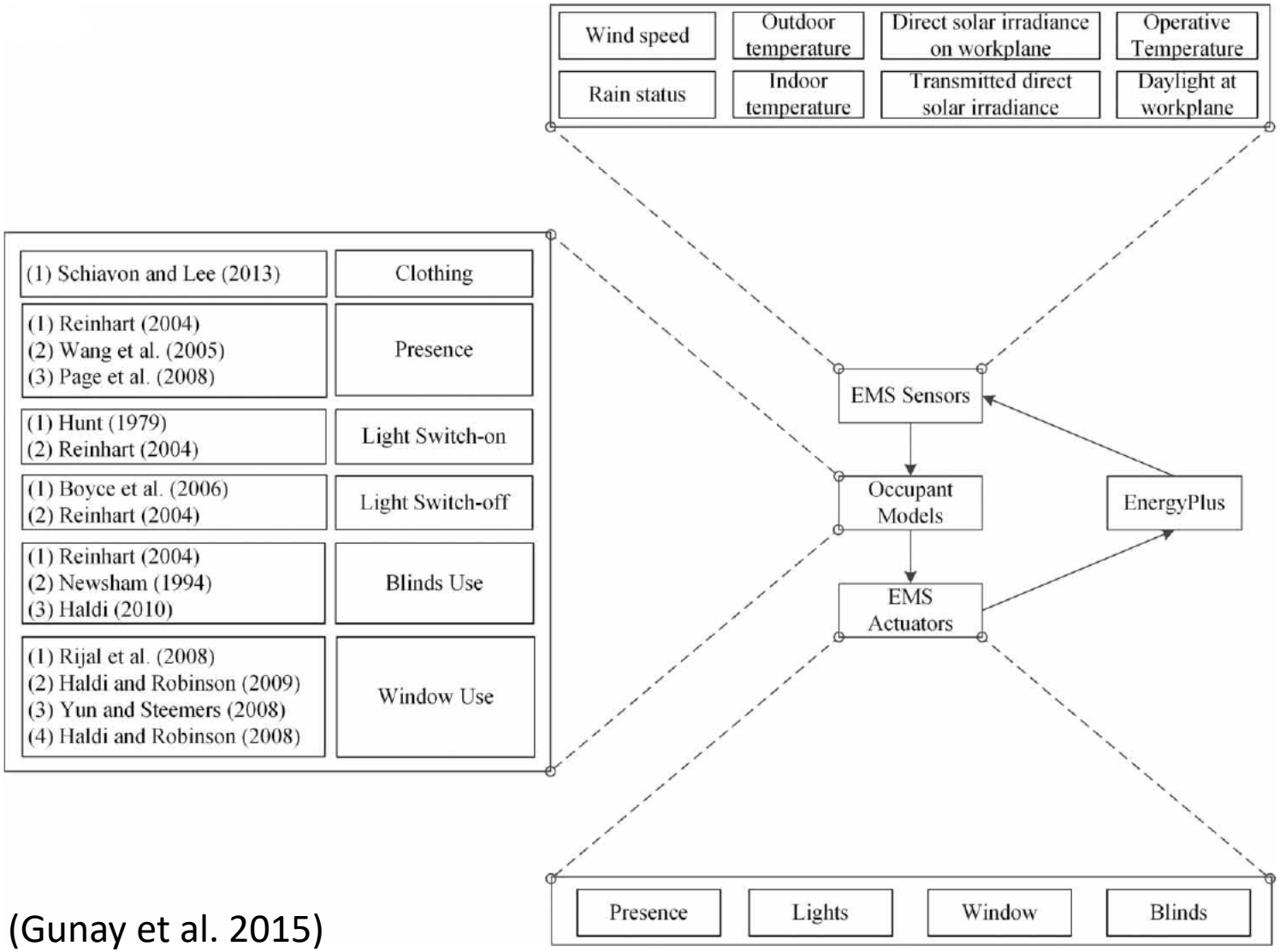
To link to this article: http://dx.doi.org/10.1080/19401493.2015.1102969

