Occupant Behavior in Buildings
Demands, Undergoing & Perspectives

Da Yan

Tsinghua University, China

April 04, 2016

Background

- **Large gaps between field data and simulation result**

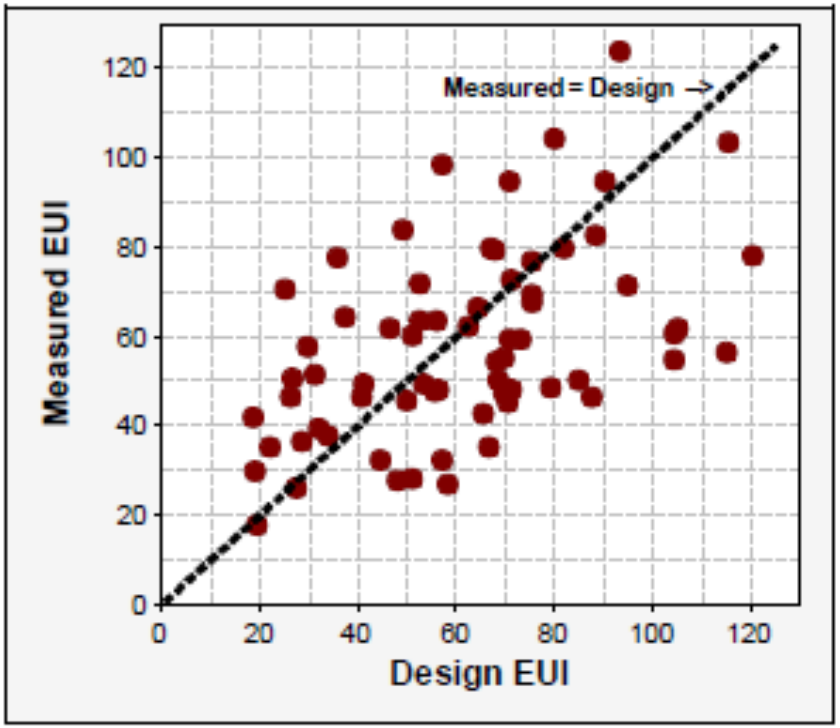
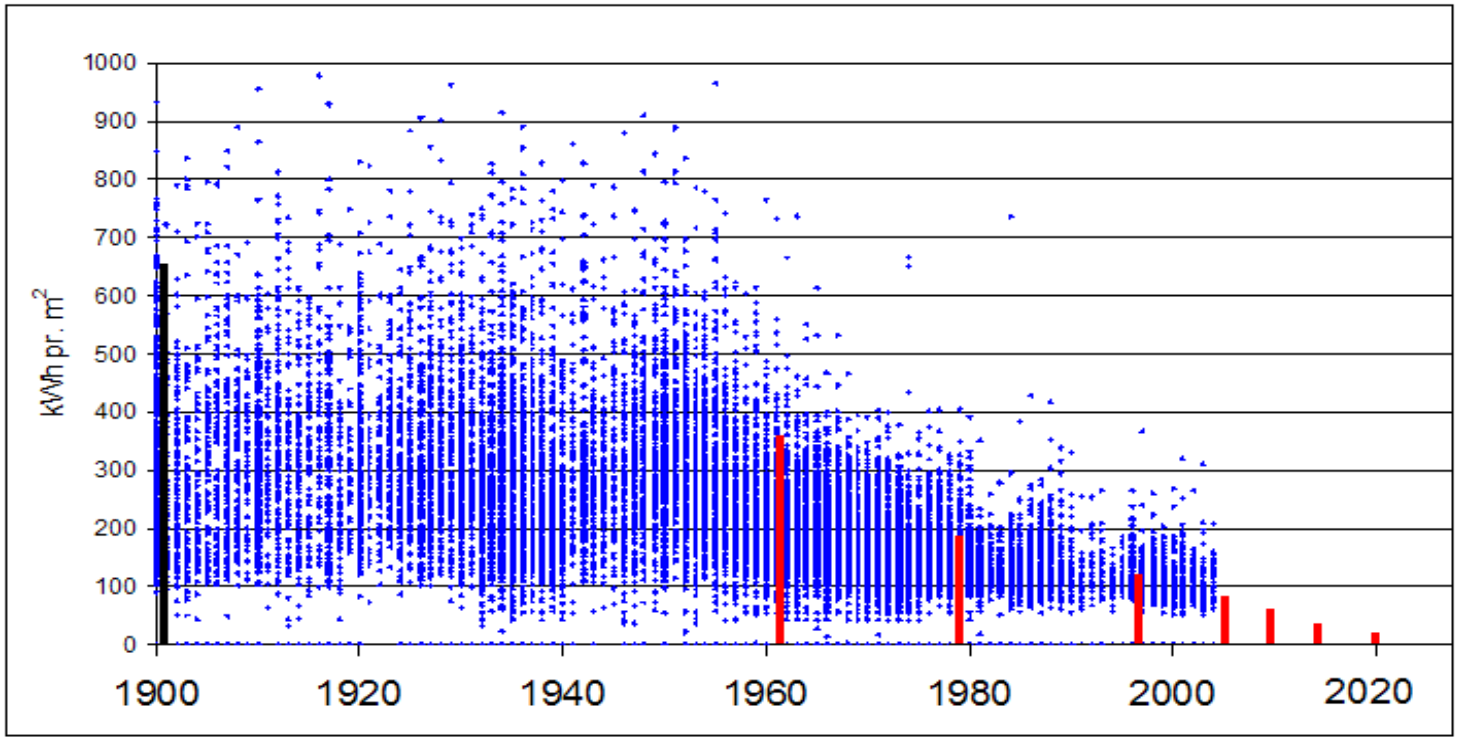


Figure ES- 4: Measured versus Design EUIs
All EUIs in kBtu/sf

Source: NBI report 2008
Energy Performance of LEED
For New Construction Buildings

Background

- building energy is not only affected by climate and system



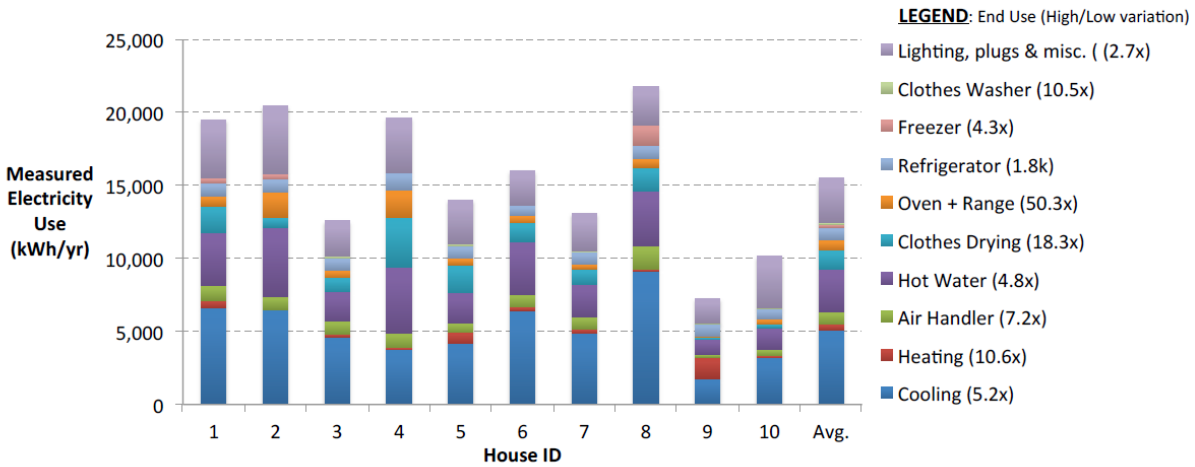
Energy Use in Danish Single Family Houses – By year of construction

Ref.: SBI/Aalborg University

Background

Homestead Cohort:
Virtually identical Homes & Efficiencies…
… but 3x Variation in Energy Use

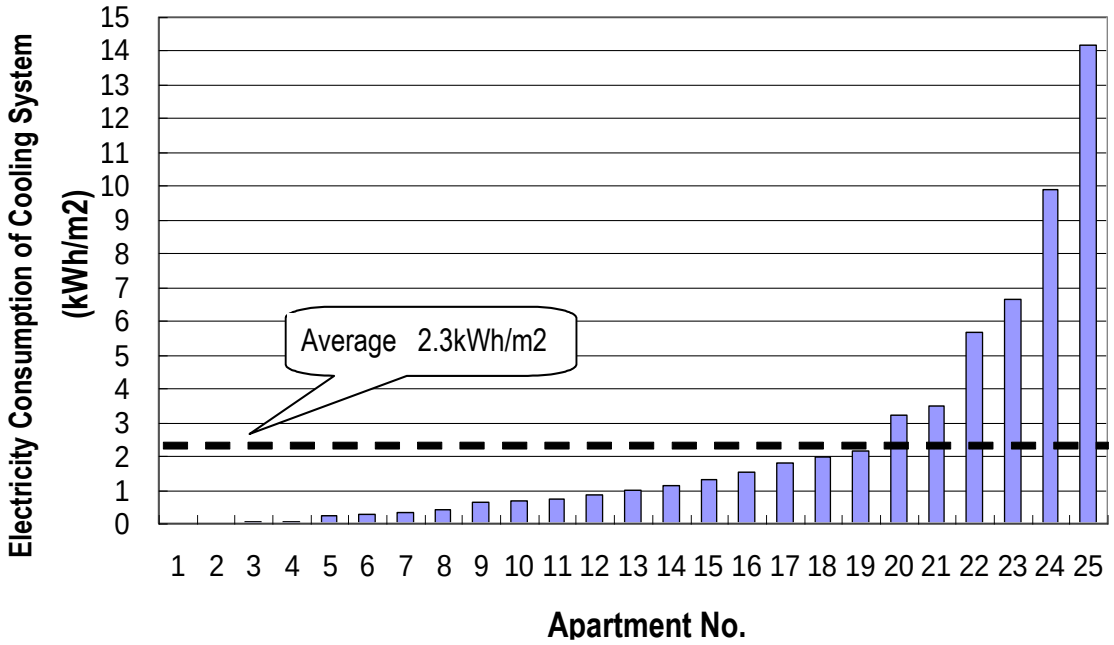
- Even greater differences at end-use level
- End-use data extremely valuable for forensic accuracy assessment



