EBC

Energy in Buildings and Communities Programme

IEA EBC Annex 66:
Definition and Simulation of Occupant Behavior in Buildings

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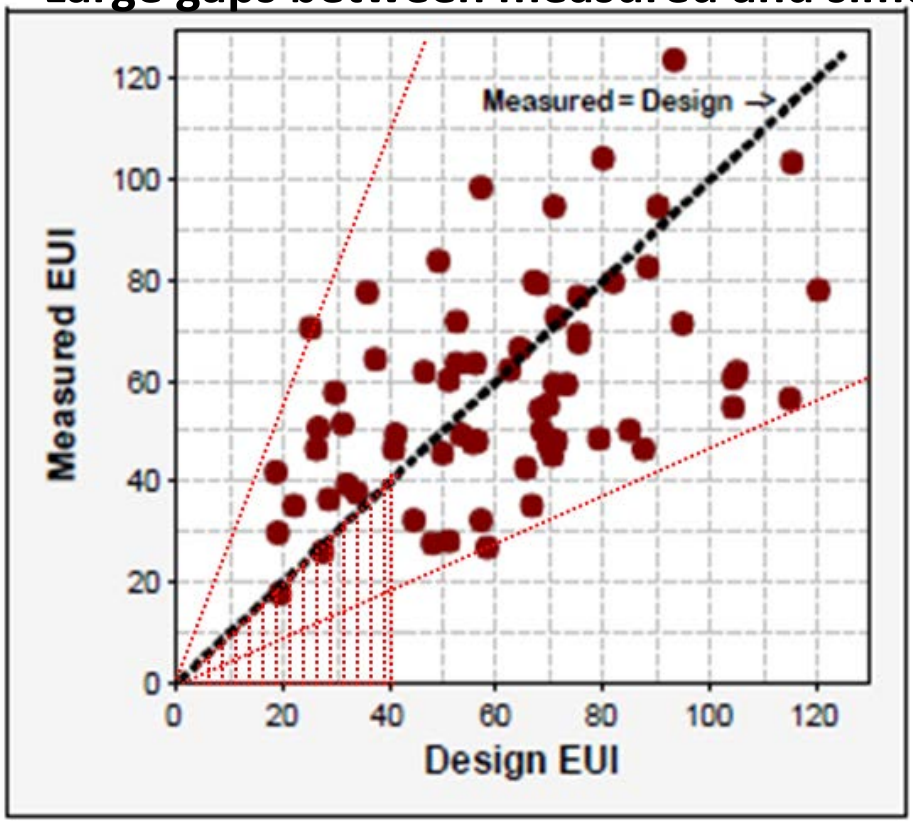
IBPSA-SF

Big Questions

1. Commercial and residential buildings consume energy mostly for human!
2. How energy is used in buildings? Quantitatively?
3. How does my building compare with peers in energy use?
4. How low can the energy use be for my buildings?
5. How to retrofit my buildings?
6. Energy use = (Energy Demand) / (Energy Efficiency)
7. Are current energy goals realistic?
8. Do we have right policy in place to help reach the goals?

Background

Large gaps between measured and simulated energy use

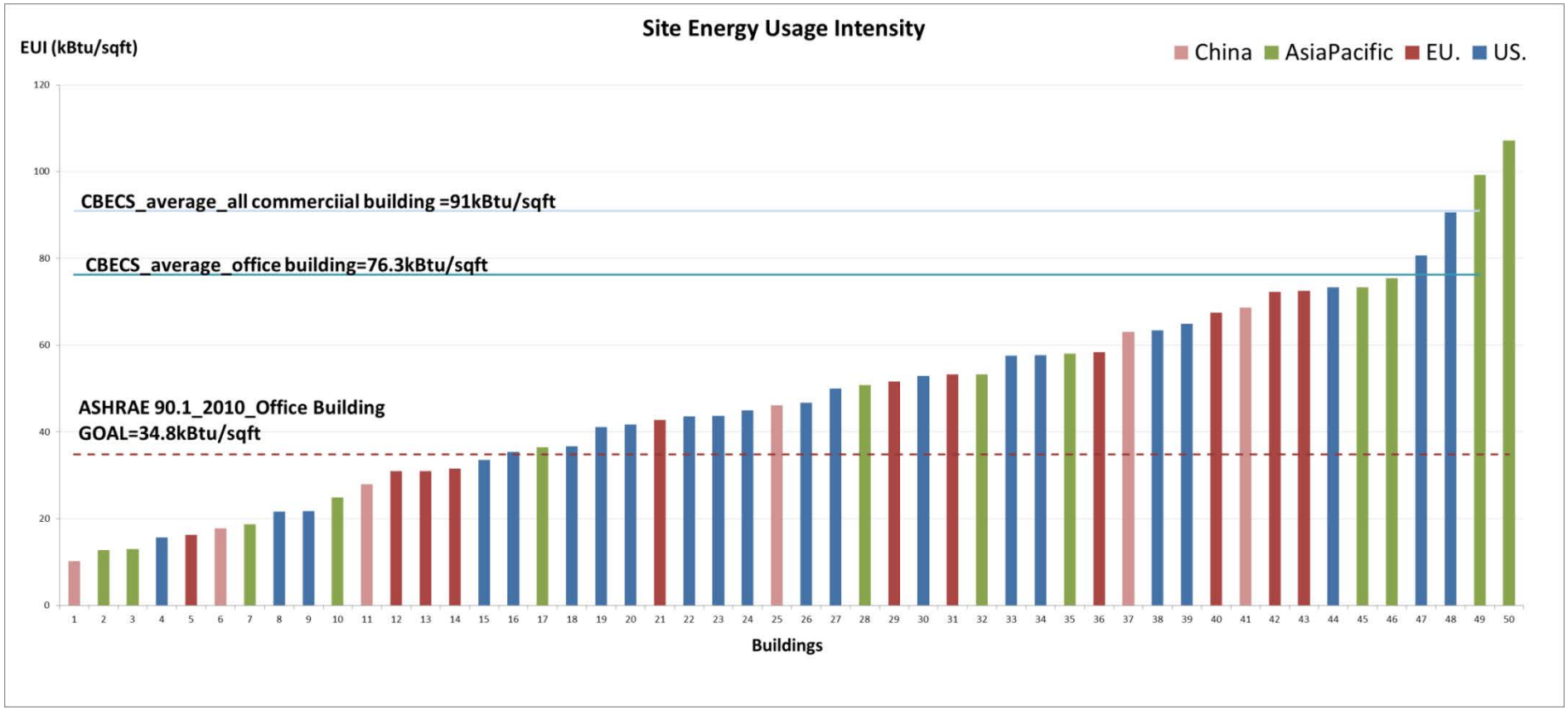


Source: NBI report 2008 Energy Performance of LEED For New Construction Buildings

Influencing factors in energy modeling:

- **Occupancy**
- **Operation and maintenance**
- **Occupant behavior**
- **Controls**
- **Actual equipment performance**
- **Weather data**
- **Simplification and errors in models!**

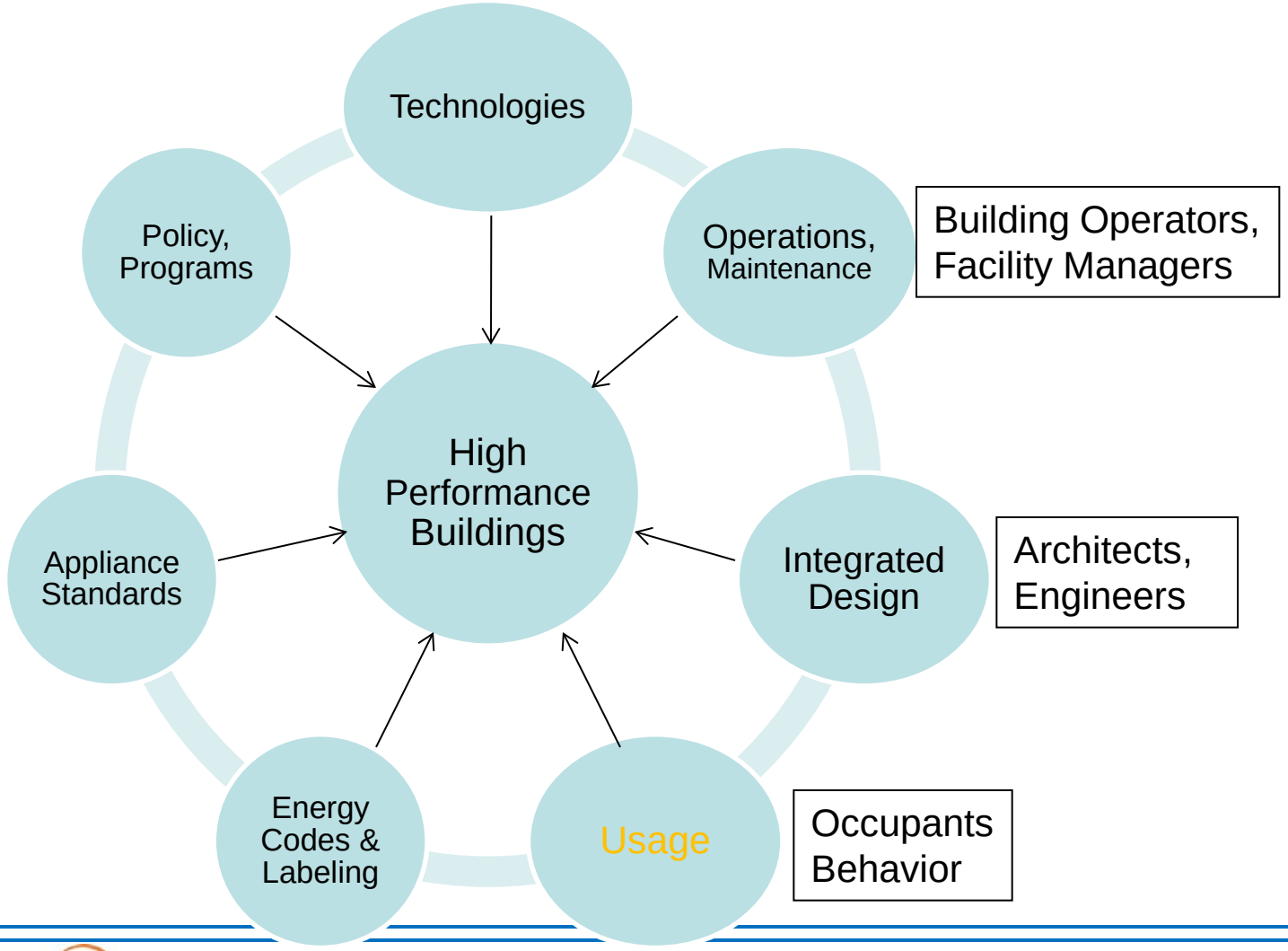
Energy Use of High Performance Buildings



Samples Distribution

	Total number of buildings	Proportion of Buildings (EUI<34.8kBtu/sqft)	Proportion of Buildings (34.8kBtu/sqft<EUI<76.3kBtu/sqft)	Proportion of Buildings (EUI>76.3kBtu/sqft)
US	21	23.8%	66.7%	9.5%
EU	11	36.4%	63.6%	0.0%
Asia	12	33.3%	50.0%	16.7%
China	7	50.0%	50.0%	0.0%

What are strategies to support design and operations of high performance buildings?