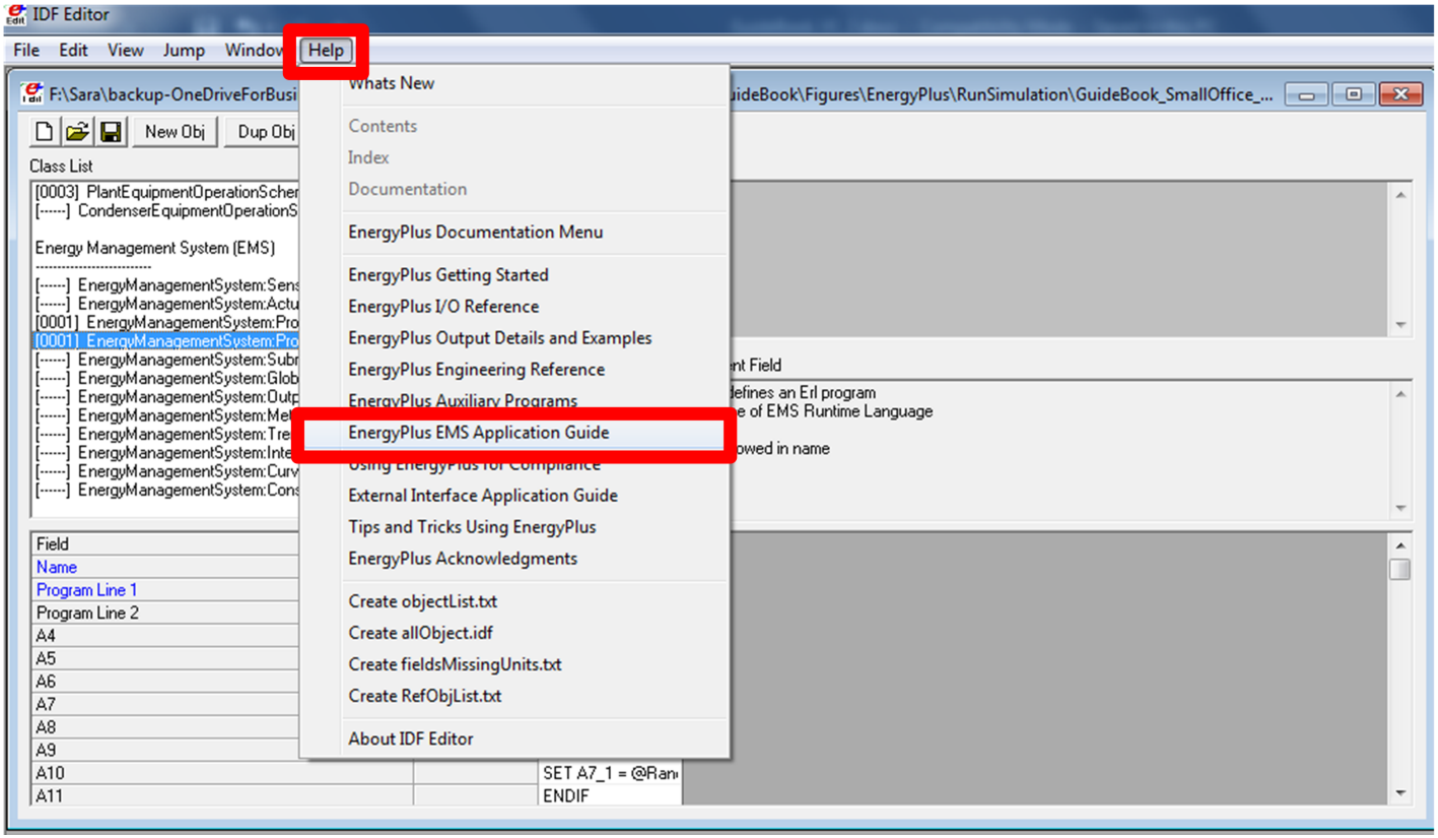
EnergyPlus EMS Application



(Gunay et al. 2015)