Courtesy: Danny Parker, FSEC

Background

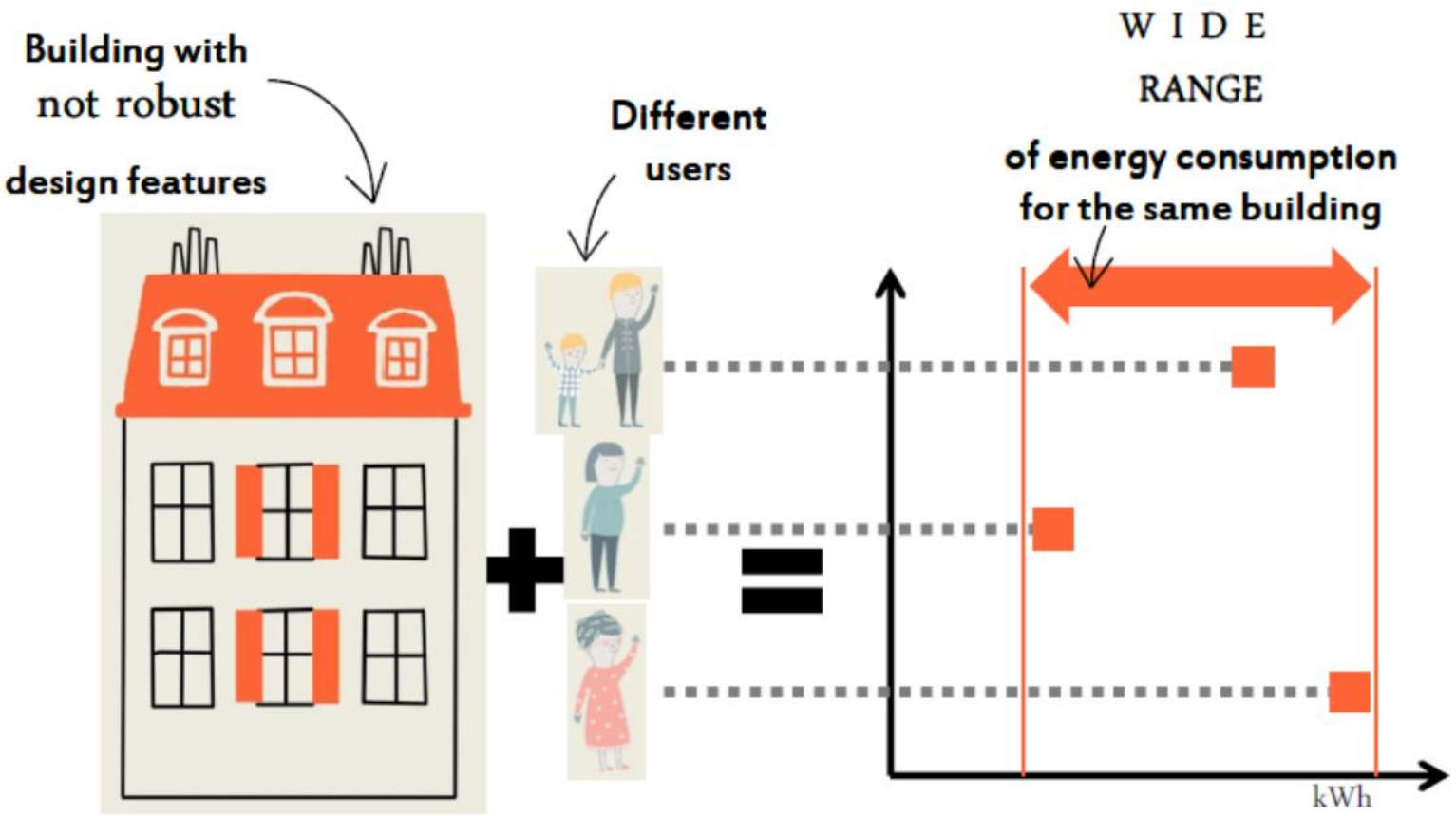
- **OB has significant influence on building energy use**



Significant discrepancy between each apartment

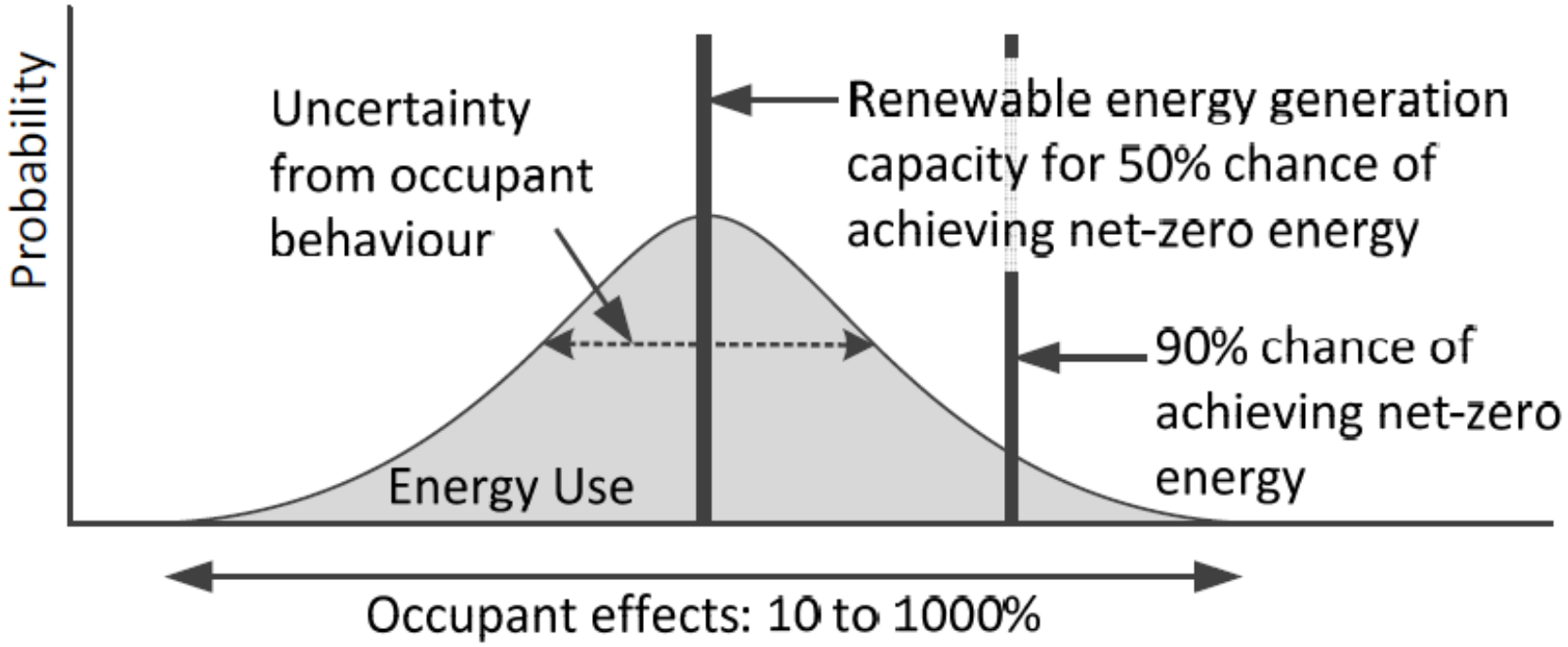
The statistics energy consumption of cooling system in different apartments of one residential building in Beijing,2006

Impact of OB on energy consumption



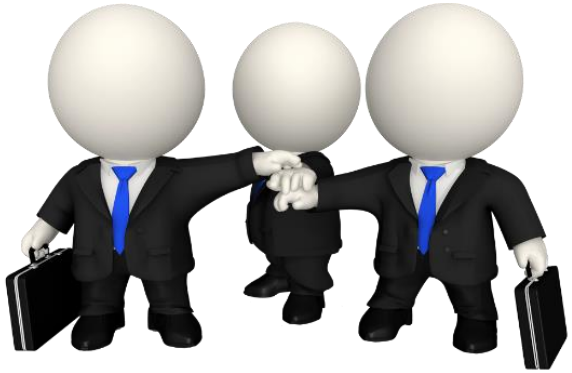
Stefano Corgnati, POLITO

Uncertainty from occupants and NZEBs

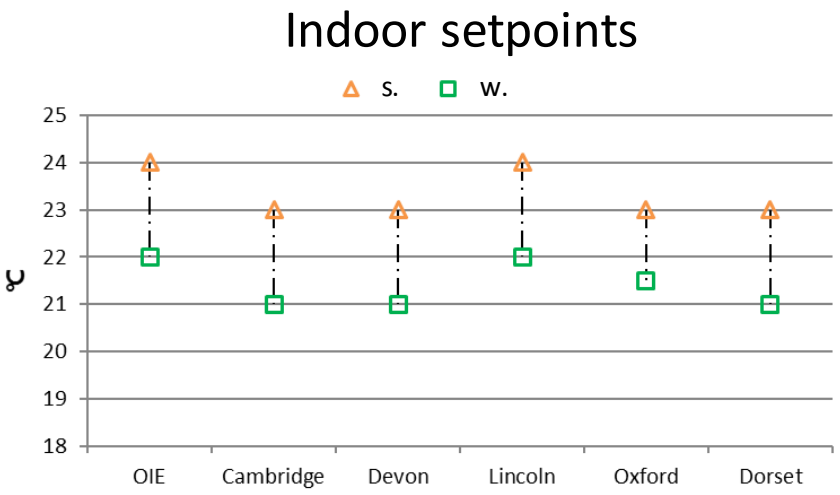


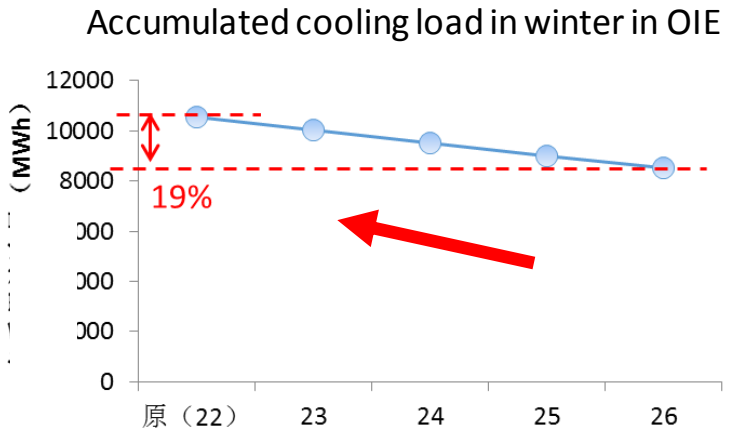
Story 1

- **Wear a tie to save energy in winter**
  - Staffs of Hong Kong office building are required to ware the tie during November to May, while not during summer
  - The set point of AC could decrease from 24 C to 20 C
  - To save the energy usage

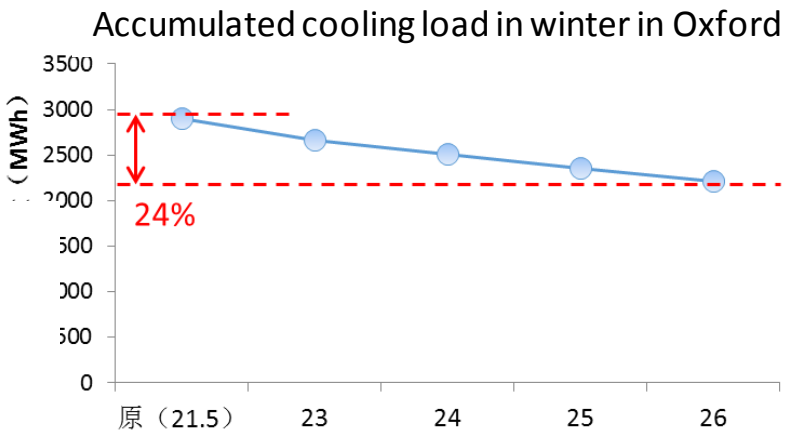


Story 1





- Setpoints in winter usually 21 or 22 ℃
- Cooling is demanded in winter in Hong Kong
- Lower setpoint results in higher cooling load