Background

- **Technologies alone not necessarily guarantee low energy use in buildings.**
- **Human behavior plays an essential role in building design, operation and maintenance, but it is not well understood and usually over-simplified or ignored!**
- **Behavior changes, usually no or low cost, has demonstrated 5 to 30% energy savings in buildings, but potential savings can be > 50% in very low energy buildings.**

Complexity of Human Behavior

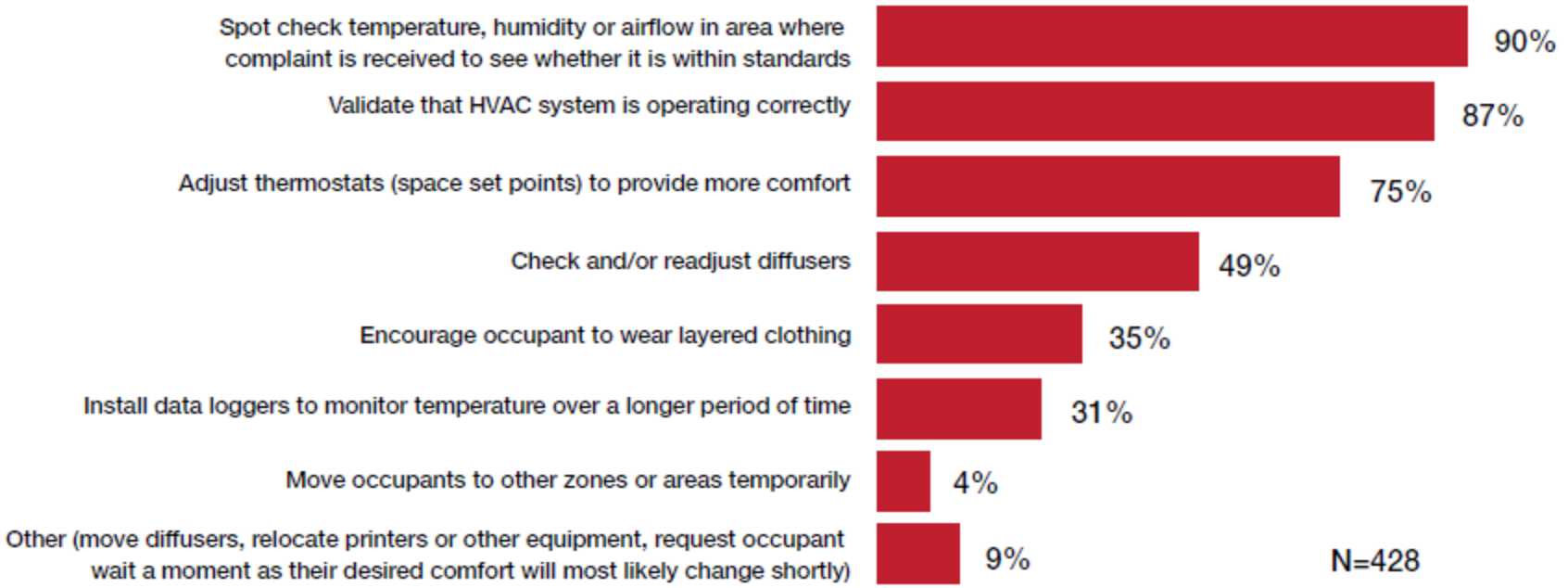
- **Inherent uncertainty**
- **Multi disciplinary**
- **Various driving factors:**
  - Individual: culture, lifestyle, habit, environmental awareness
  - Time of the day, day of the year
  - Location: office, home,…
  - Indoor and outdoor environmental conditions
- **Very limited data to help us understand**

Operator Behavior – an example

One occupant complained too hot during summer (VAV system):

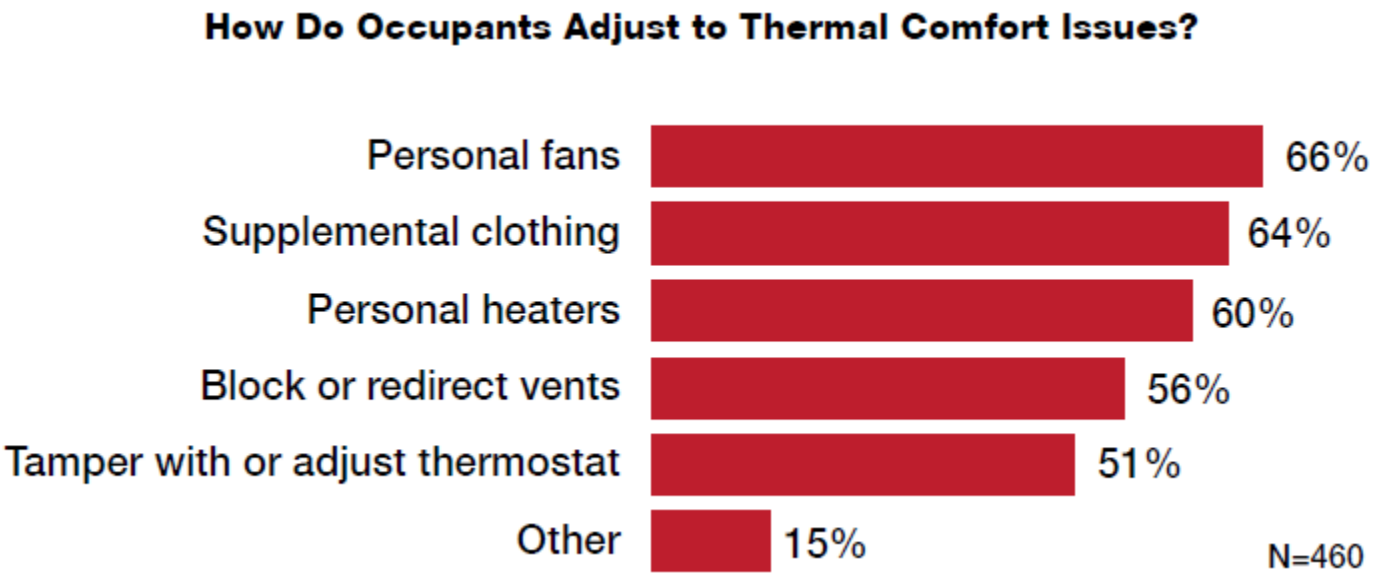
- Other occupants feel ok – no action
- VAV box fully open – raise fan static pressure setpoint
- VAV box partially open – overwrite minimal damper position settings
- For later two options, often forget to restore settings

Steps Taken by Building Operators to Address Thermal Complaints



IFMA 2009 HVAC Survey

Diversity of Occupant Behavior



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

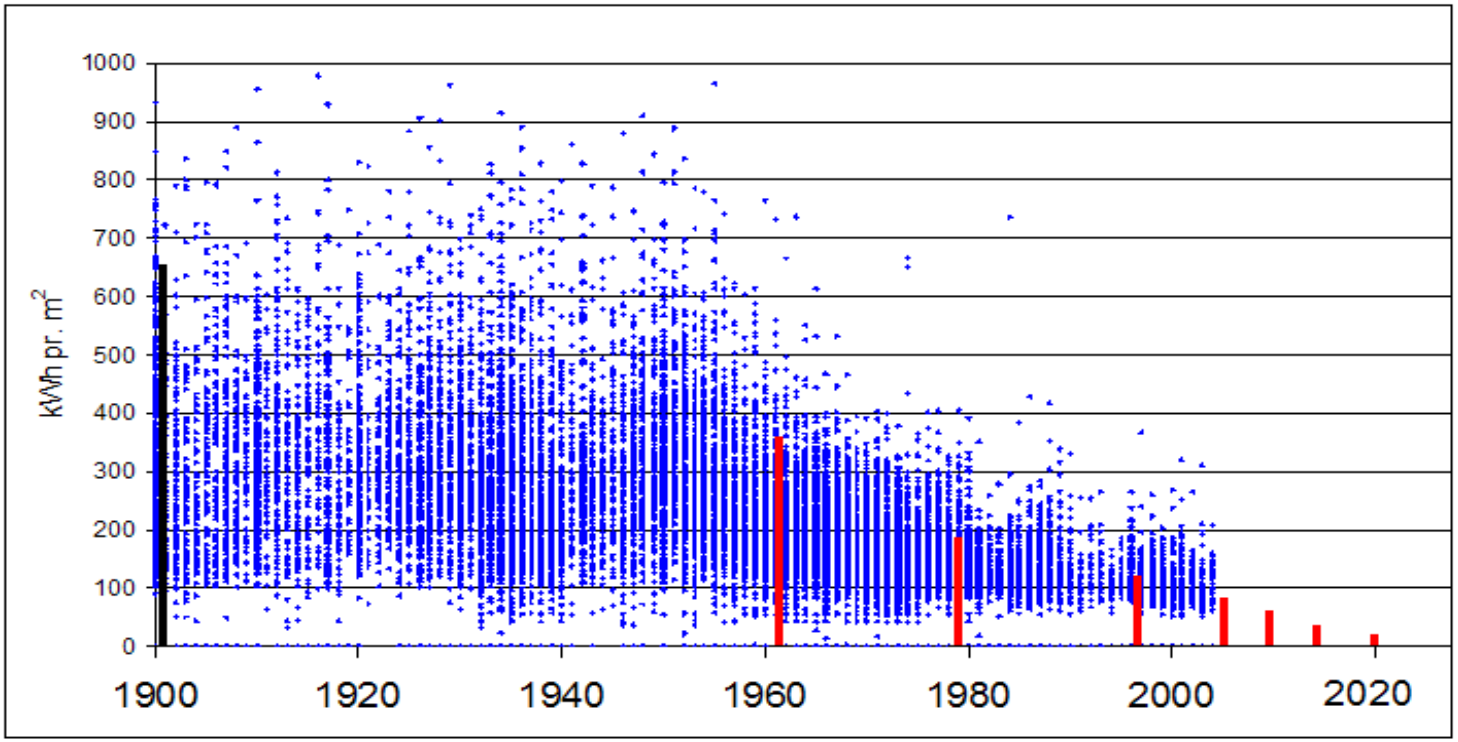
Practical Reasons that Natural Ventilation may not work

Occupants would not open windows due to:

1. **Outdoor air dusty**
2. **Outdoor air polluted**
3. **Outdoor air bad smell**
4. **Adjacent pepper factory**
5. **Outdoor too noisy**

Background

- building energy is not only affected by climate and system



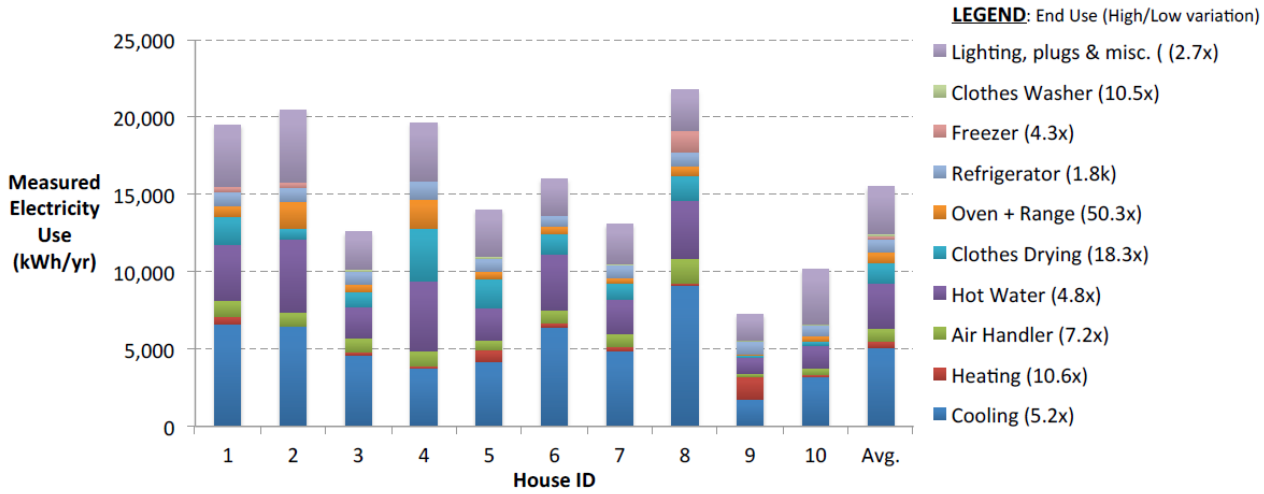
Energy Use in Danish Single Family Houses – By year of construction

Ref.: SBI/Aalborg University

Background

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

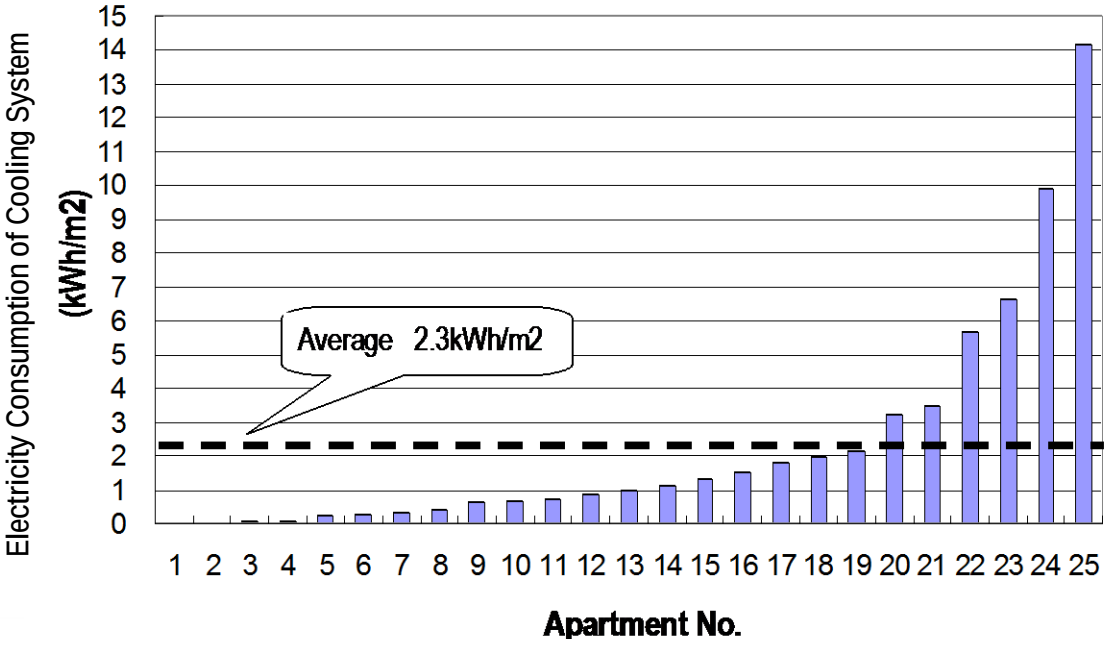
- Even greater differences at end-use level
- End-use data extremely valuable for forensic accuracy assessment