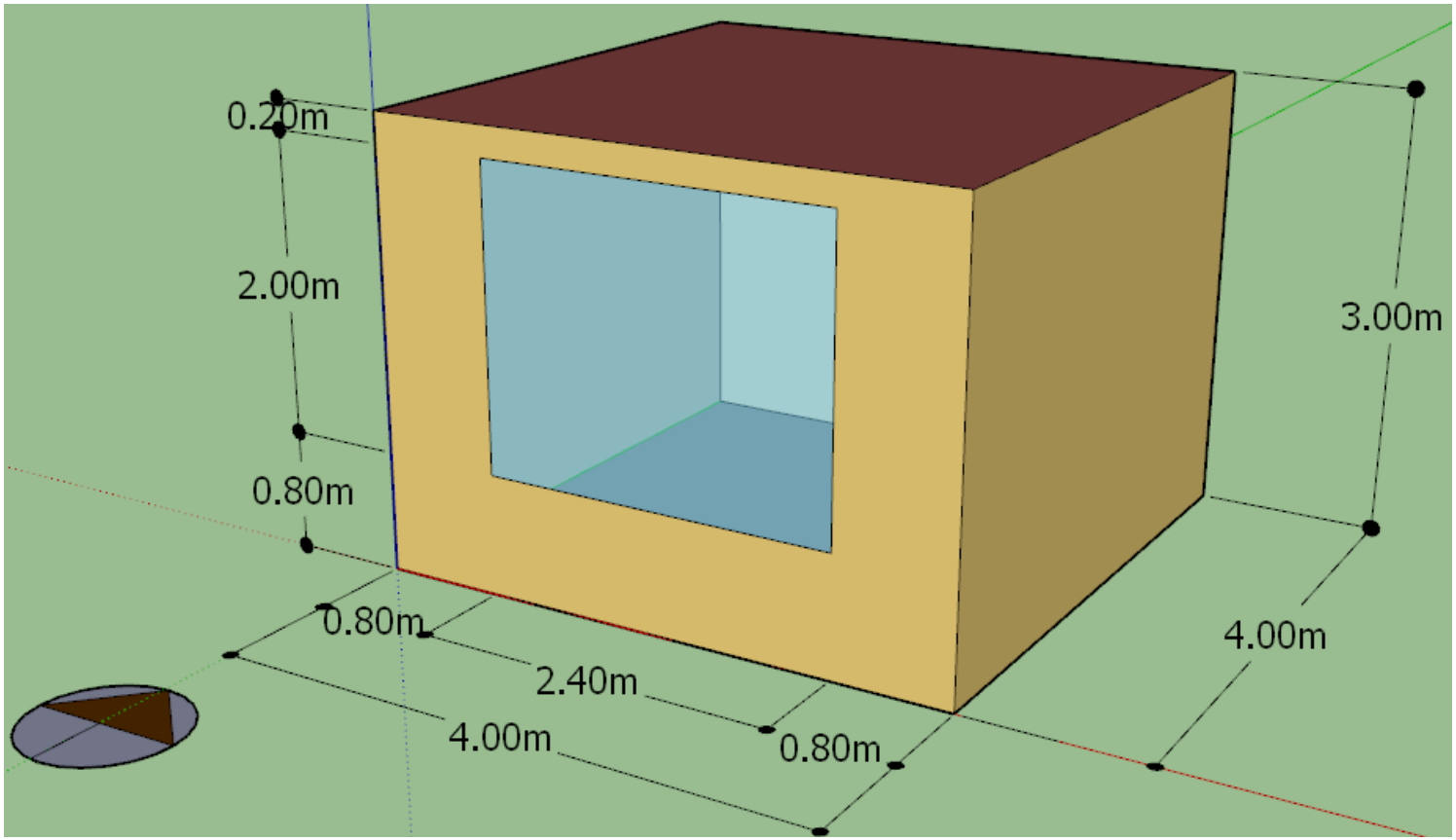
EnergyPlus EMS Application

EMS variables →
- Sensors
- Actuators
- Built-in variables
- Global variable



South-facing shoebox model

Daylight sensor in the center and at the workplane height (0.8 m)



EnergyPlus EMS Application

- We will implement advanced occupant models for:

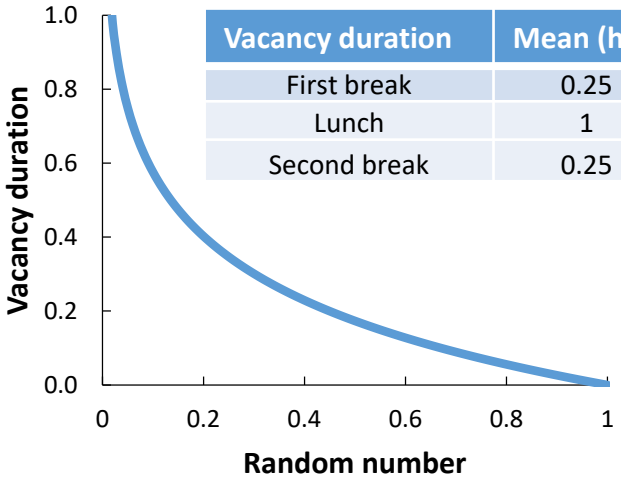
    1. Occupancy: Wang et al.'s (2005) model
    2. Light: Reinhart's (2004) model