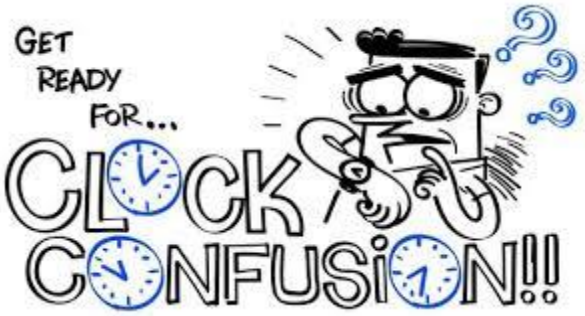


Story 2

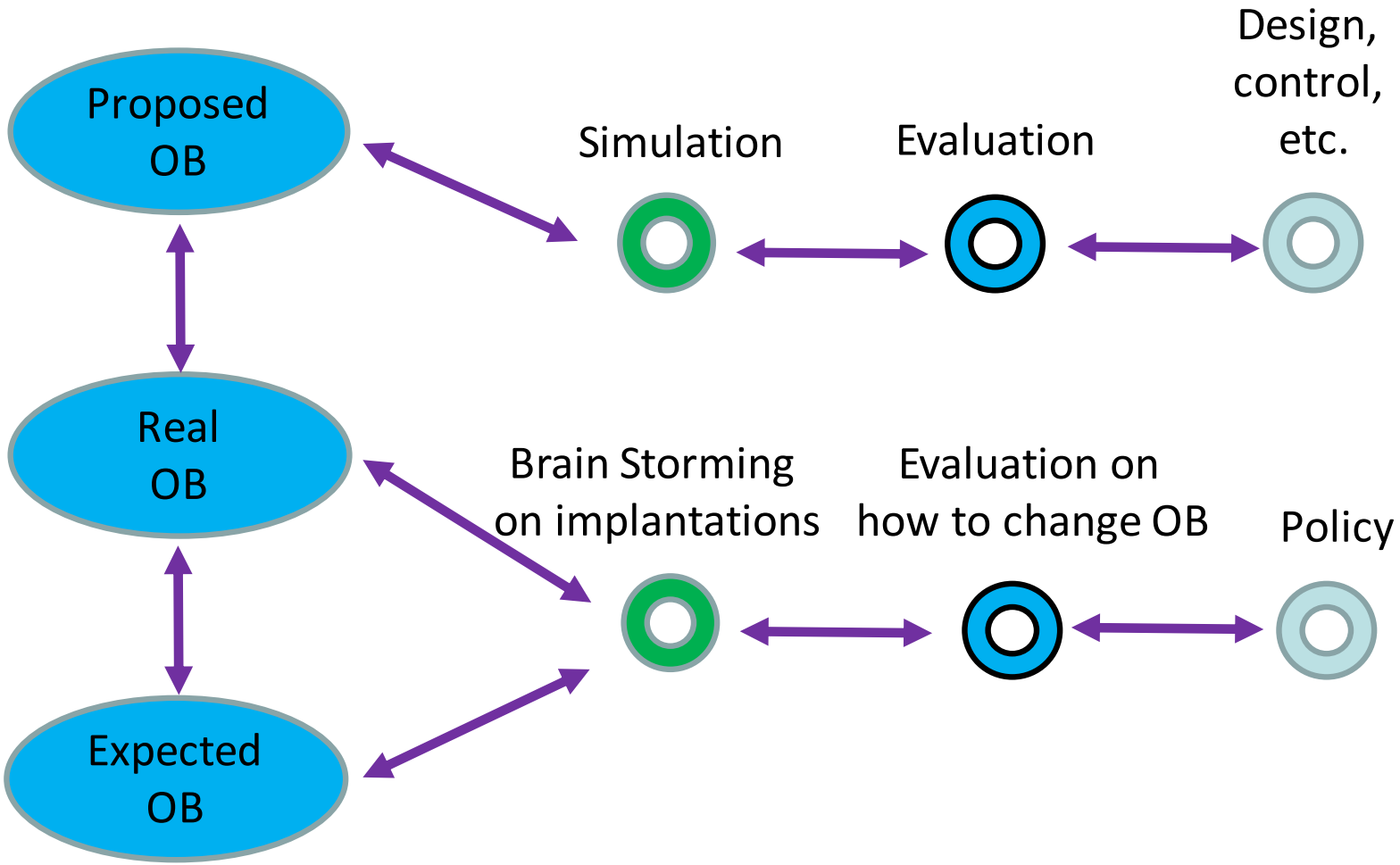
- **Large WWR**
  - Many simulation show benefit to lighting
  - People shut down shading when feeling uncomfortable
  - But will not open the shading
  - Lighting benefit sometime overestimated by simulation

Story 3, Summer time

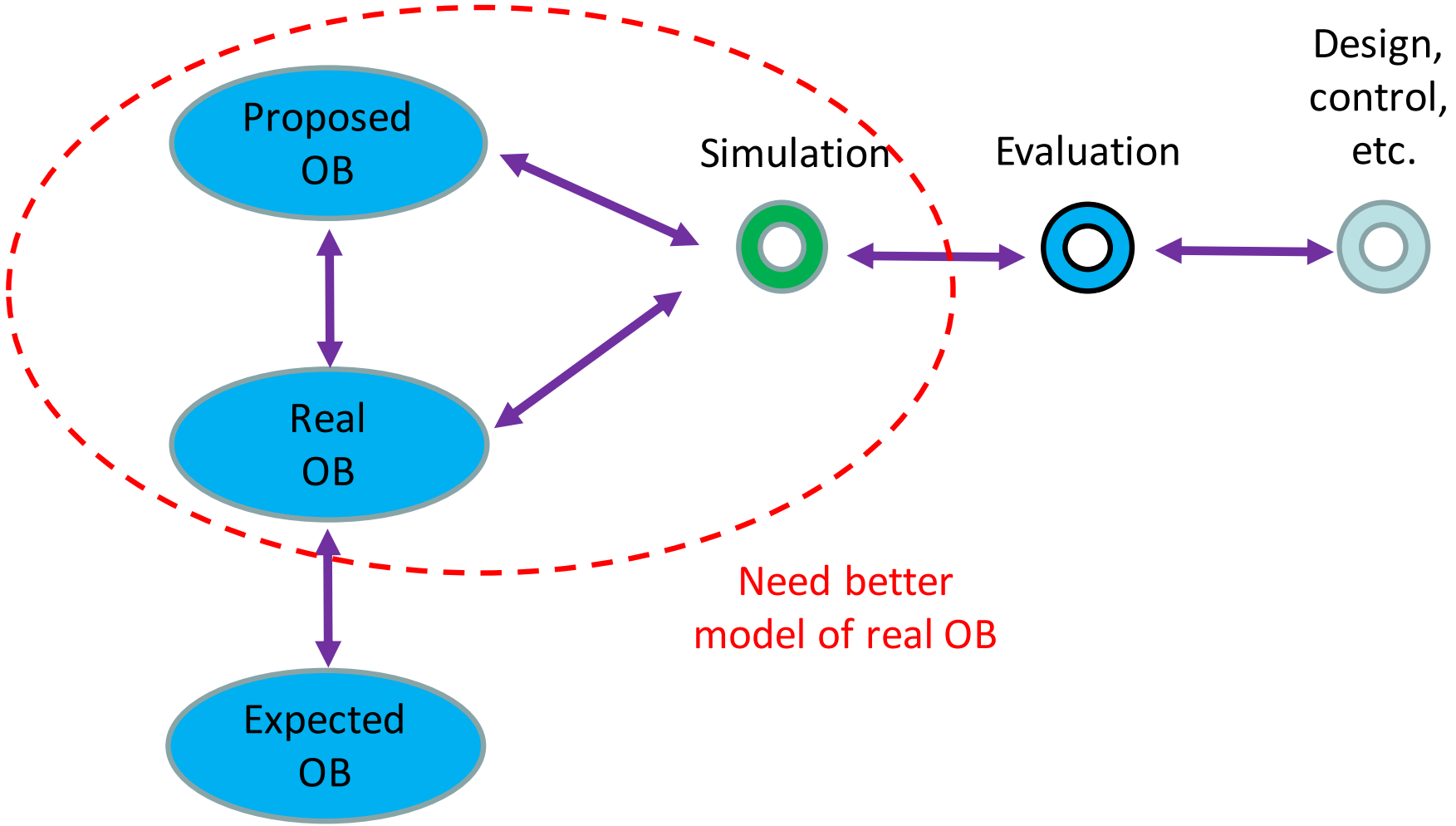
- Summer time is one typical practice to save energy by changing OB
- It suppose to affect on lighting usage
- But will induce more usage of car lighting and will increase the possibility of traffic accident
- More proof is needed to verify the impact of summer time