Courtesy: Danny Parker, FSEC

Background

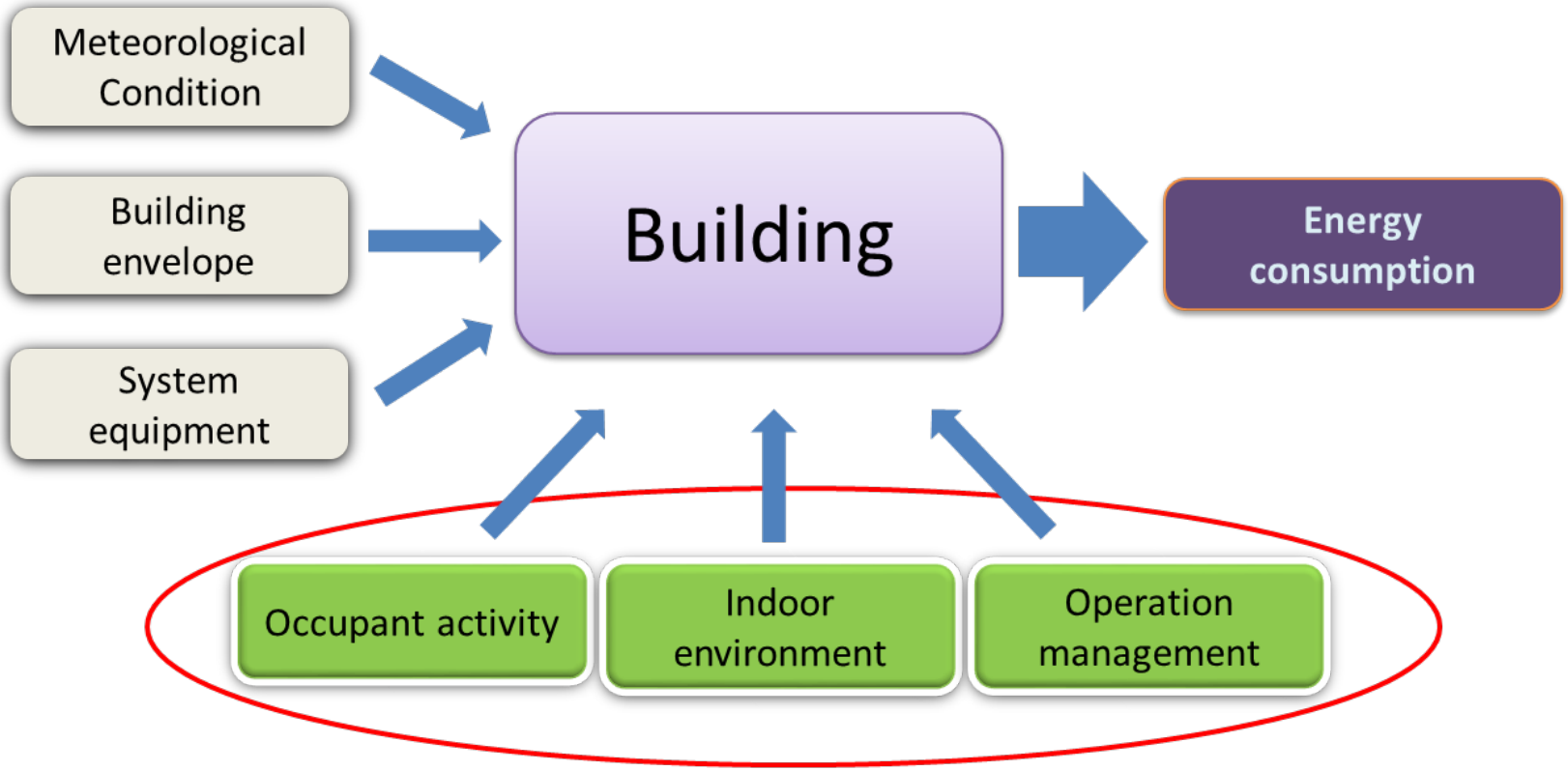
- **OB has significant influence on building energy use**



Significant discrepancy between each apartment

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

Occupant behavior is a key factor

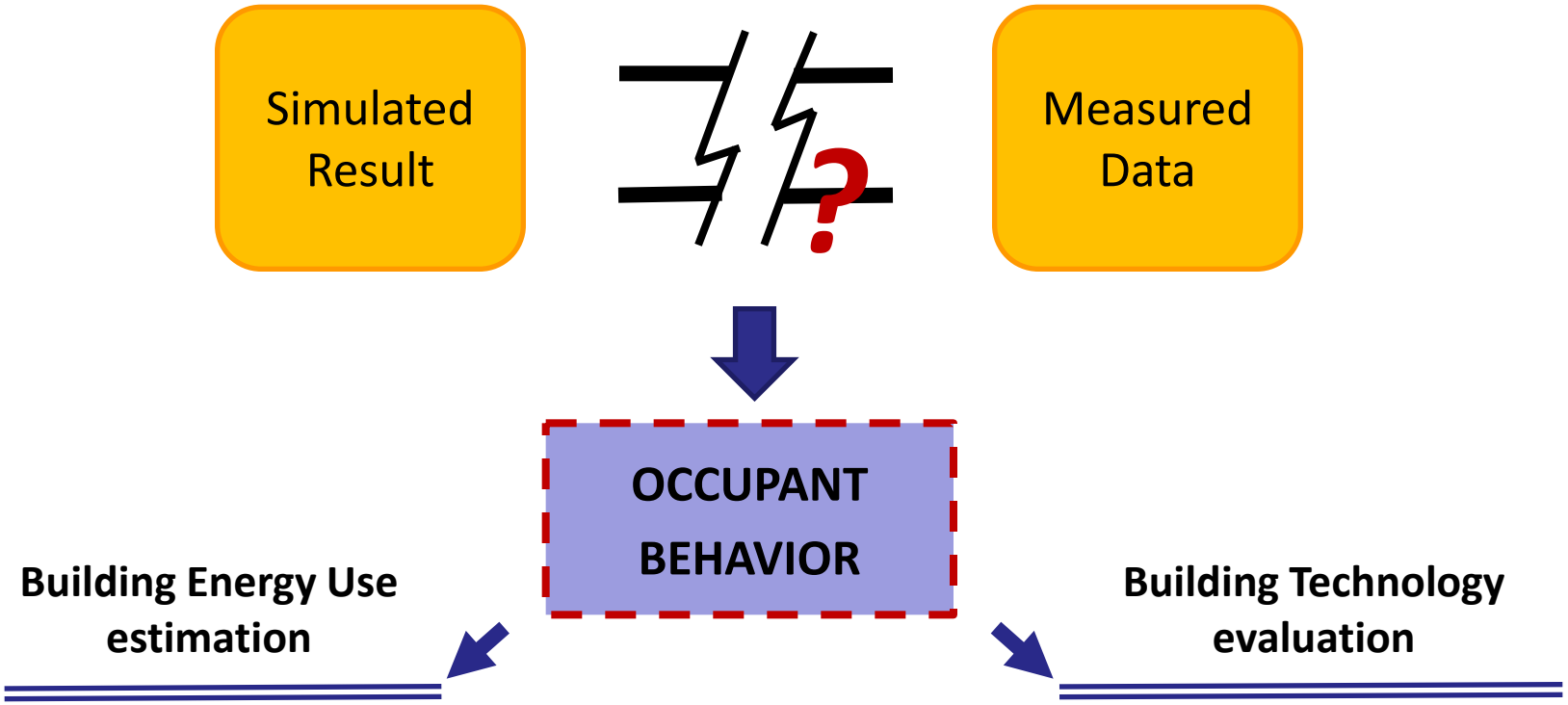


Occupant behavior is a key influencing factor of building energy consumption

Importance and Urgency

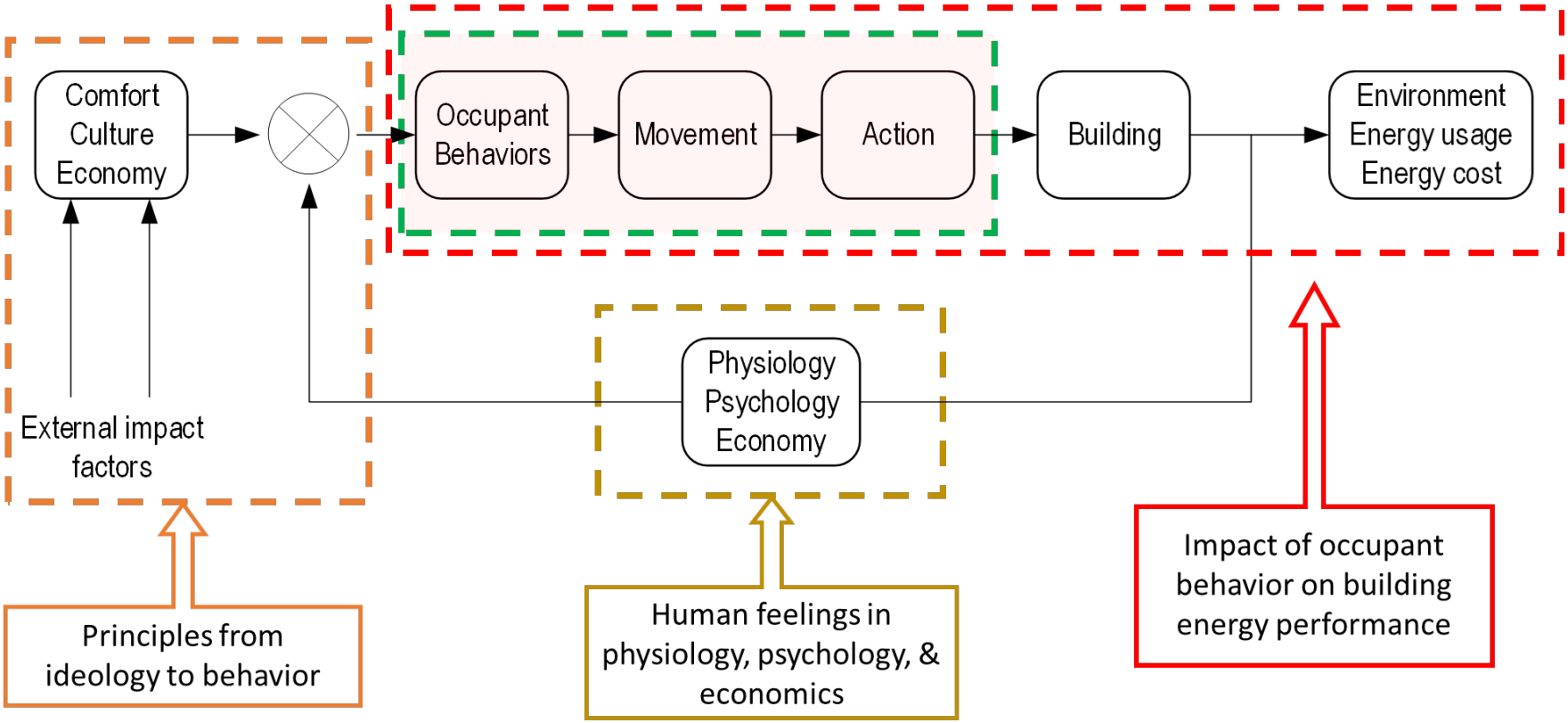
- OB is a **Key factor** for design optimization, energy diagnosis and performance evaluation, and also building energy simulation
- Limited understanding or inadequate over-simplification on OB;
- **In-depth quantitative analysis** urgently needed;
- Over 20 groups all over the world studying OB individually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