Wang et al.'s occupancy model

EMS Sensor → **EMS Program** → **EMS Actuator**

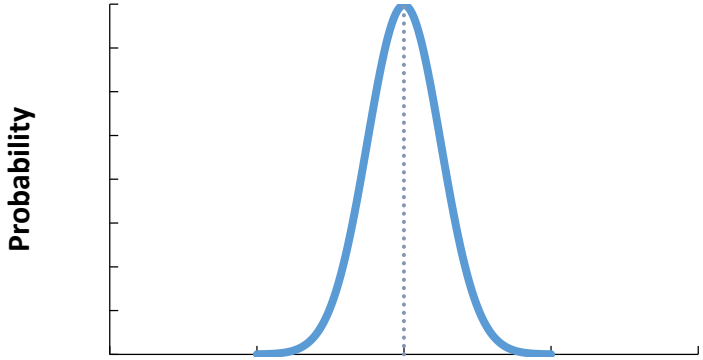
Current time → Wang et al.'s model → Occupancy state

Vacancy duration:
Exponential distribution



Vacancy duration	Mean (hr)	Std (hr)
First break	0.25	0.1
Lunch	1	0.25
Second break	0.25	0.1

Event time (arrival, departure, lunch, two breaks):
Normal distribution



Event time	Mean (hr)	Std (hr)
Arrival	8	0.25
First break	10	
Lunch	12	
Second break	15	
Departure	18	