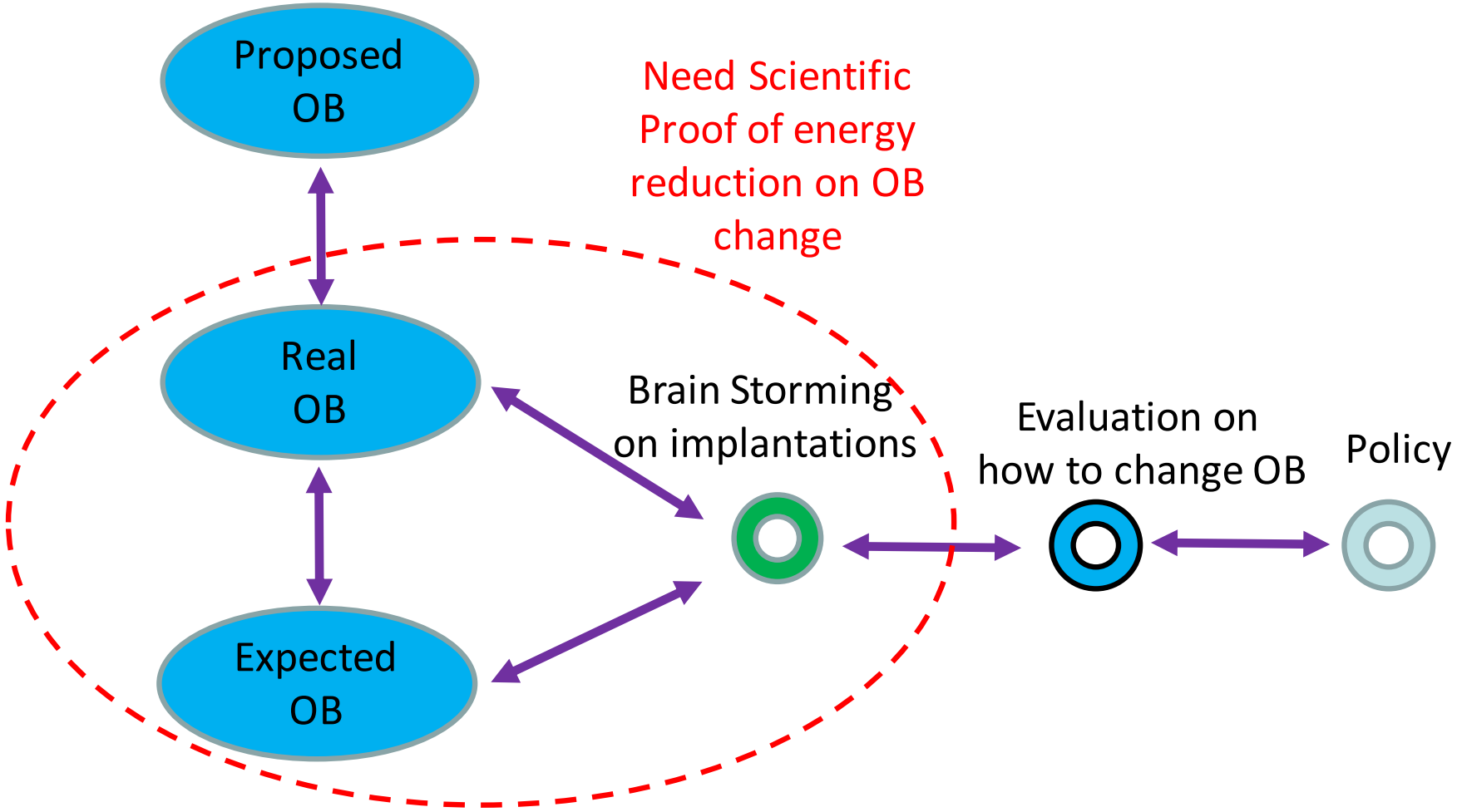
Modelling and Evaluation of OB



Modelling and Evaluation of OB



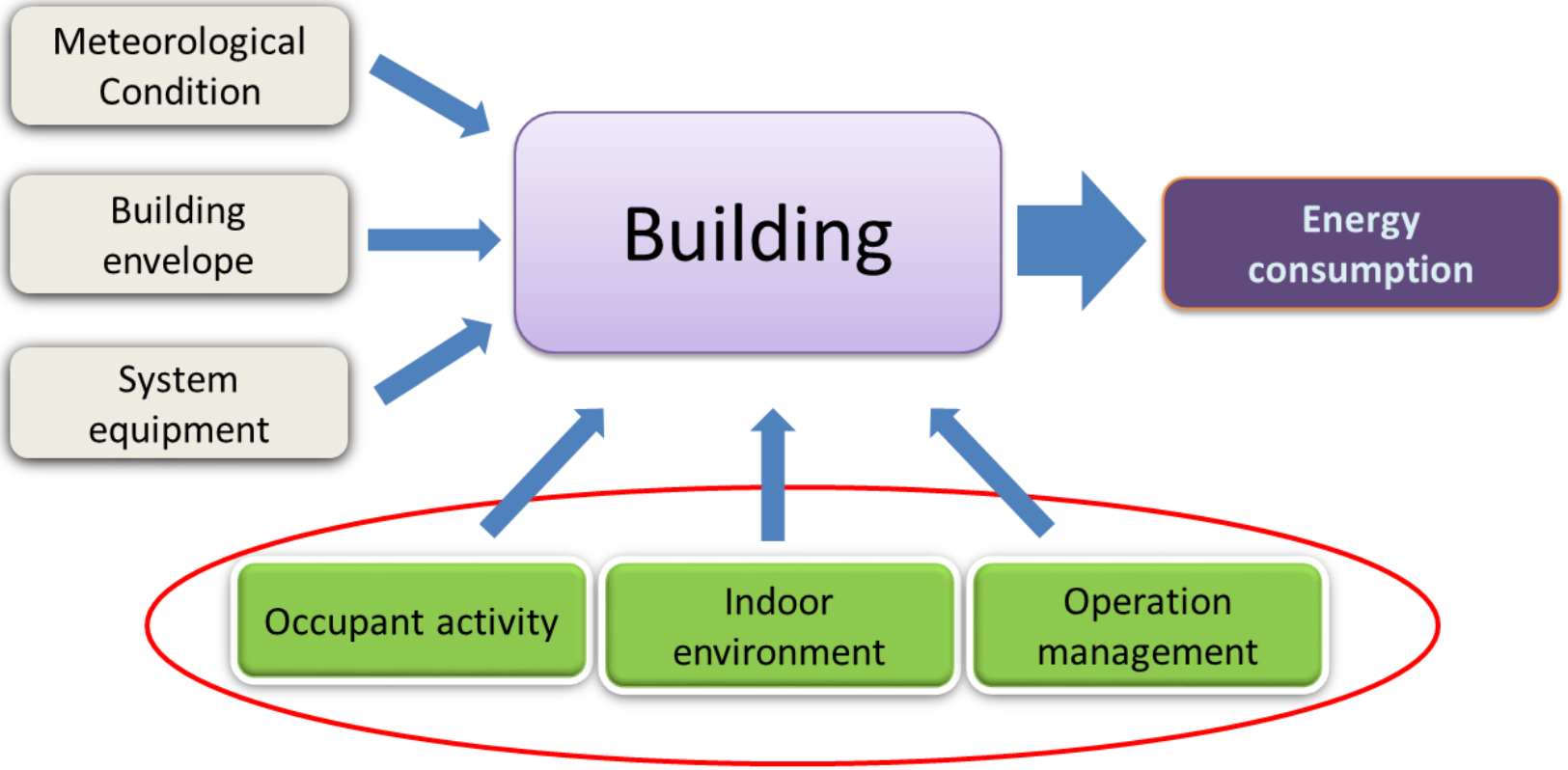
Modelling and Evaluation of OB



Key bottleneck

- Building design and operation
- Energy audit and benchmarking
- Modeling predict control
- Demand side management
- Policy and education
- …

Background

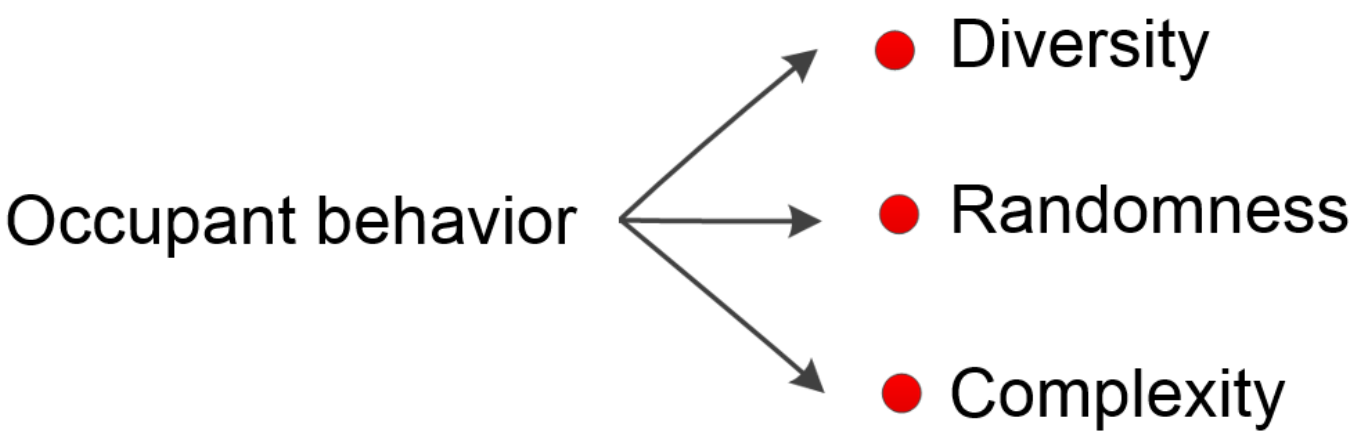


Occupant behavior is a key influencing factor of building energy consumption

Importance and Urgency

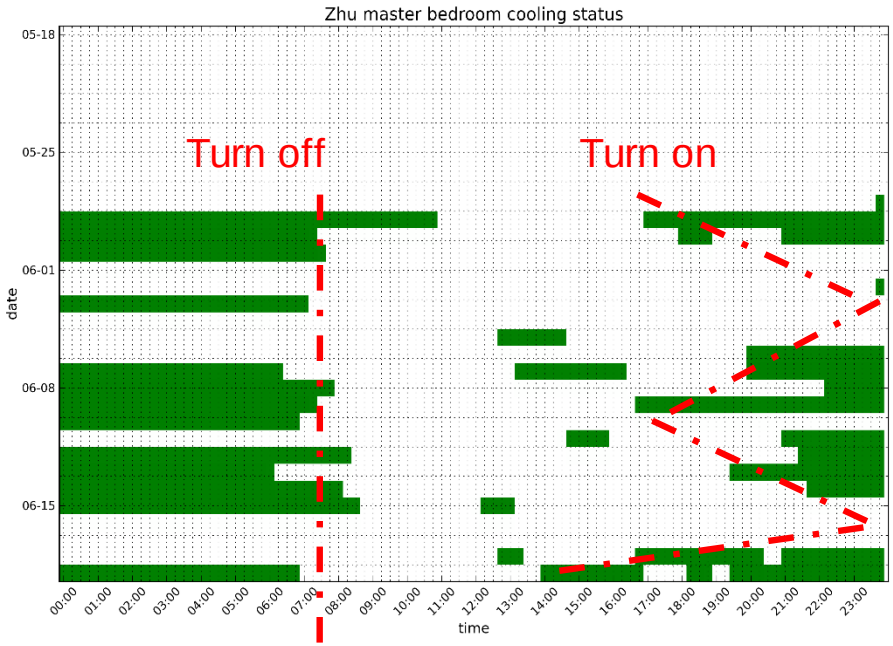
- OB is a **Key factor** for design optimization, energy diagnosis and performance evaluation, and also building energy simulation
- Limited understanding or inadequate over-simplification on OB;
- **In-depth quantitative analysis** urgently needed;
- Over 20 groups all over the world studying OB individually
- **Lack of consensus** in common language, in good experimental design, and in modeling methodologies.