Importance and Urgency



Challenges

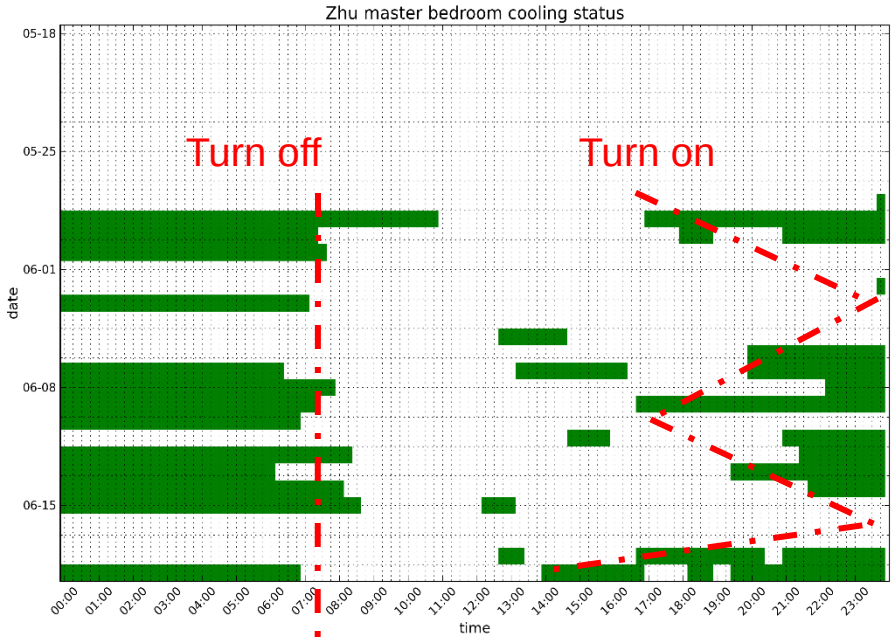
- **<u>Focus on how OB physically and quantitatively affect on building performance</u>**



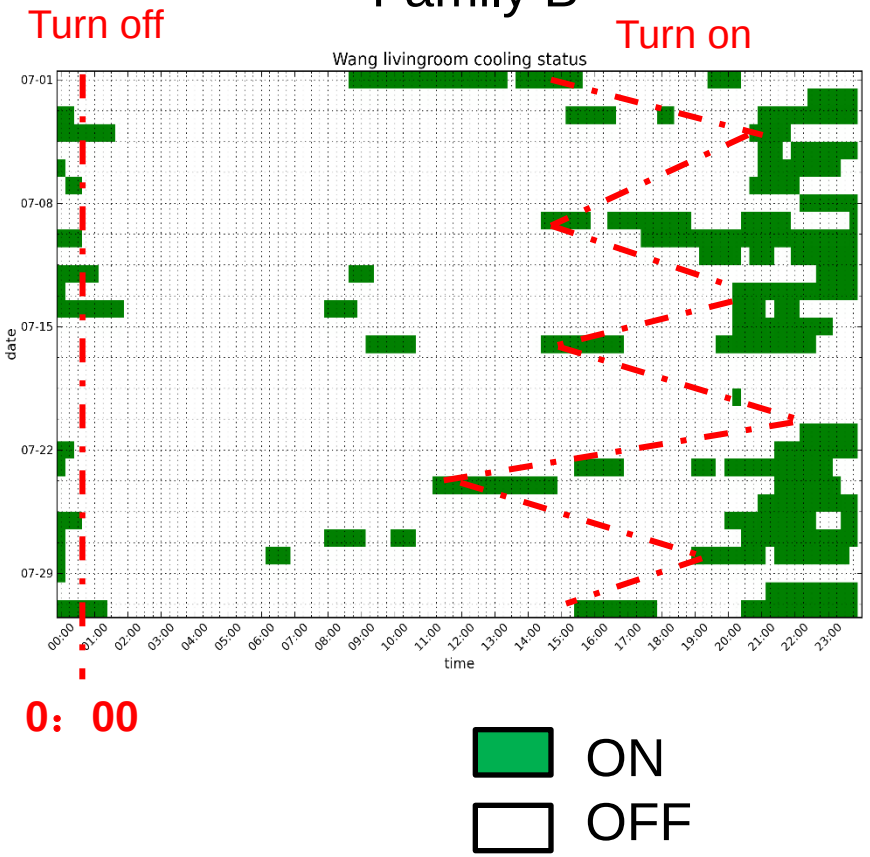
Challenges

- **Stochastic and uncertain**

Family A



Family B



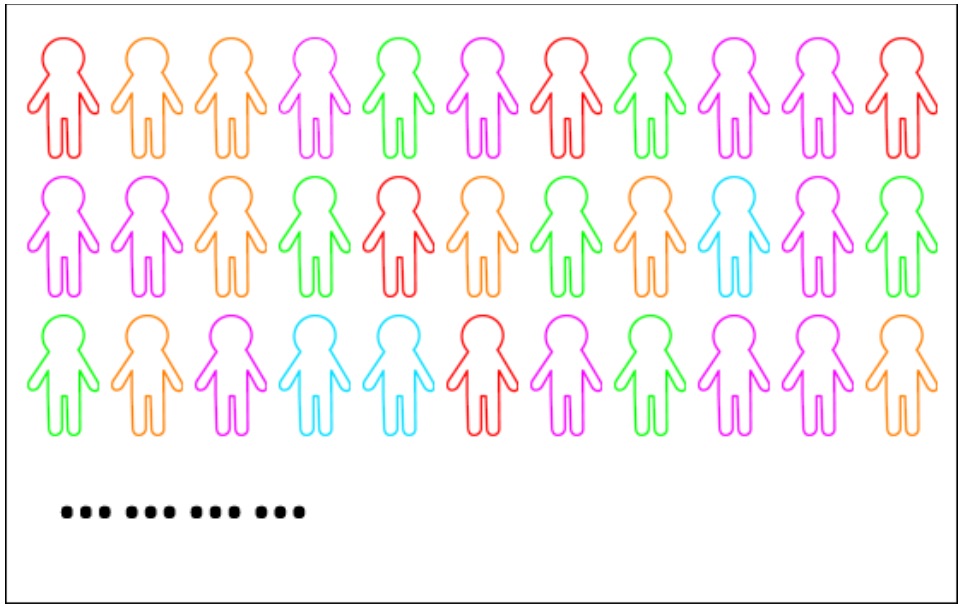
Challenges

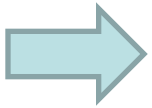
- **Complexity of OB**

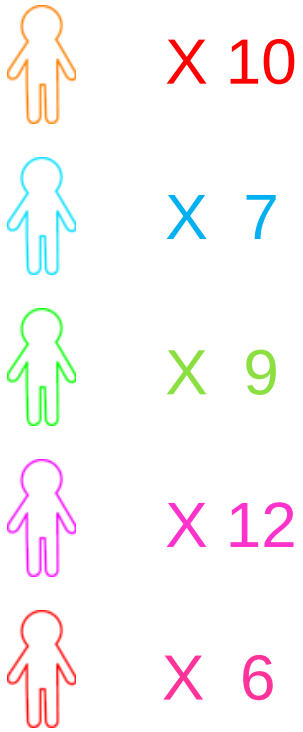
- ☑ always turn on
- ☑ turn on when entering
- ☑ turn on when feeling hot
- ☑ turn on before sleep
- ☑ never turn on
- ☑ randomly turn on

Challenges

- **Typical OB Category and Distribution**



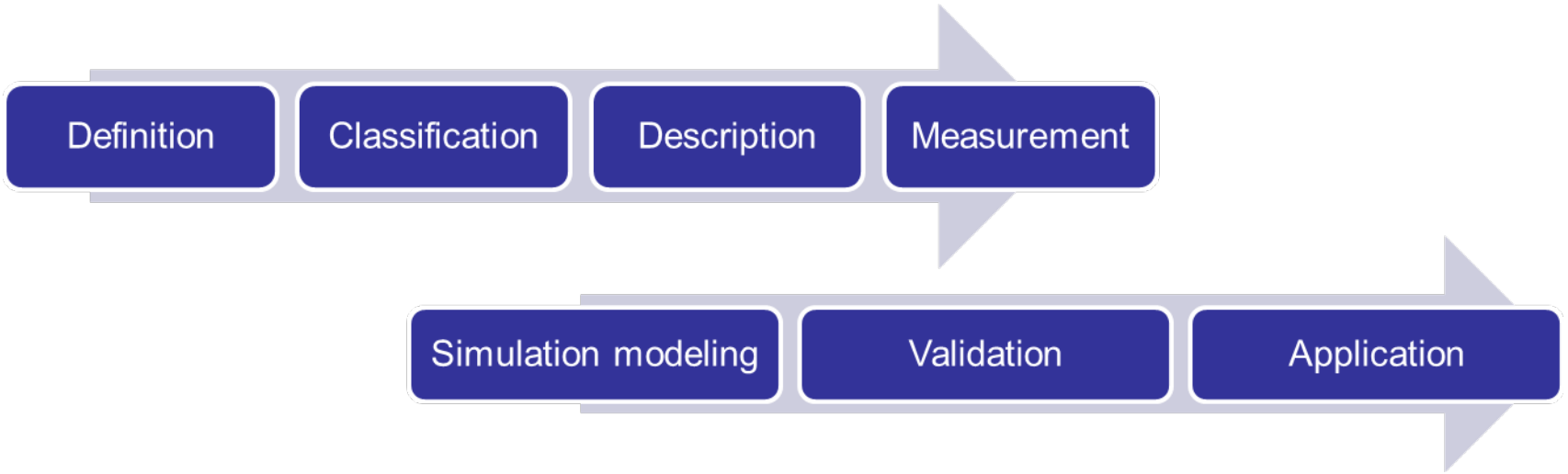




Research Target

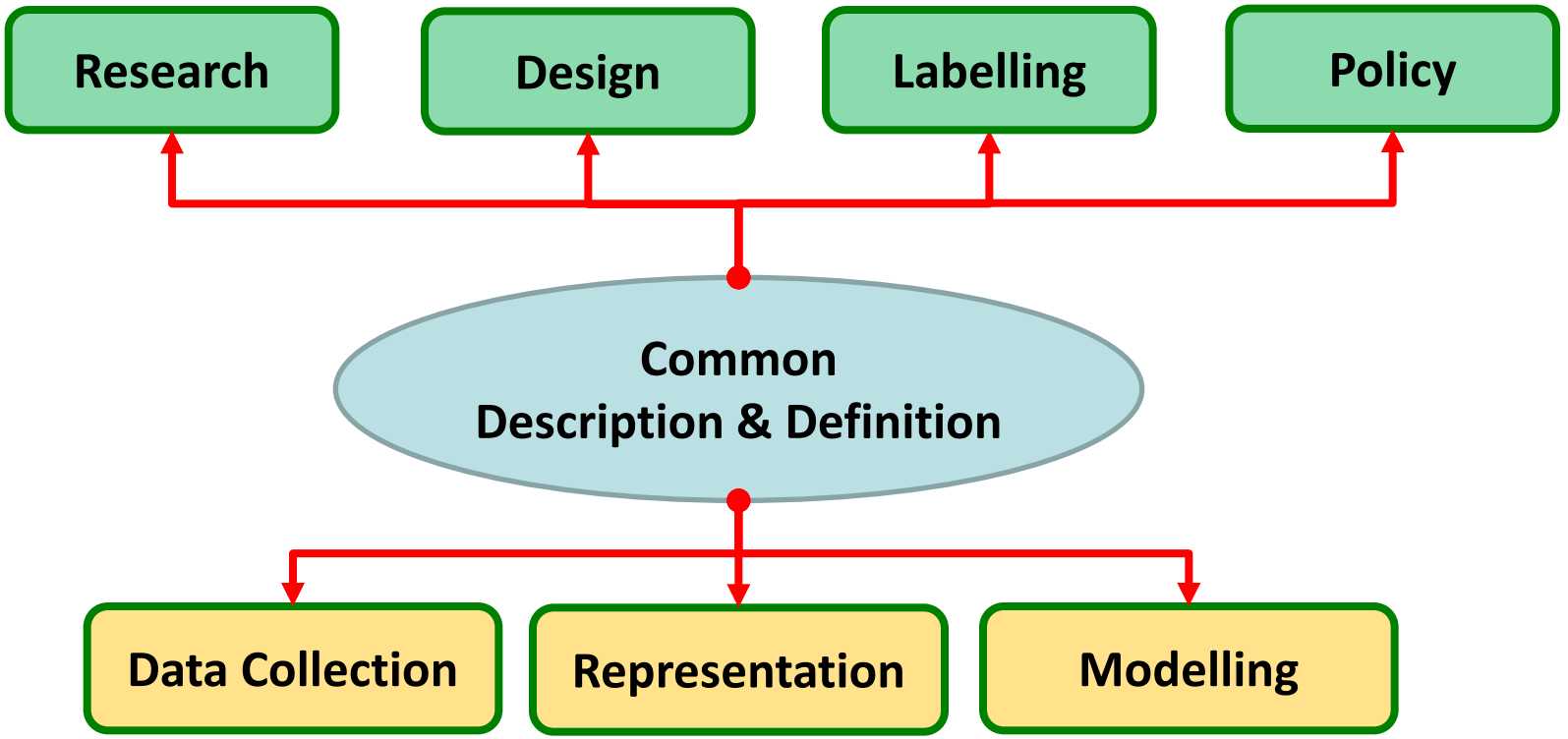
- Identify quantitative definition, description and classification of OB
- Develop effective simulation methodologies of OB
- Integrated OB models with building energy simulation tools
- Demonstrate the OB models in design, evaluation, operation management and policy making by case studies