Reinhart's light switch model

EMS Sensor

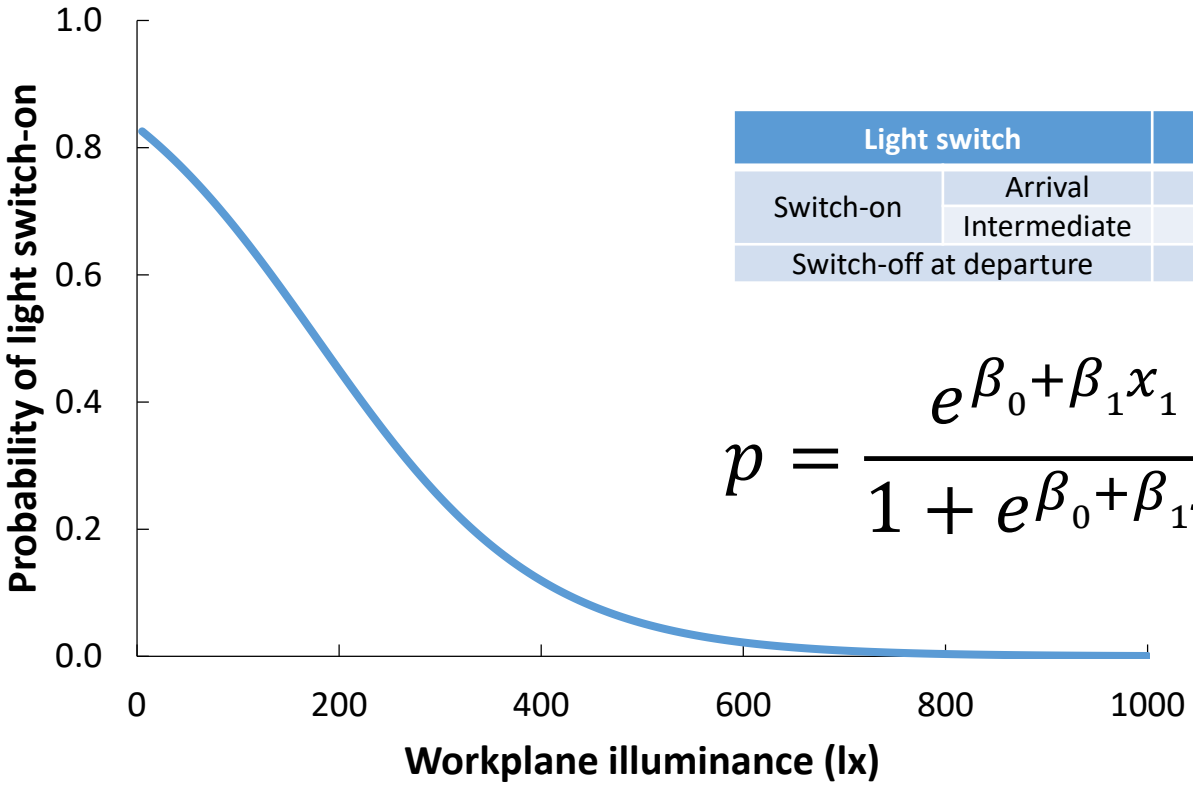
- Current time
- Occupancy
- Daylight

EMS Program

Reinhart's model

EMS Actuator

Light state



Light switch		β_0 (μ±σ)	β_1 (μ±σ)
Switch-on	Arrival	1.6 ± 0.3	−0.009 ± 0.002
	Intermediate	-3.9 ± 0.5	−0.002 ± 0.0005
Switch-off at departure		-1.3 ± 0.3	0.003 ± 0.001

$$p = \frac{e^{\beta_0+\beta_1 x_1}}{1+e^{\beta_0+\beta_1 x_1}}$$

Light switch-on:

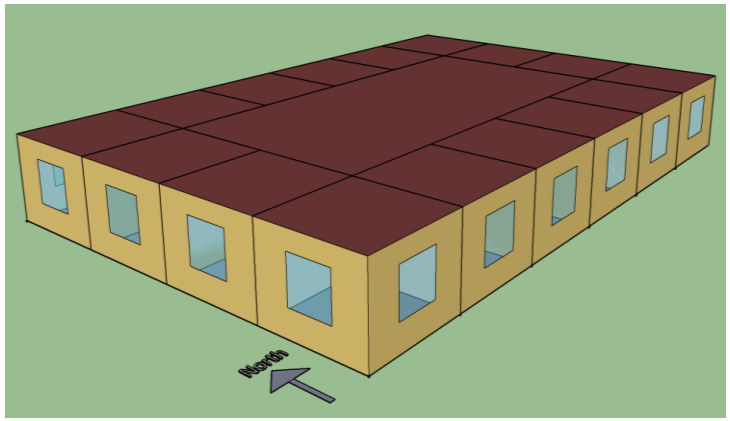
x = workplane illuminance

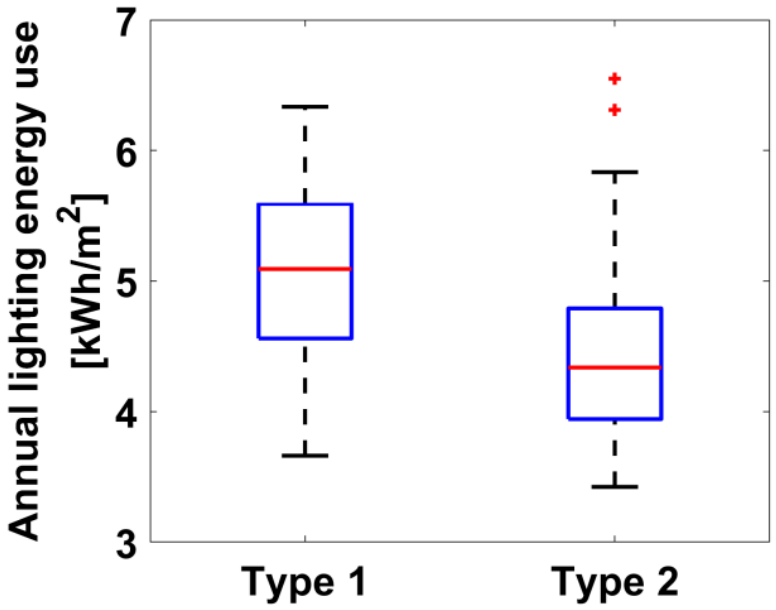
Part 3:

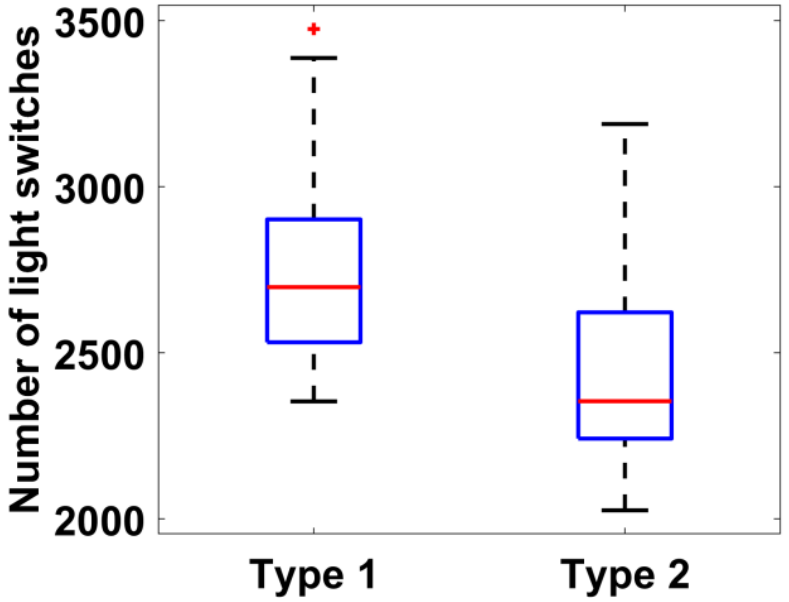
Sensitivity analysis

Sensitivity analysis

Glazing systems design parameters			
Type	U-factor (kWh/m^2)	SHGC	VT
1	1.82	0.36	0.64
2	1.42	0.48	0.69





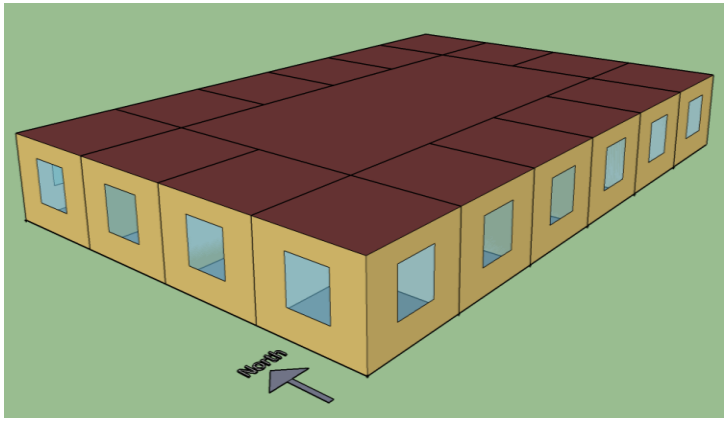


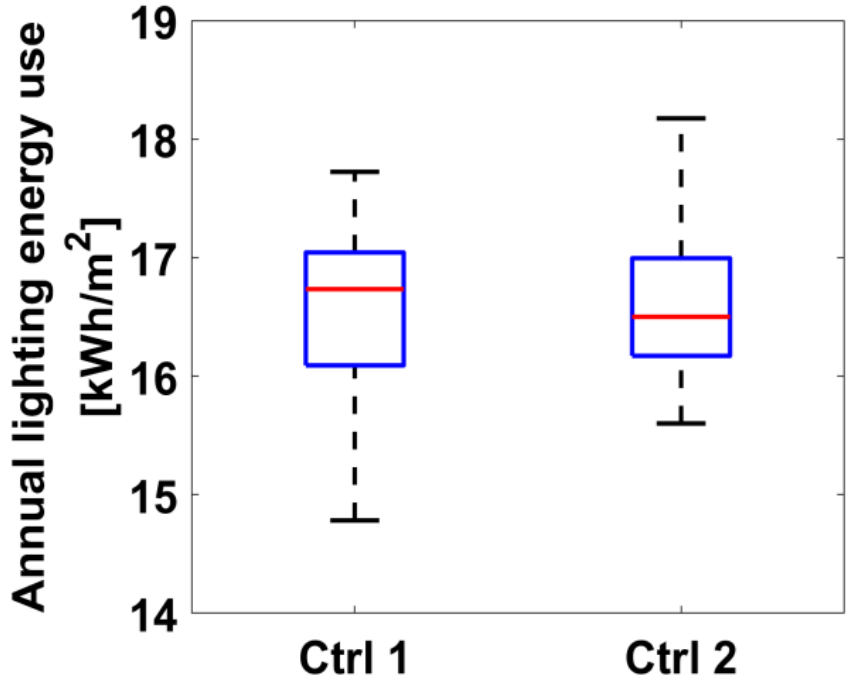
Sensitivity analysis

- Two window shade control systems:

(1) blinds are closed all the time

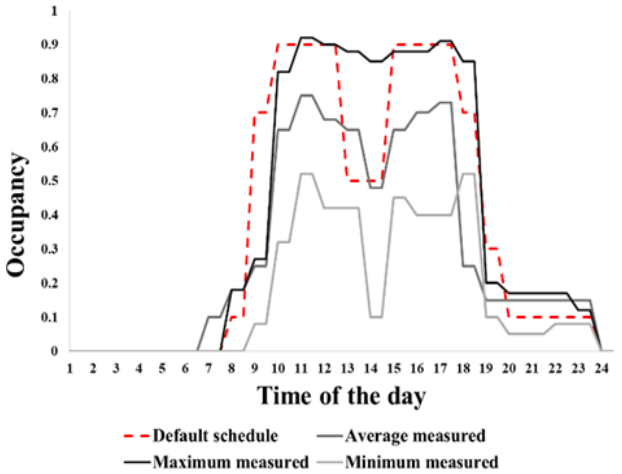
(2) blinds are open all the time

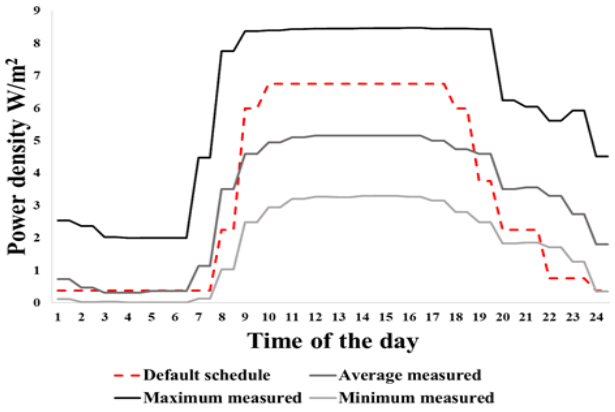




Sensitivity analysis

- Impact of energy conservation measures (ECMs) on the predicted building energy use





(Abuimara et al., 2018)

Design option with default loads & schedules			
Rank	Design Options	EUI MJ/m2	Reduction
1	(WT-01)	507	9%
2	(WWR20)	523	6%
3	(BO-0.95)	532.56	5%
4	(CH-COP)	539.6	3%
5	(WI-4.4)	539.87	3%
6	(RI-8.81)	540.64	3%
7	(WT-02)	542.31	3%
8	(WI-3.52)	542.66	3%
9	(BO-0.9)	542.71	3%
10	(RI-7.04)	544.99	3%
11	(INFL30)	547.85	2%
12	(RI-5.28)	549.12	2%
13	(DCV)	549.29	2%
14	(WI-2.64)	549.53	2%
15	(ERV)	553.77	1%
16	(P&F)	557.57	0%
17	Base	558.98	0%
18	(SH-0.4)	561.74	0%
19	(SH-0.6)	566.07	-1%
20	(WWR40)	571.95	-2%
21	(WWR60)	618.22	-11%

Design options with average measured loads & schedules		
Design Options	EUI MJ/m2	Reduction
(WT-01)	469.63	10%
(WWR20)	491.9	6%
(BO-0.95)	496.65	5%
(WI-4.4)	505.32	3%
(CH-COP)	506.18	3%
(RI-8.81)	506.48	3%
(BO-0.9)	506.81	3%
(DCV)	509.39	3%
(RI-7.04)	510.23	2%
(WI-3.52)	510.51	2%
(WT-02)	510.64	2%
(RI-5.28)	515.69	1%
(WI-2.64)	515.91	1%
(INFL30)	516.12	1%
(ERV)	518.16	1%
(P&F)	521.67	0%
Base	523.1	0%
(SH-0.4)	526.86	-1%
(SH-0.6)	528.94	-1%
(WWR40)	537.3	-3%
(WWR60)	585.12	-12%

Sensitivity analysis

- Various parameters:
  - ECMs
  - Climate zones
  - Building types
  - Building sizes
  - Building users-related domains

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Thank You

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