Challenges



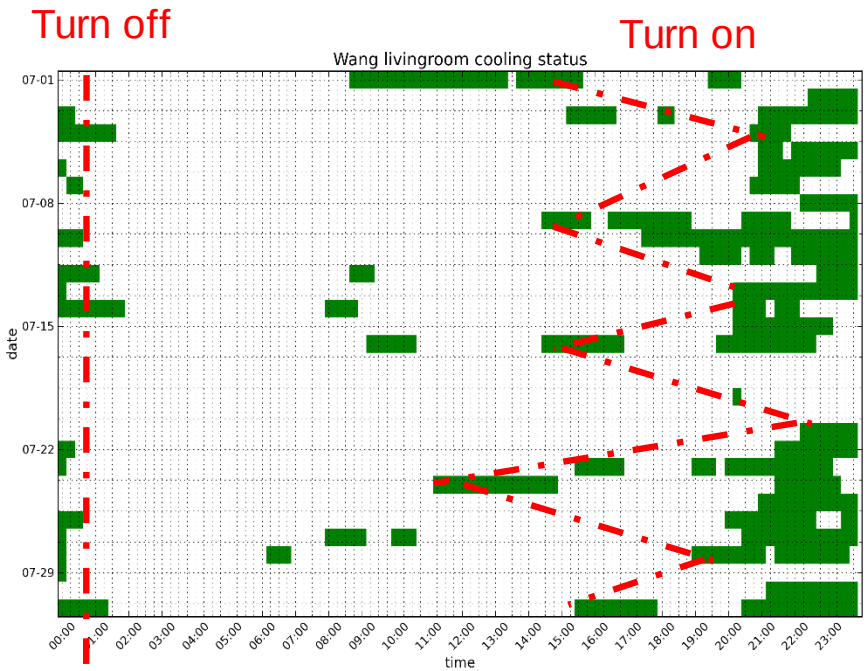
Diversity

- **Zhu, 2011/5-6**



8：00

- **Wang,2011/7**

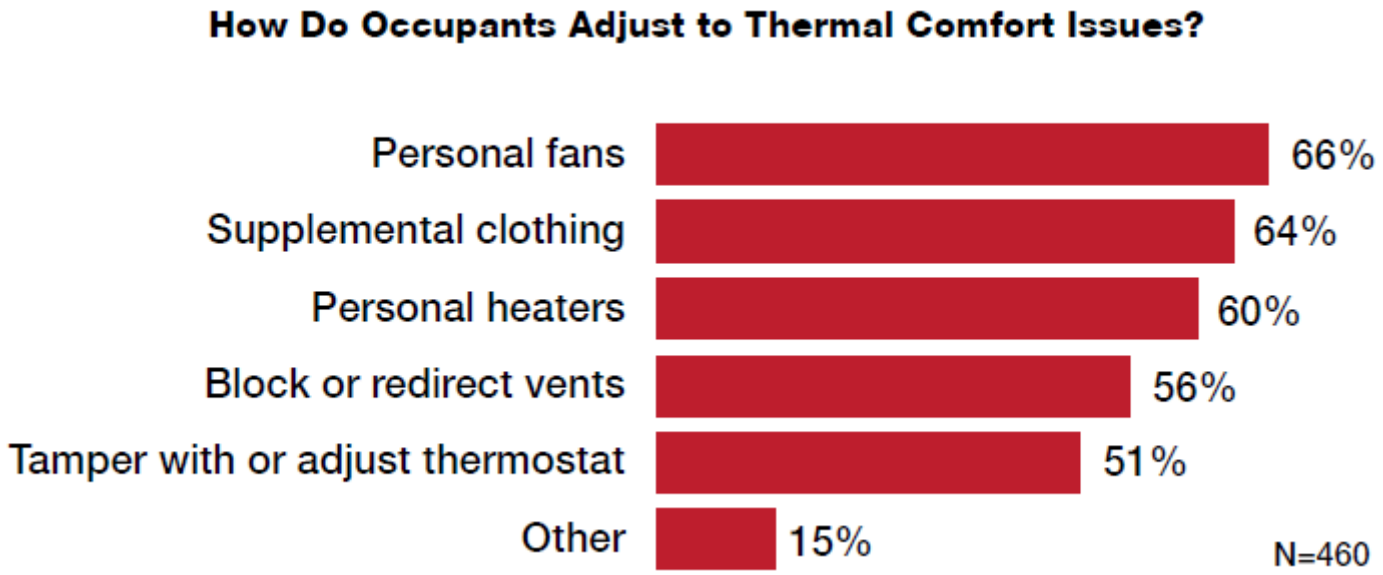


0：00

ON

OFF

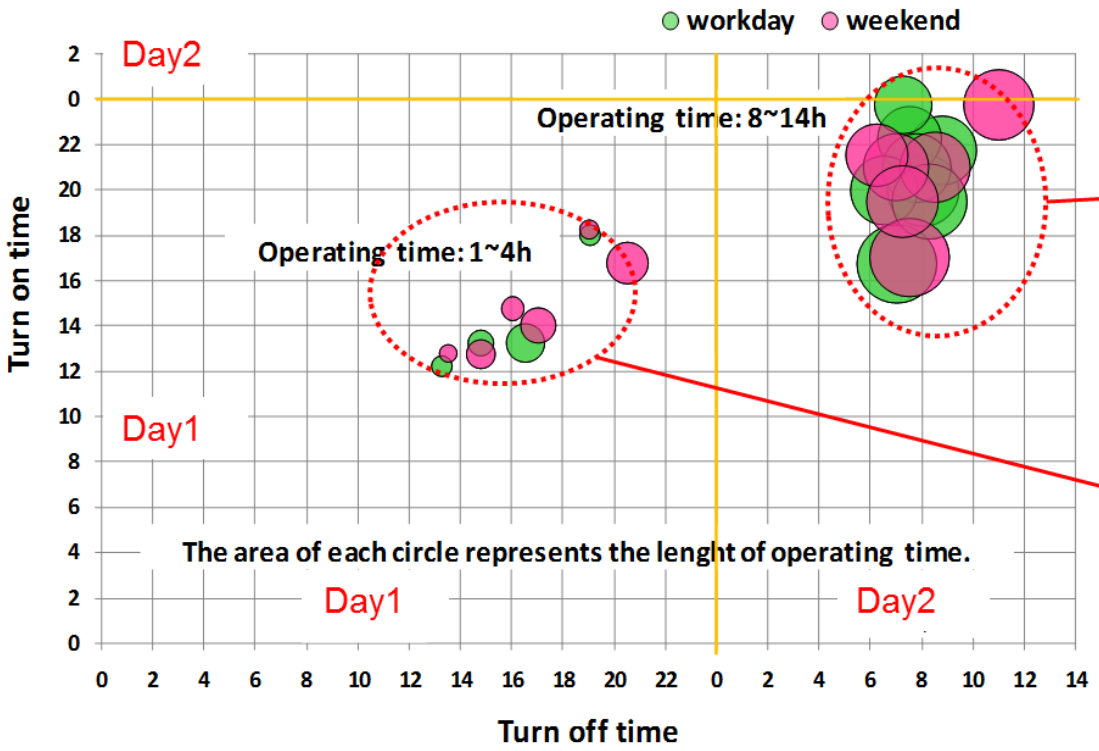
Diversity



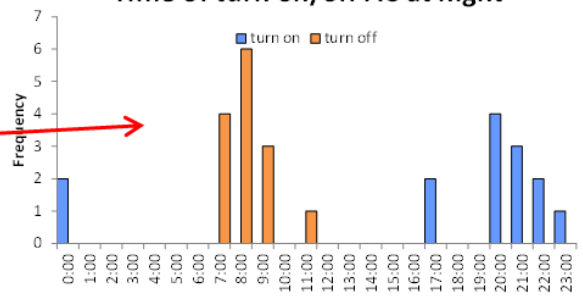
Other responses include: complain, contact facilities department, keep blankets and sweaters within reach, and open windows.

IFMA 2009 HVAC Survey of IFMA members in US and Canada with 452 responses from 3357 samples

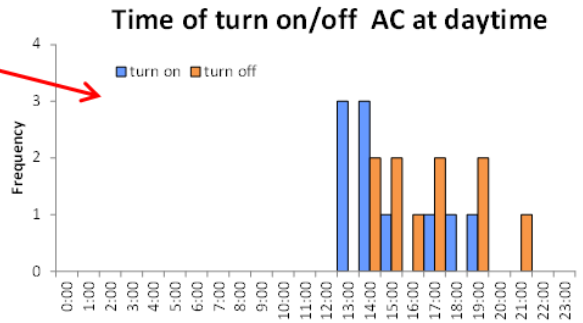
Stochastic process



- **Scheduled part**



- **Random part**

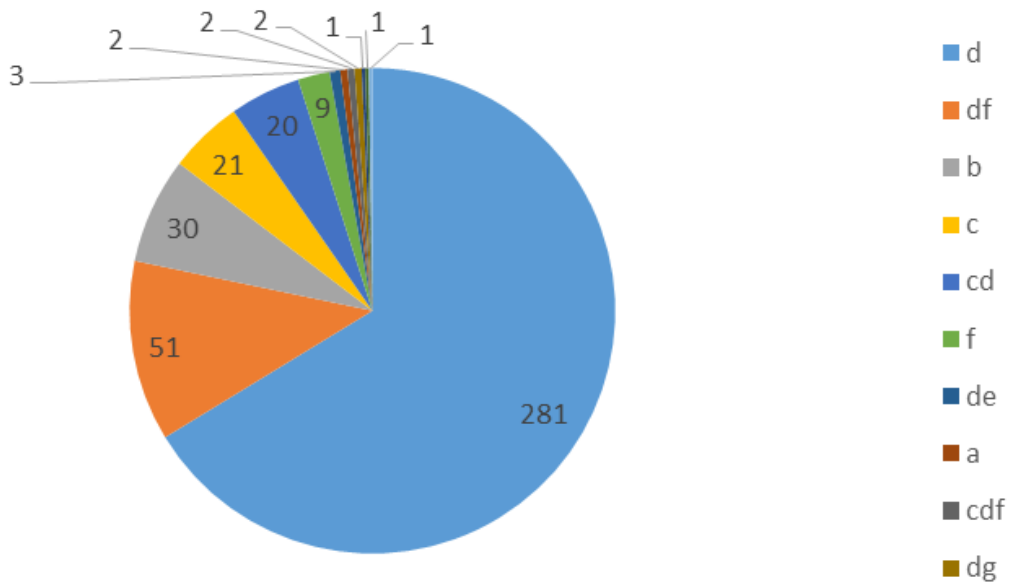


Complexity

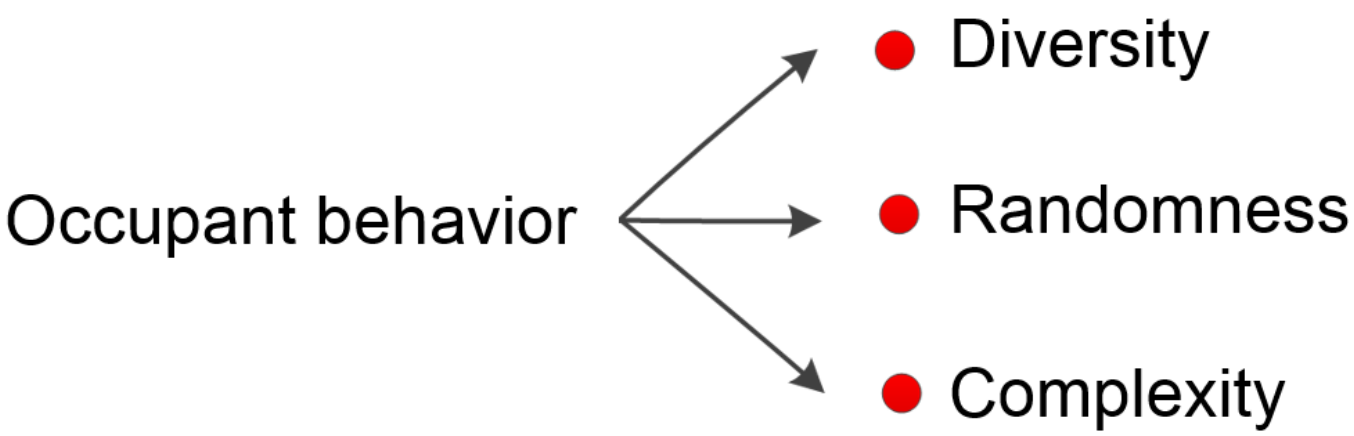
- **Behavior may be triggered by multiple factors for an individual**
- **And behavior would interactive with each others**

Questionnaire survey results in Chengdu

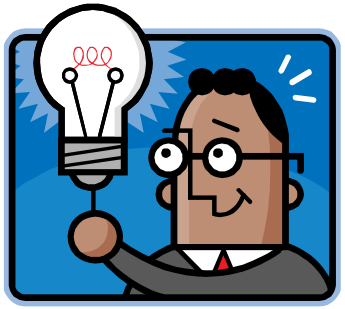
Opening mode	
a	Never on
b	Always on in summer
c	On as long as entering
d	On feeling hot
e	On regular at ___ o'clock
f	On when guests come
g	Others

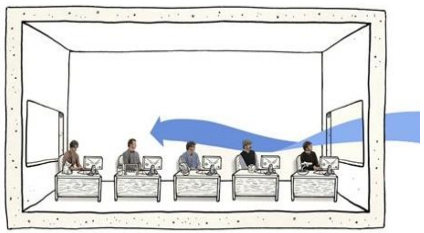


Challenges



Personnel presence and movement model





Personal
Presence & Movement

Occupant's presence and movement is strongly connected with Space, Time and Events

Personnel presence and movement model

Building level – # of occupants

- Q: How many occupants are there in a building at a time?

Space level – occupied status

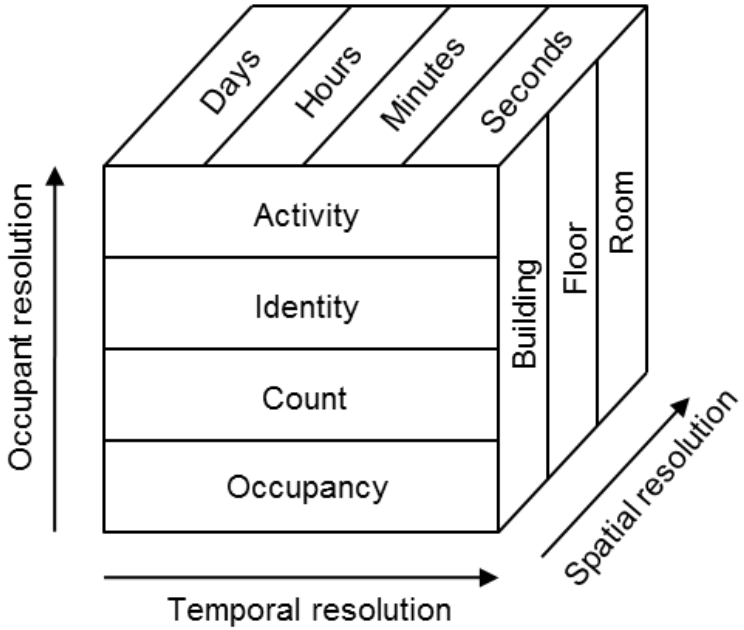
- Q: whether or not a space (room) is occupied?

Space level – # of occupants

- Q: How many occupants are there in a space at a time?

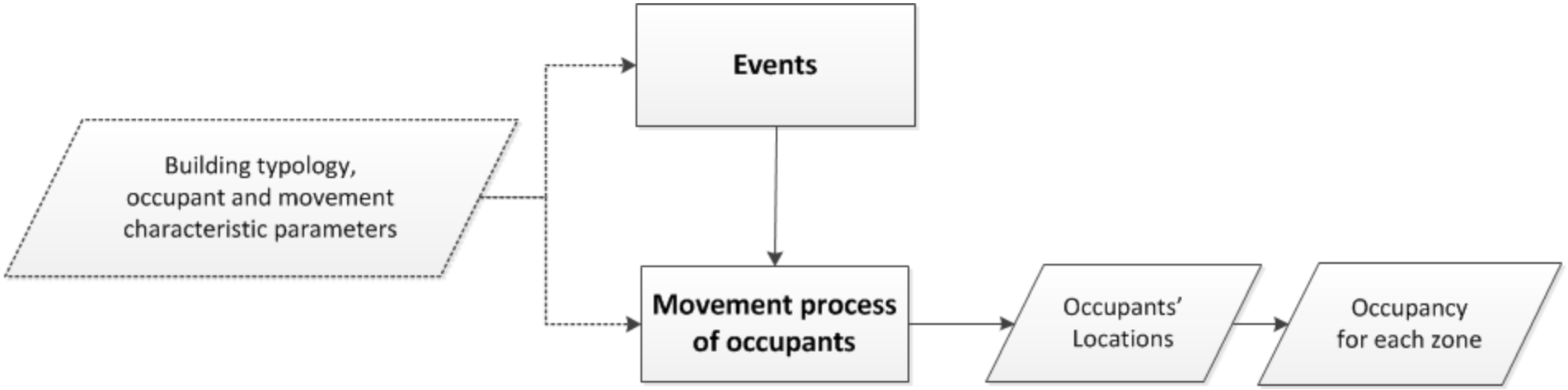
Occupant level - individual tracking

- Q: In which space an occupant is at a particular time?