Research Target



Develop a scientific framework for OB quantitative definition and simulation methodologies

Research Target

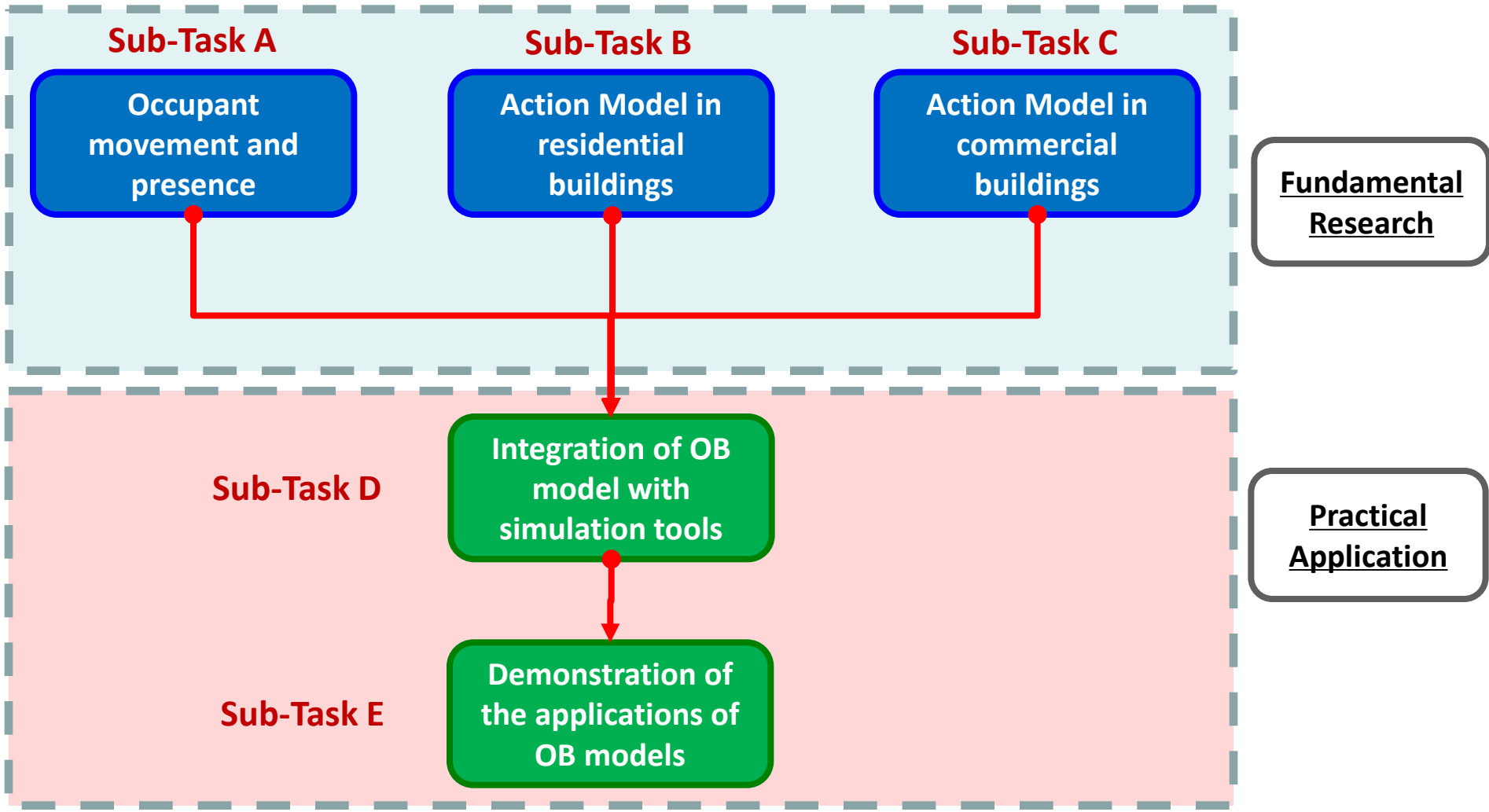


Set up Common Description and Definition for OB

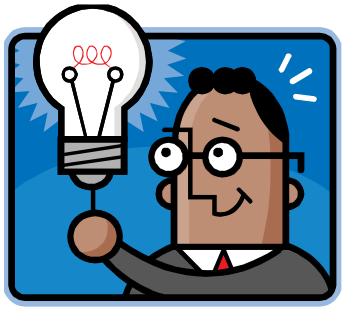
Technical Approach

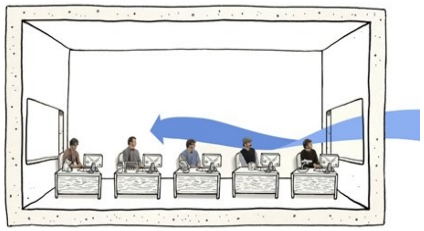
Targeting Building types:

Residential buildings & Office buildings



ST-A Personnel presence and movement model





Personal
Presence & Movement

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

ST-A 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

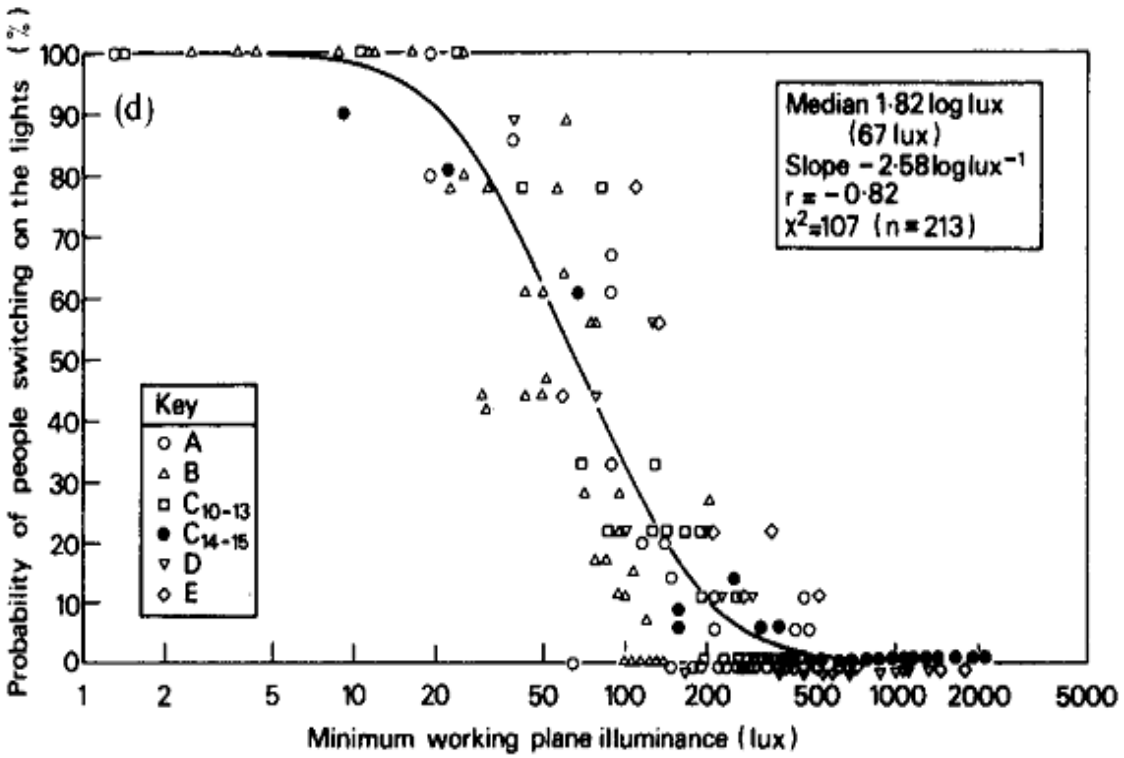
- Q: How many occupants are there in a space at a time?

Occupant level - individual tracking

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

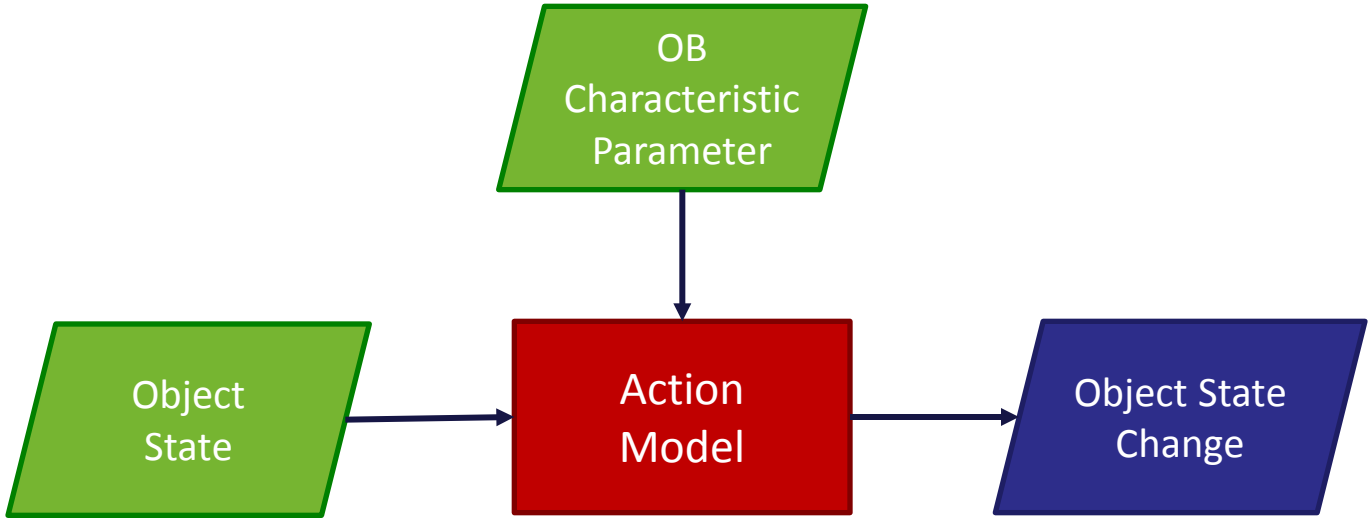
A set of coherent personnel presence models are demanded for different application purposes

ST-B Action model in residential buildings



Occupant's actions are influenced by environmental and physical parameters in a stochastic way

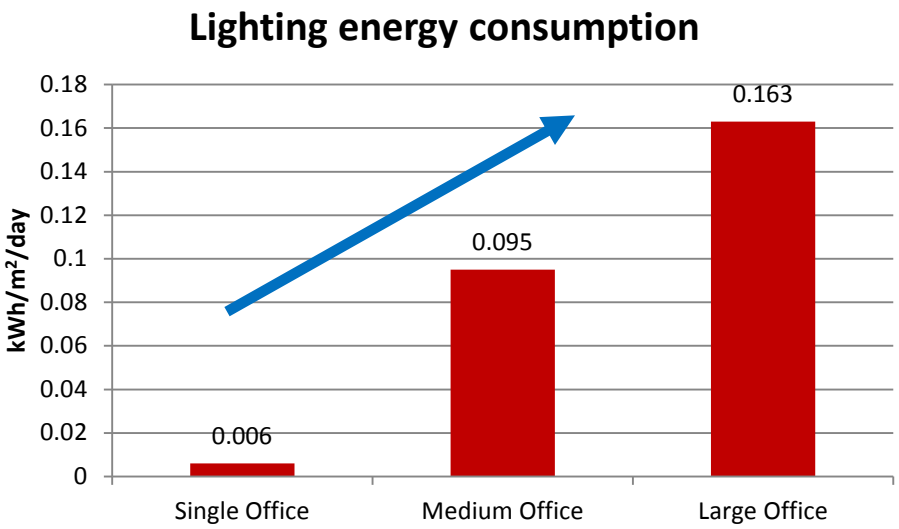
ST-B Action model in residential buildings

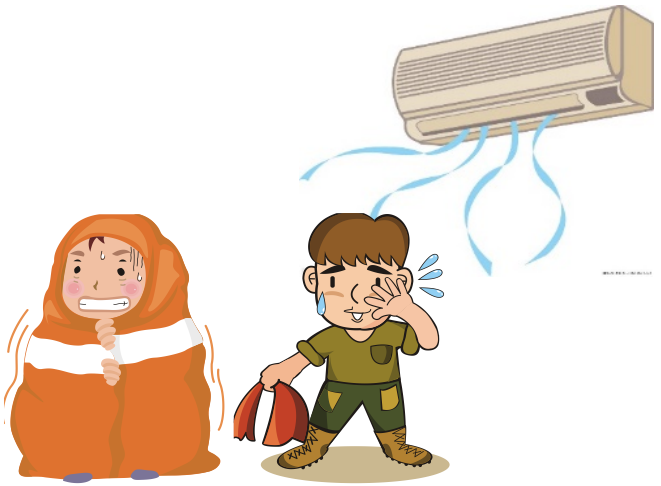


State based → Action Based

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

ST-C Action model in commercial buildings





Higher possibility of interaction and negotiation among occupants in commercial buildings

ST-C Action model in commercial buildings

Occupants

Indoor Environment and System Control Authority

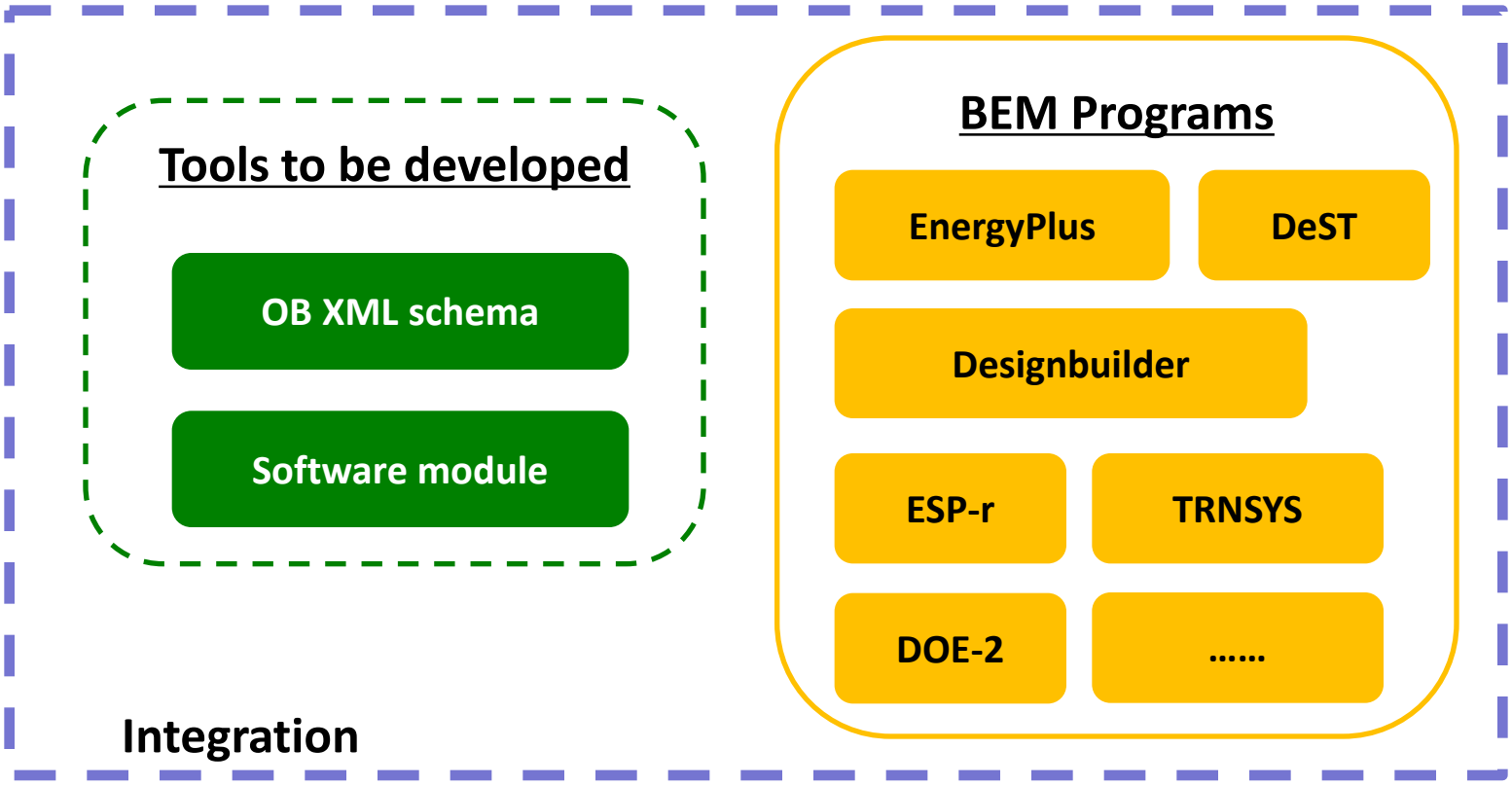
Operation Manager

Decentralized Control

Centralized Control

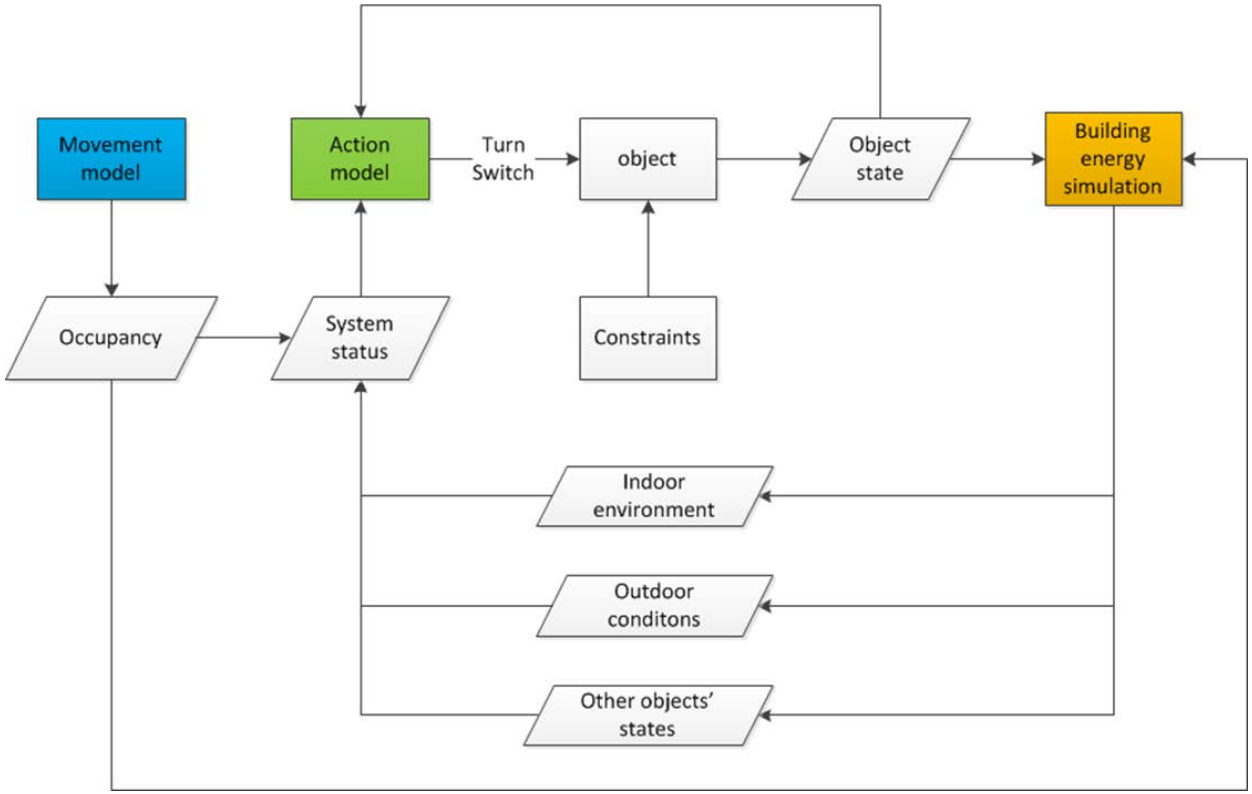
Assignment of the Control Authority between Occupants and Operation Managers affects performance significantly

ST-D Integration with simulation software



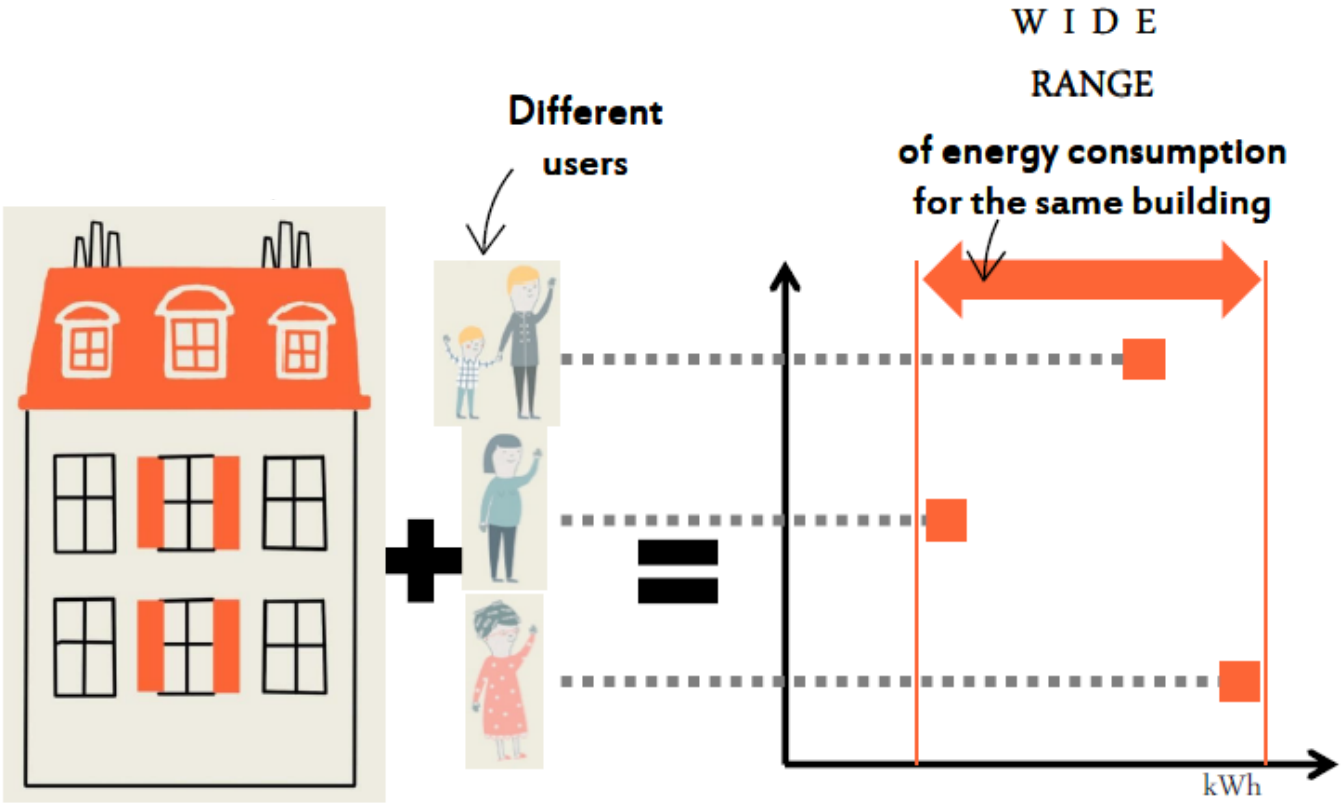
Essential to integrate the OB models with BEMs to exhibit the influence of OB on building energy and performance

ST-D Integration with simulation software



Develop flexible, sustainable, robust module for simulation

ST-E Applications of OB models



To exhibit OB's influence on comfort, environment, energy usage and technology adaptability, improve applications by case studies & guidelines

Outcomes & Audience

	Outcomes	Target Audience
1	Standard definition, description and classification of occupant behaviour in building	**Building Energy Researchers** **Energy Modellers** **Simulation Software Developers**
2	Systematic measurement approach, simulation modelling and validation methodology	
3	Occupant Behavior Database with data of different temporal and spatial resolution	
4	Software to simulate OB, integrated with a building thermal and energy model	**Building Designers** **Energy Saving Evaluators** **HVAC Engineers** **System Operators** **Energy Policy Makers**
5	Case studies and guidelines to demonstrate applications of the new OB definitions and models	