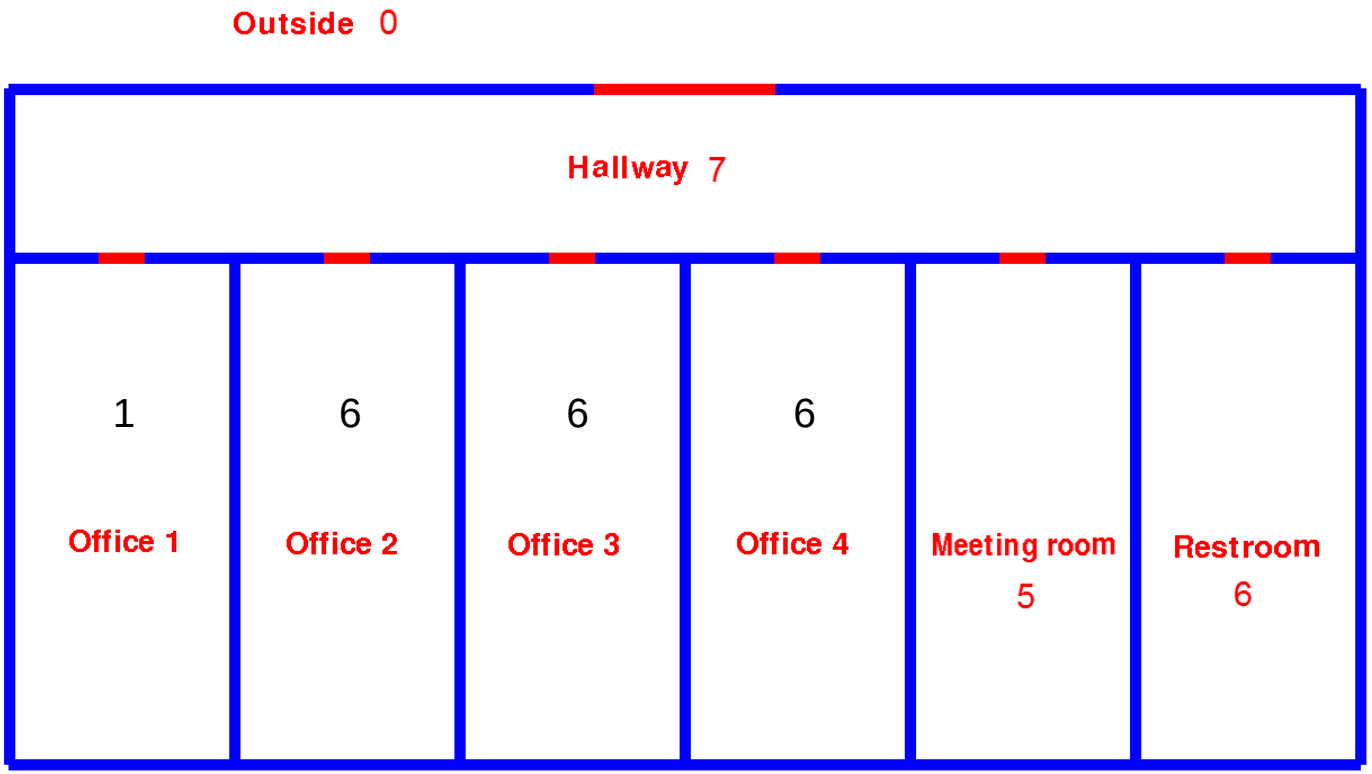
A set of coherent personnel presence models are demanded for different application purposes

Schematic of movement model



Reference: A novel approach for building occupancy simulation. Chuang Wang, Da Yan and Yi Jiang. Building Simulation: An international Journal, 2011, Vol 4, No 2: 149-167. DOI: 10.1007/s12273-011-0044-5 (2011 best paper award)

Simulation example in an office bldg.

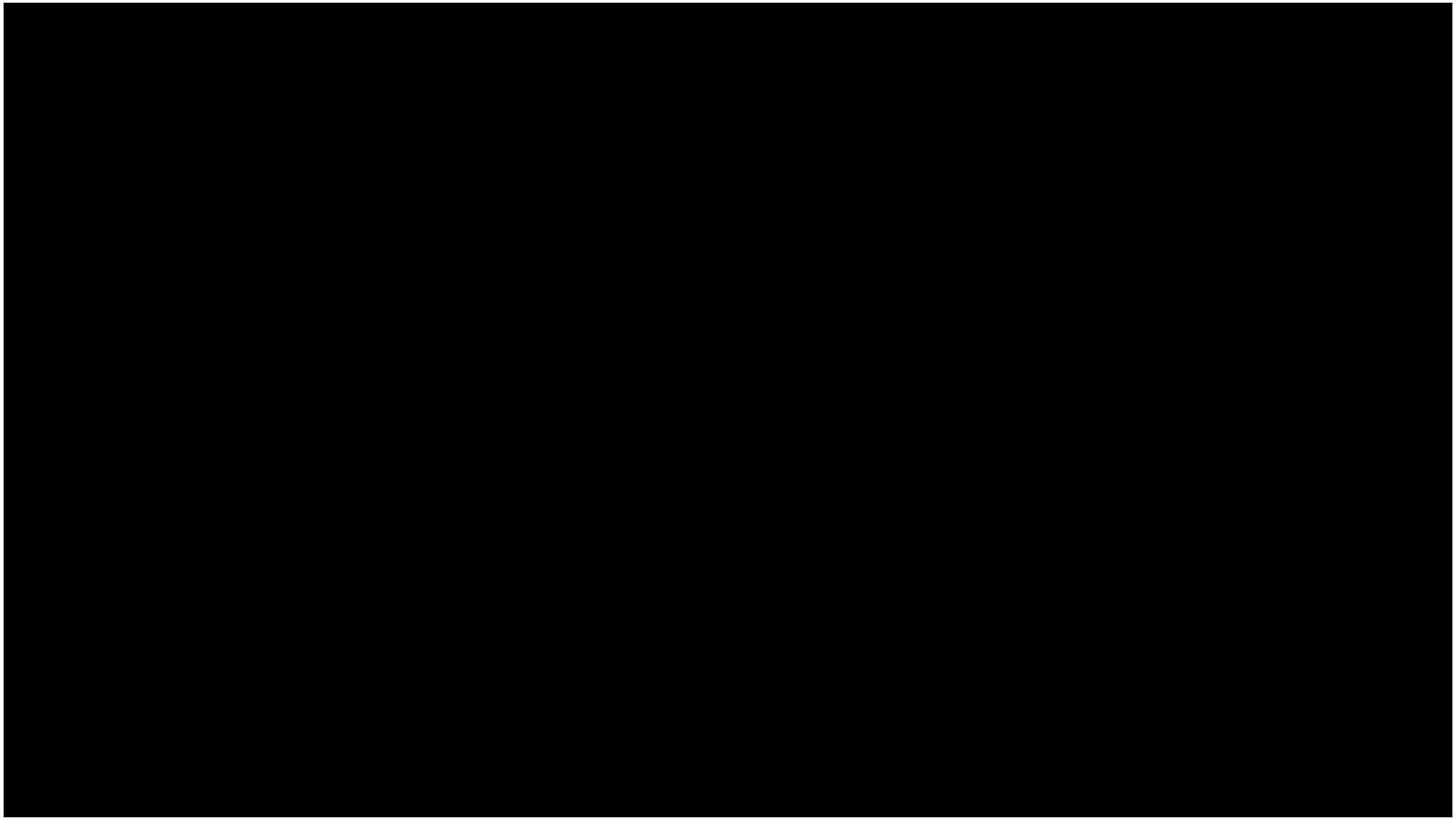


Characteristic parameters for OM

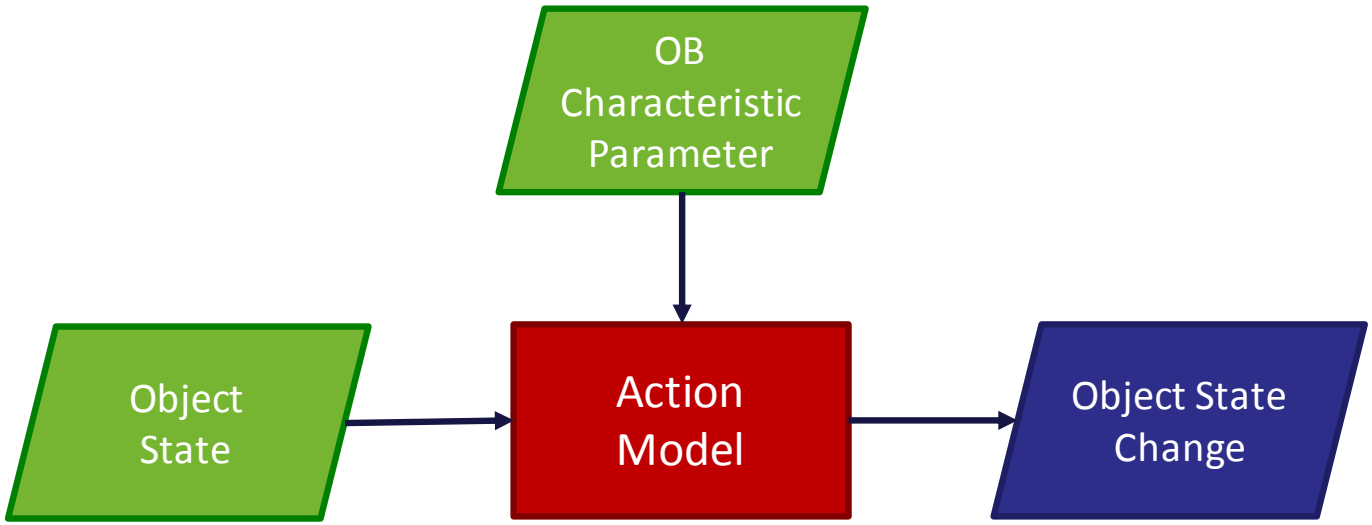
Weekday schedule	Event	Valid Period	Characteristic parameters of occupants		
Working time 8:00~17:00 Lunch time 12:00~13:00	**Go to office**	7:00~8:30	Mean morning arrival time		7:45
	Leave for lunch	11:30~12:30	Mean leaving time		12:00
	Return after lunch	12:30~13:30	Mean return time		13:00
	Get off work	17:00~21:00	Mean night departure time		18:00
	Walk around	8:00~17:00		proportion of time	mean sojourn time in room
			In own office	0.93	3h
			In other rooms	0.06	10min
			In outside	0.01	10min
	Meetings	8:00~17:00	*See table for meeting rooms*		
	Close	23:00	Closing time		23:00

Type of meeting room	Occupied time proportion	Mean duration per time	Minimum attendees	Meeting type	
Meeting room	0.2	1h	2	Group meeting	2/3
				Mixed	1/3

Demo. of simulation results



Action model



State based → Action Based

Action based models has more advantage to exhibit the relationship between OB phenomenon and physical driven force

Conditional Probability Model

- Physical driving forces
  - Environment related (feedback)
    - indoor temperature, humidity, illuminance, CO_2 concentration
  - Event related
    - enter a room, leave a room, sleep, get up
  - Random

E.g: Turn on AC when feeling hot

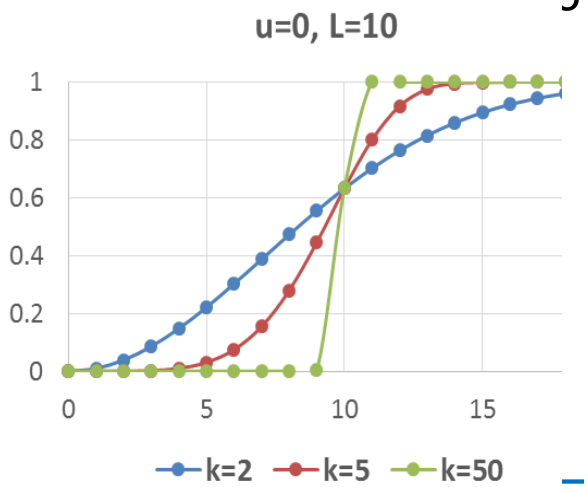
E.g: Turn off light before sleep

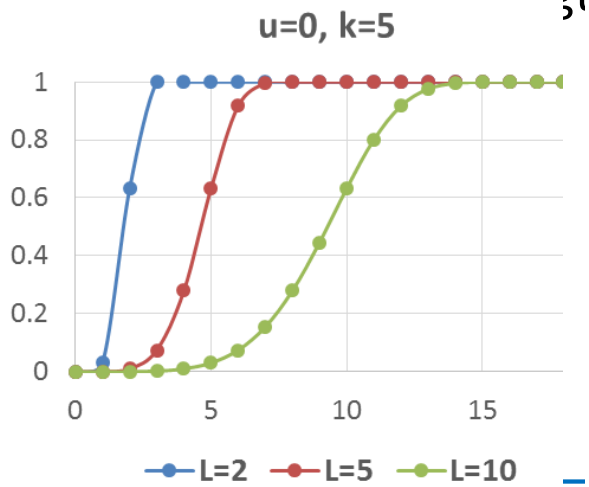
Conditional Probability Model

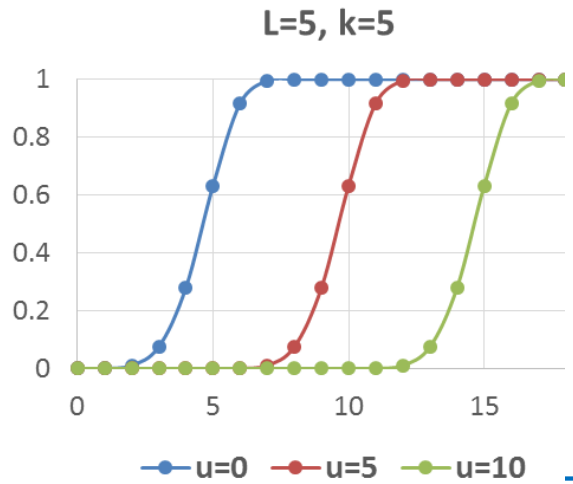
- **Model characteristic**
  - Conditional probability model;
  - Action-based;
  - Environment-related & Event-related;
  - Patterns work alone or in concert;
  - Discrete 3-parameter Weibull cumulative function;

$$P = \begin{cases} 1 - e^{-\left(\frac{x-u}{L}\right)^{k}\Delta\tau}, & x \geq u \\ 0, & x < u \end{cases}$$

$$1 - P^{(n)} = (1 - P^{(1)})^{n}$$





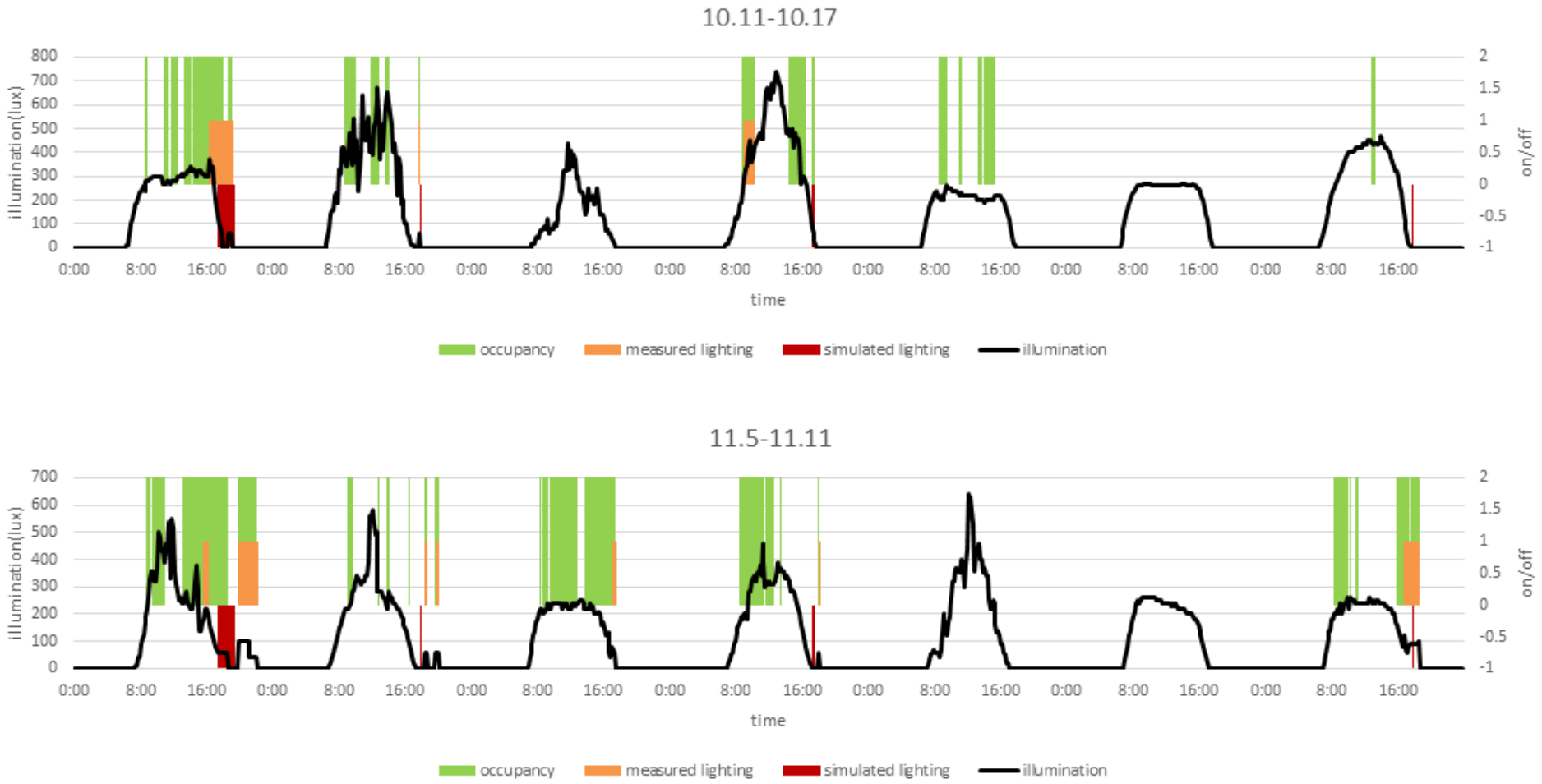


Slope (k)

Scale (L)

Threshold (u)

Simulation result of a office lighting



Case studies: Measurement & monitoring

Res: 49，Com: 22

Temperature & humidity

CO_2

Lighting

AC

Illuminance

Occupancy

Questionnaire

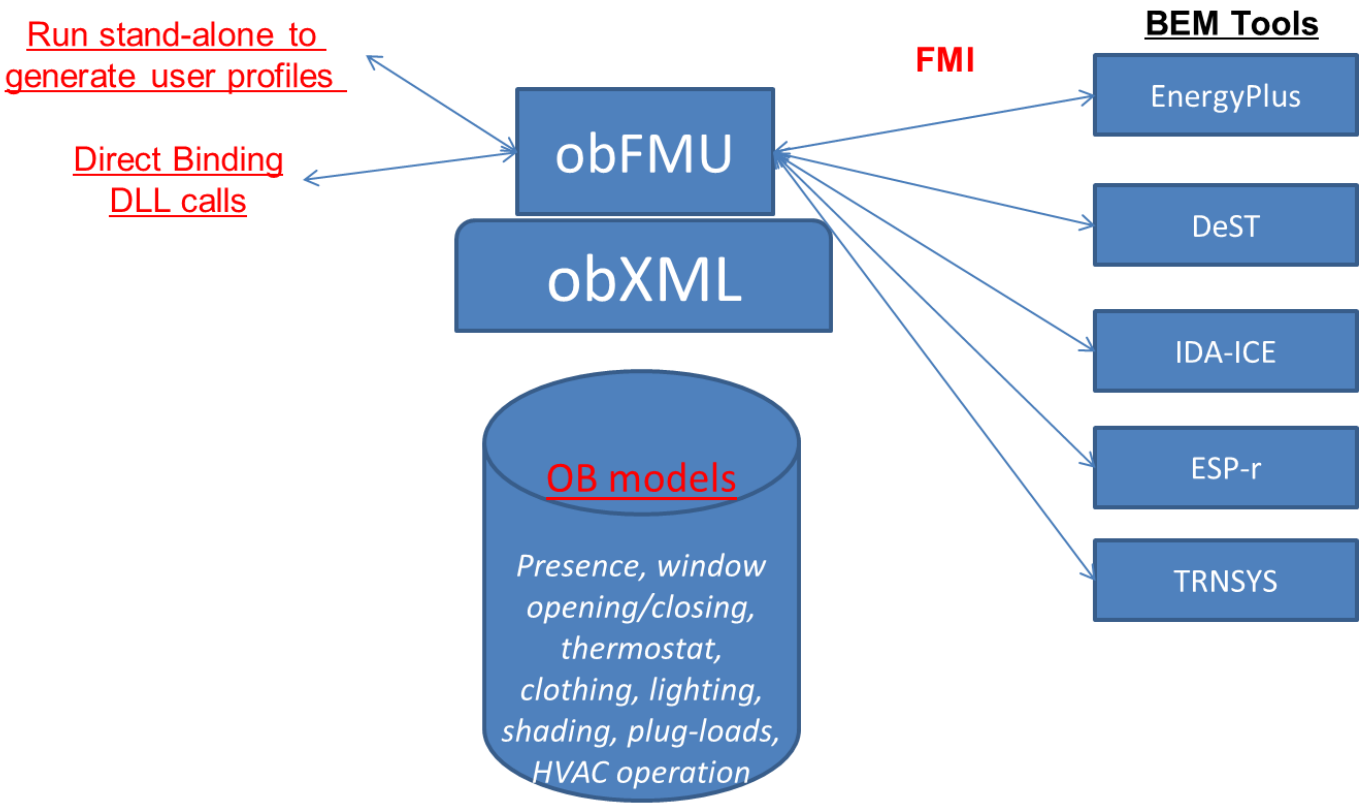
Window

Heating

National Wide Questionnaire Survey

More than 30,000 questionnaires have been done nationwide

Integration with simulation software



Essential to integrate the OB models with BEMs to exhibit the influence of OB on building energy and performance