International Workshop for New ANNEX

- August 23rd, 2013 at IEA HQ in Paris
- 24 participants from 13 countries
- One day's presentation and discussion about the scope of work, technical approach and next steps

Forum in ISHVAC 2013

- Oct 21st, 2013
- Xi'an, China
- Half day with 10 presentations
- 40 participants from 6 countries

EBC
Energy in Buildings and Communities Programme

1st expert meeting in Hong Kong

- March 12 to 14, 2014
- Hong Kong
- Half day Open forum + 2 days expert meeting
- 39 participants from 13 countries

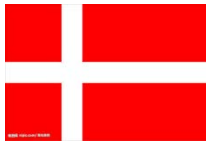
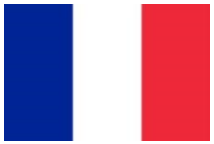
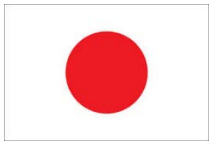
Annex 66

EBC
Energy in Buildings and Communities Programme

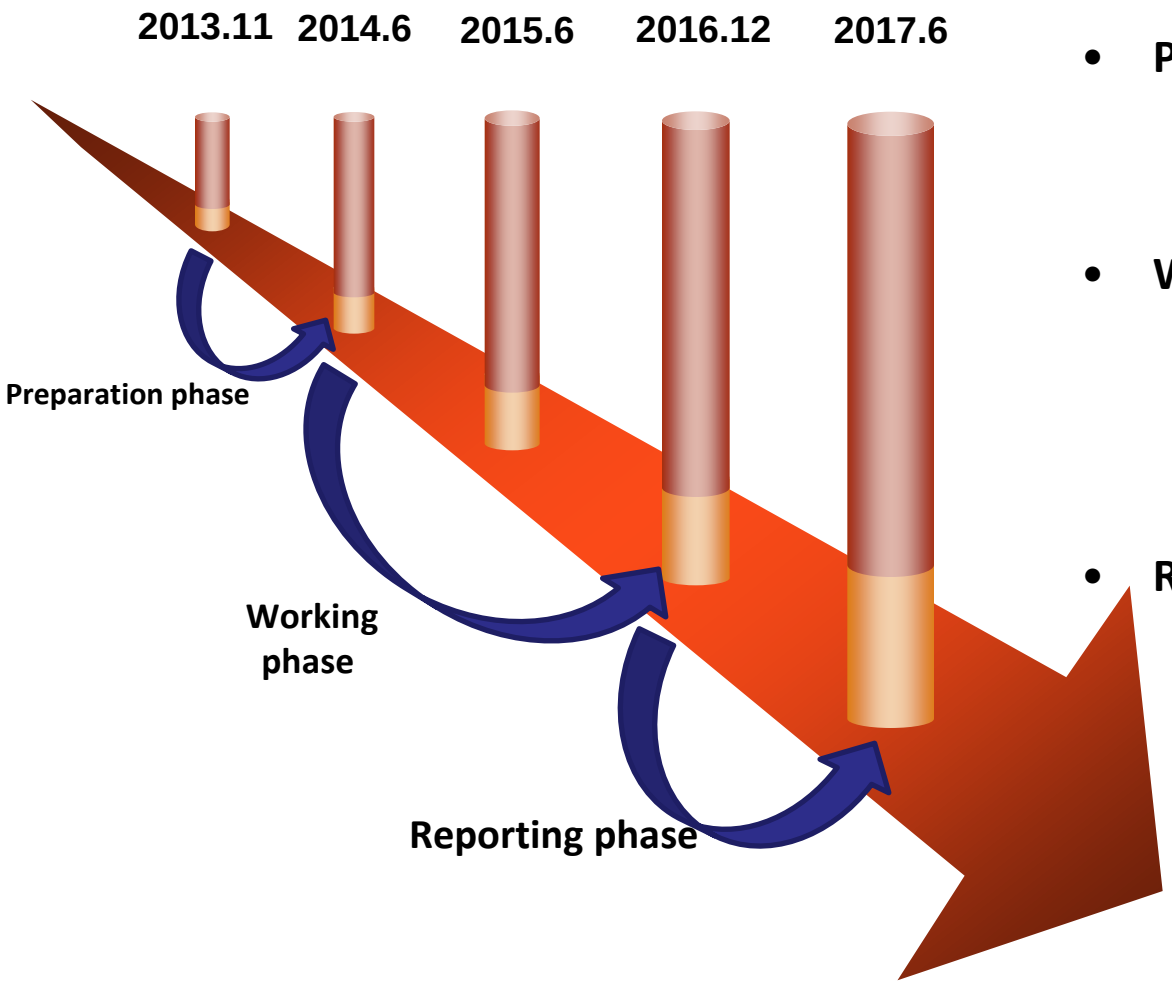
- **Operating Agents**
  - Dr. Da Yan, Tsinghua University, China
  - Dr. Tianzhen Hong, LBNL, USA
- **Participants**
  - 60+ institutions, 90+ individual
  - 23 countries
  - ASHRAE + (IBPSA + CIBSE)
- **Web site: annex66.org**

Participants

23 Countries and Regions

					
Australia	Austria	Belgium	Brazil	Canada	China
					
Denmark	Finland	France	Germany	HongKong	Hungary
					
Italy	Japan	Korea	Netherland	Norway	Poland
					
Spain	Sweden		UK	USA	Singapore

WORK PLAN

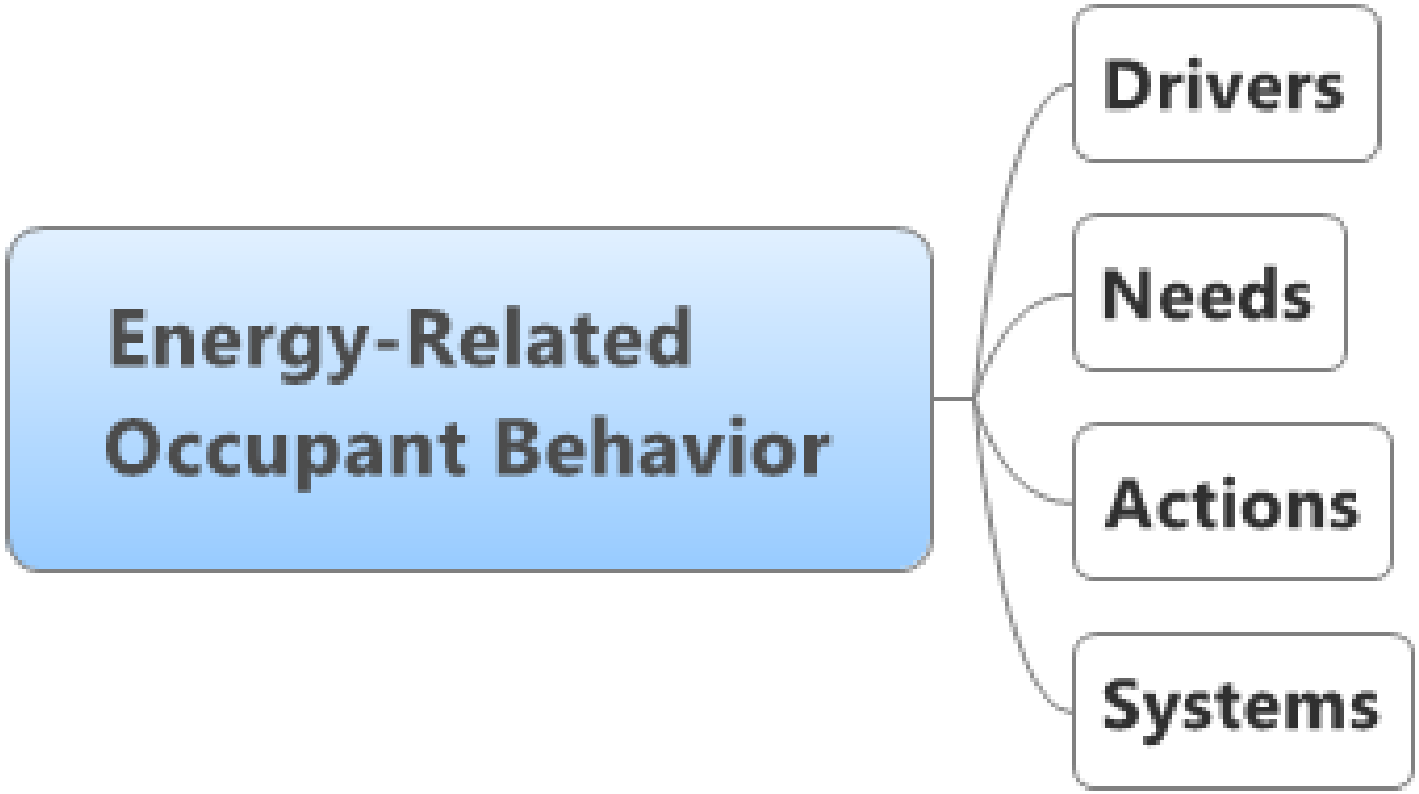


- **Preparation phase**
  - One year (2013.11 — 2014.11)
- **Working phase**
  - Two and a half years (2014.11 — 2017.6)
- **Reporting phase**
  - Half a year (2017.6 — 2017.12)

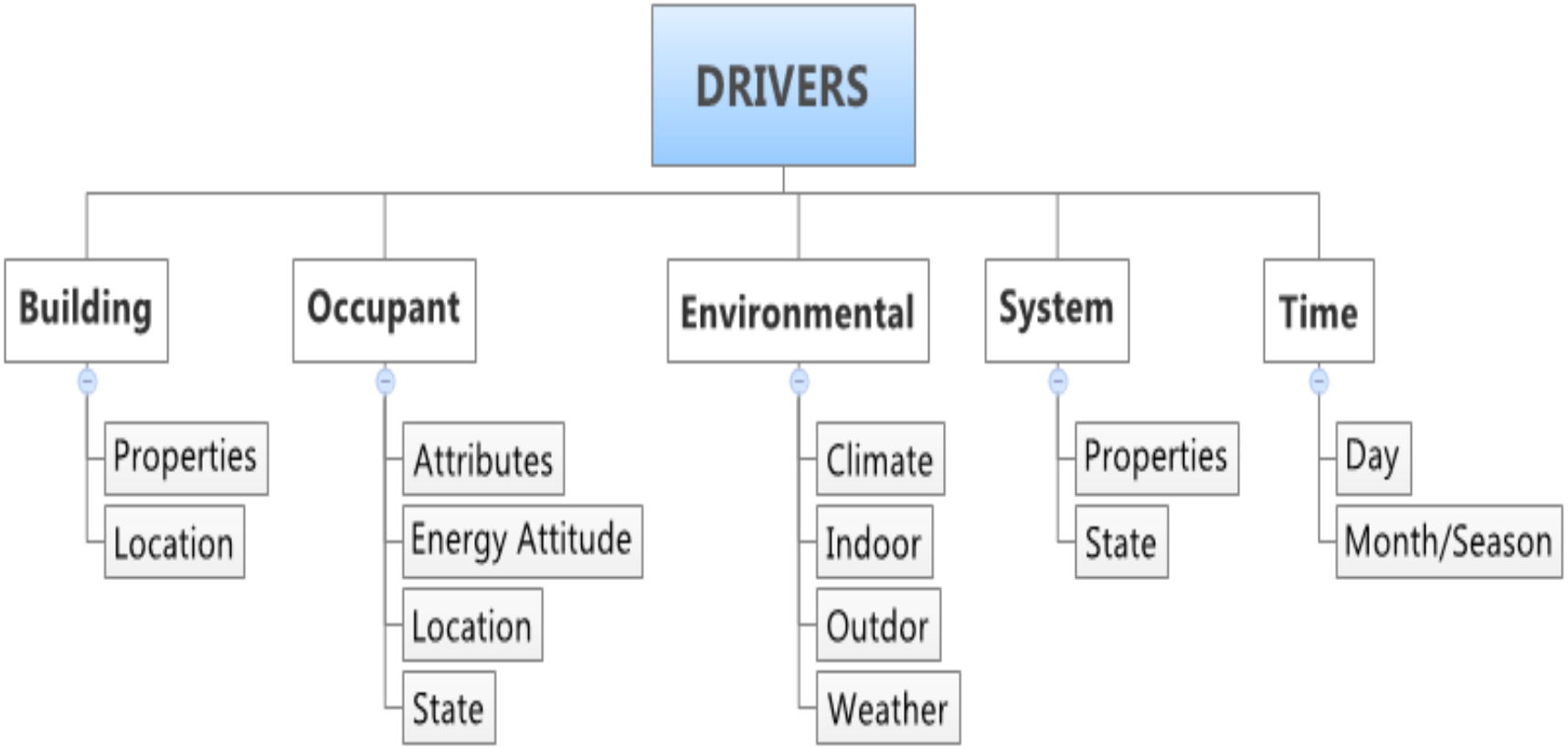
Summary

- OB has **great influence** on building energy usage and also technology evaluation
- There are still lack of **quantitative methods and common language** for OB description and simulation
- ANNEX 66 is focused on setting up **a scientific framework** for OB definition, description, simulation and applications in the coming four years efforts