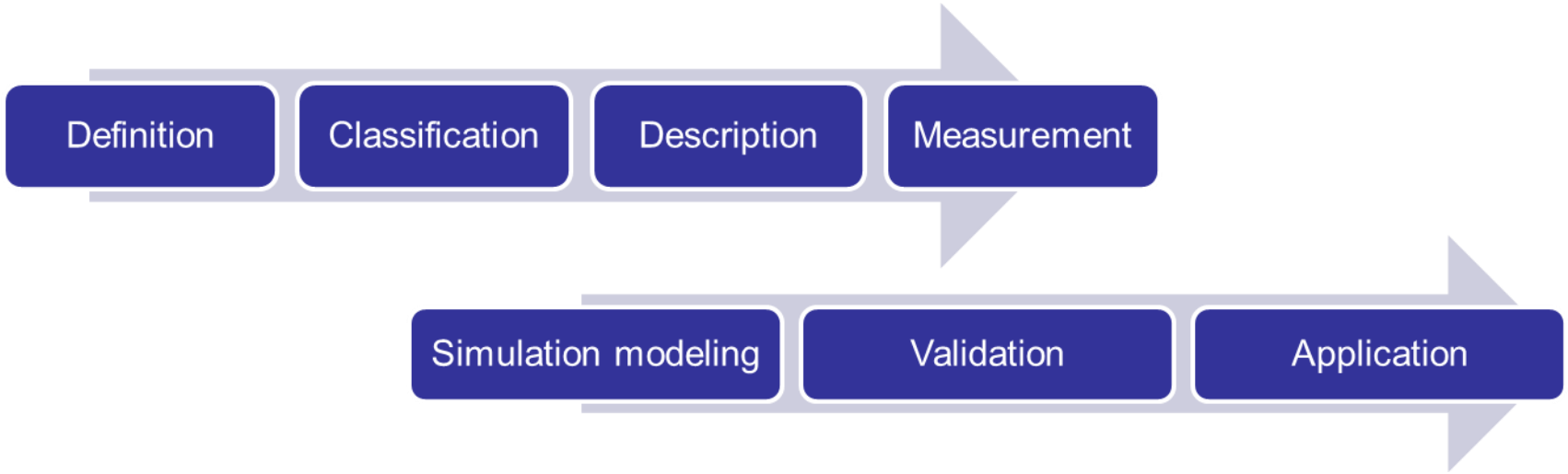
IEA-EBC-ANNEX66

- ANNEX 66, Definition and Simulation of Occupant Behavior in Buildings
- ANNEX is international self-funded project
- **IEA**: International Energy Agency
- **EBC**: Energy in Buildings and Community Programme, carries out research and development activities toward near-zero energy and carbon emissions in the built environment

Energy in Buildings and Communities Programme

www.iea-ebc.org
www.annex66.org

Research Target

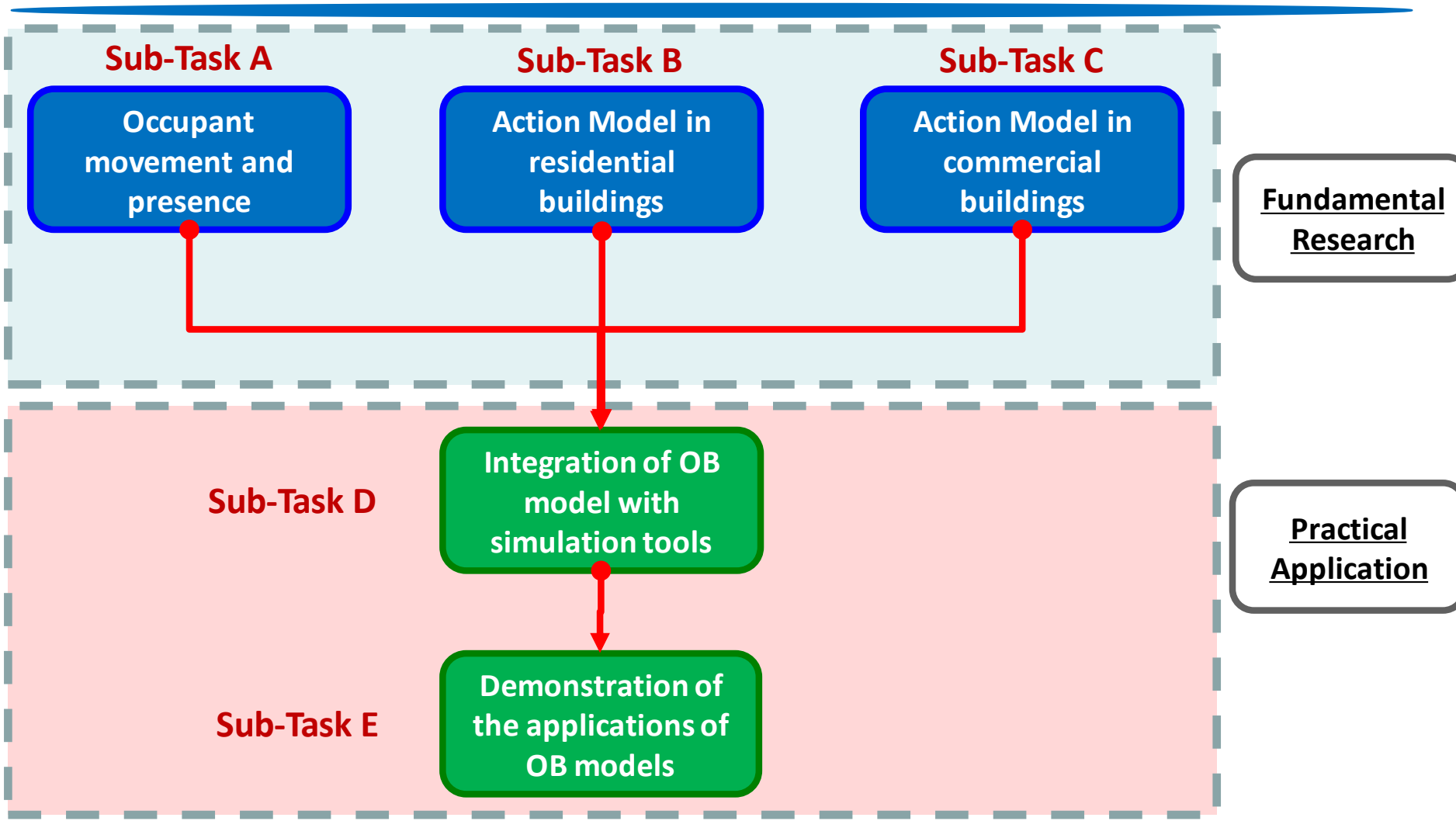


- **Quantitative methods & common language for OB description and simulation**
- **Develop a scientific framework for OB quantitative definition and simulation methodologies**

Technical approach

Targeting Building types:

Residential buildings & Office buildings



Subtask Leaders

Subtask A

Andreas Wagner
KIT, Germany

Bing Dong
UTSA, USA

Subtask B

Henrik Madsen
DTU, Denmark

David Shipworth
UCL, UK

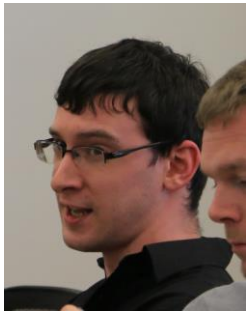
Subtask C

Ardeshir Mahdavi
Vienna University of Technology, Austria

Liam O'Brien
Carleton University, Canada

Subtask D

Tianzhen Hong
LBNL, USA



Andrew Cowie
University of Strathclyde, UK

Subtask E

Khee Poh Lam
CMU, USA

Cary Chan
Swire Properties, Hong Kong

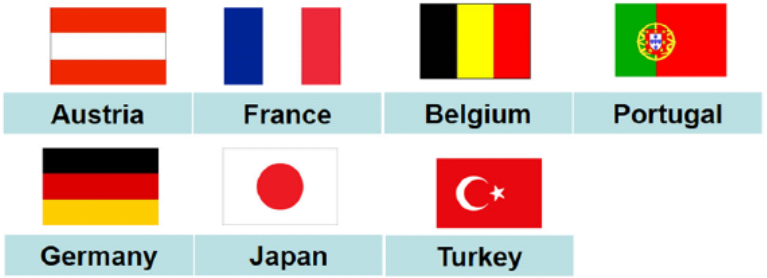
Clinton Andrews
Rutgers University, USA

Participation

12 +1 Official National Participation, 150 participants

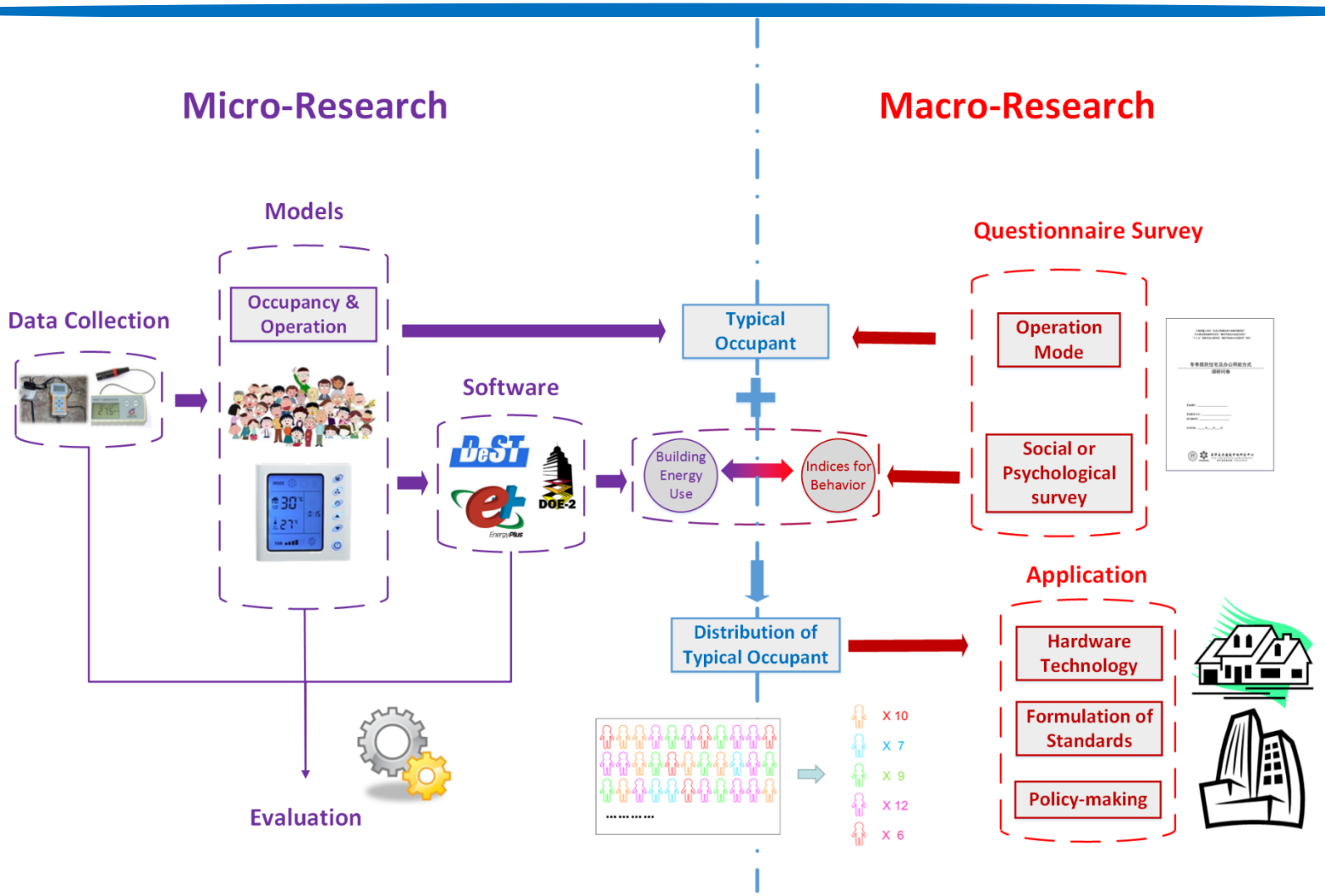
13 Official National Participants

7 Soon-to-be Participants



5 Countries Showing Interest

Perspectives of OB Research



Summary

- OB has **great influence** on building energy usage and also technology evaluation
- There are still lack of **quantitative methods, scientific criteria and common language** for OB description and simulation
- By comparing the OB difference between UK and China, it would be greatly benefit to fully understand the demands, energy usage charteristic and solutions for each countries
- We are looking forward to cooperating to achieve fruitful output in three years efforts.

Thank you for your attention!

yanda@tsinghua.edu.cn

www.annex66.org