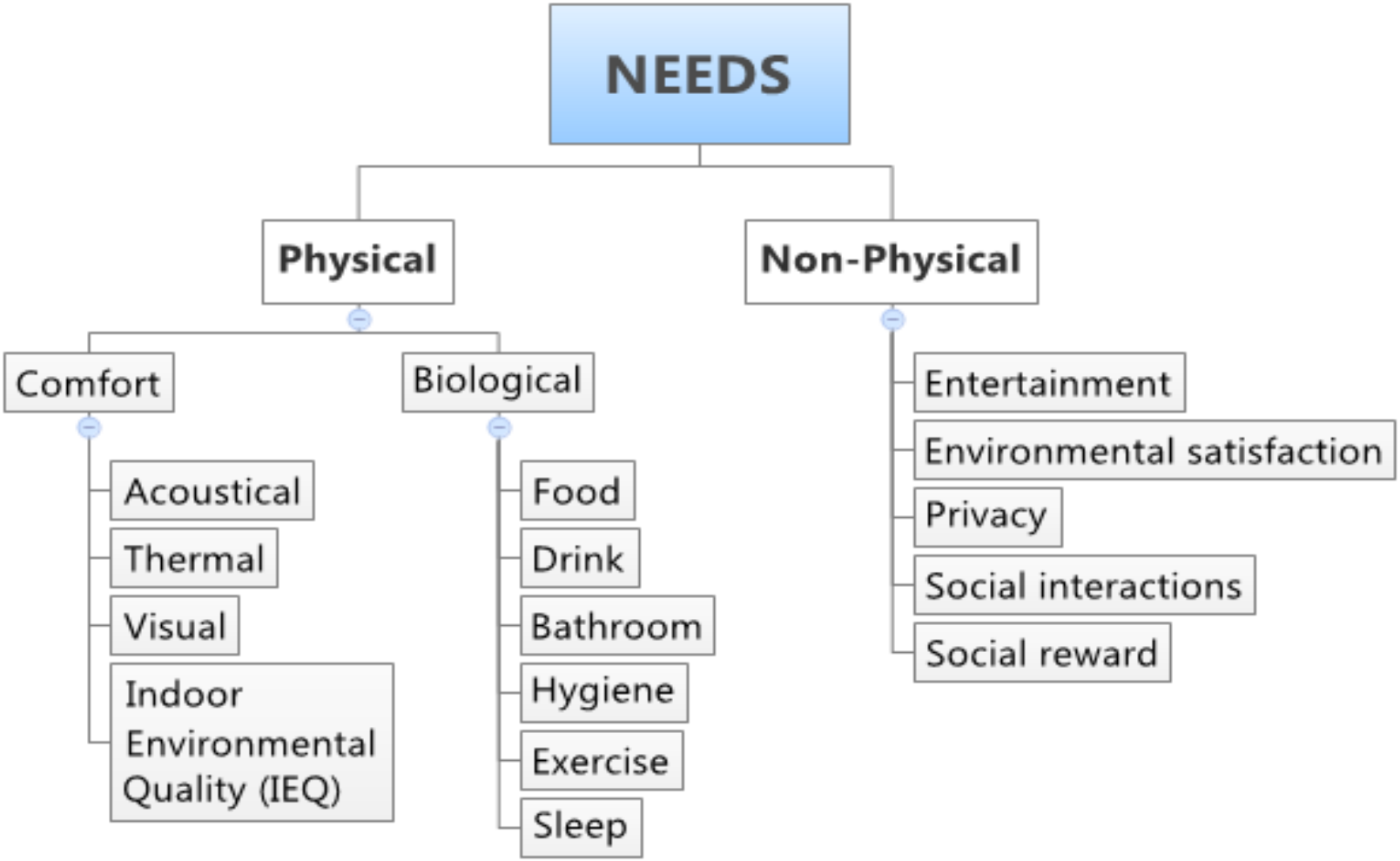
A Framework to Describe Occupant Behavior - the concept…



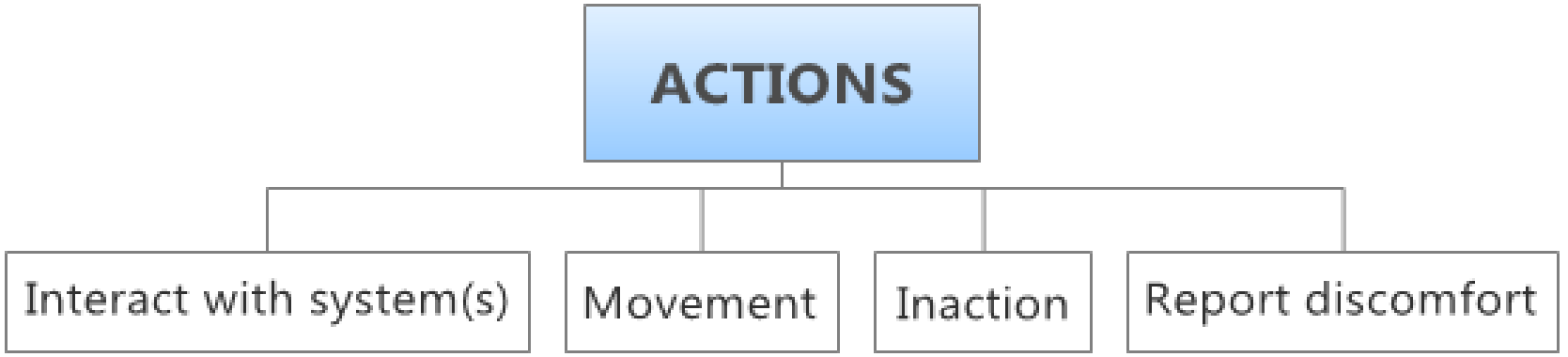
Drivers represent the stimulating factors that provoke energy-related occupant behavior



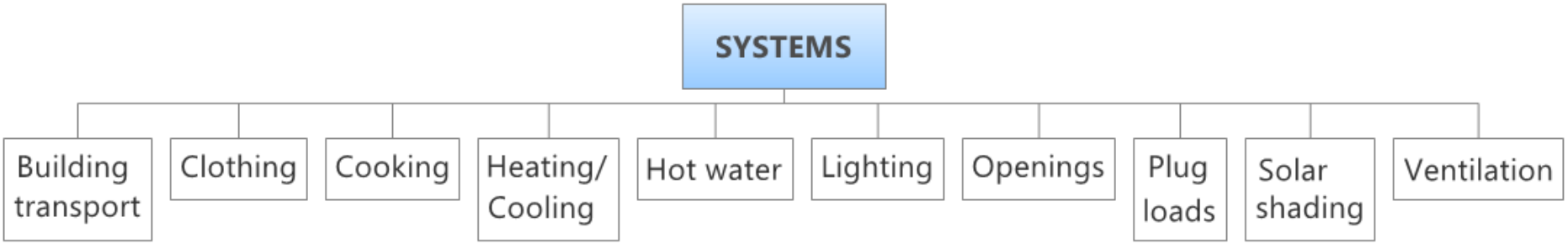
Needs **represent the requirements of an occupant that must be met in order to ensure satisfaction with the environment**



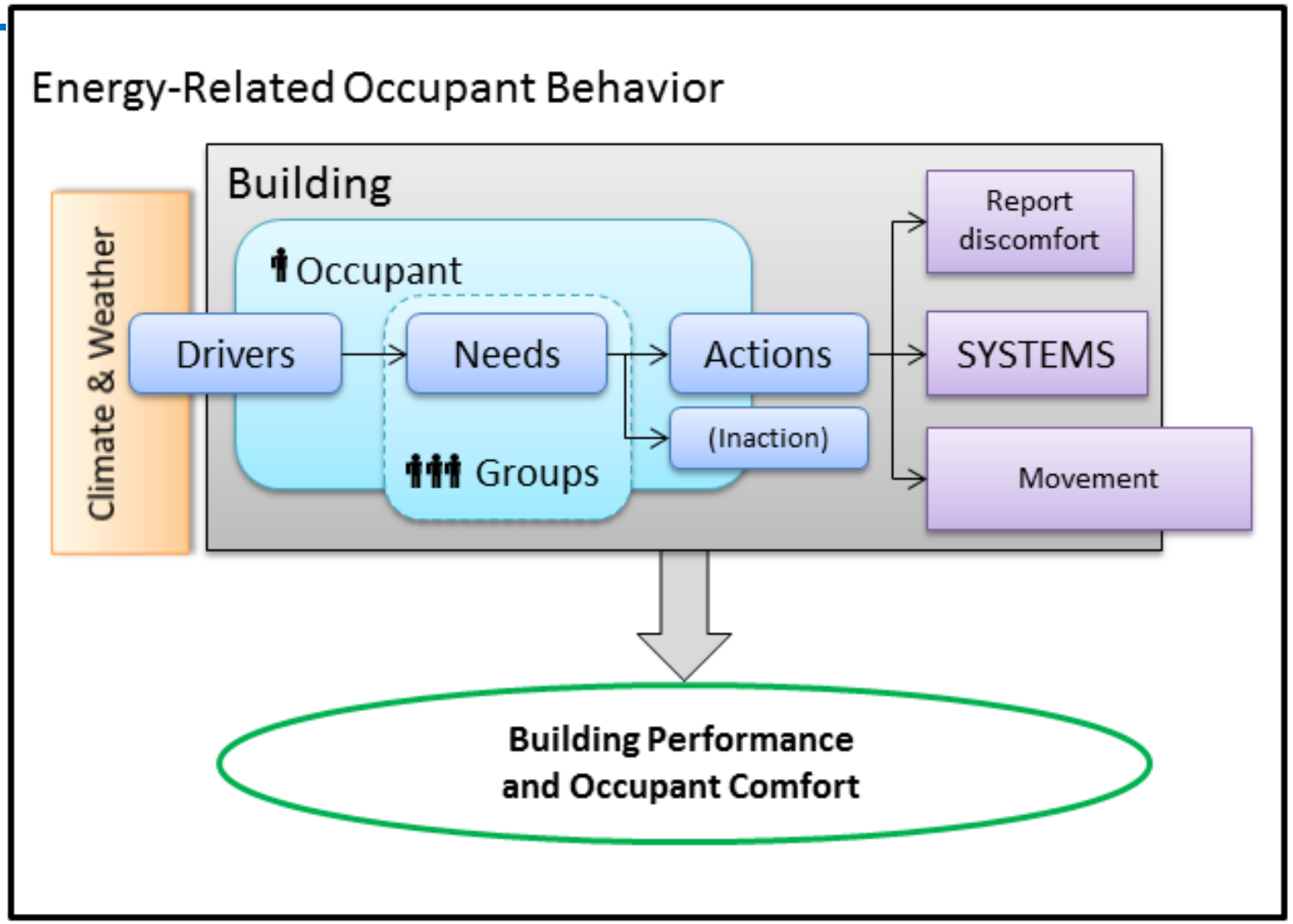
Actions **are interactions with building systems or activities that an occupant can conduct in order to satisfy their needs**



Systems are the equipment or mechanisms with which an occupant may interact to restore comfort

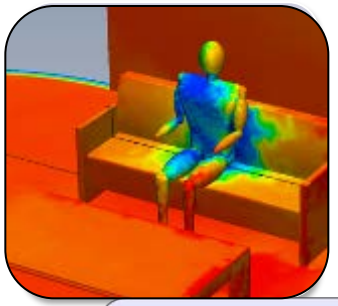


The DNAS Framework



Example 1 – Window opening

Driver:
Indoor air temp

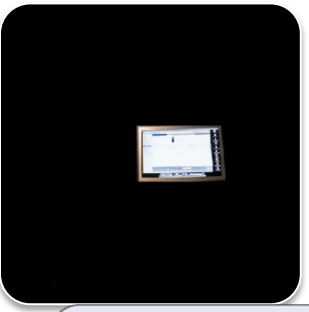


Need:
Thermal comfort

Action:
Open

System:
Window

Example 2 – Light operation



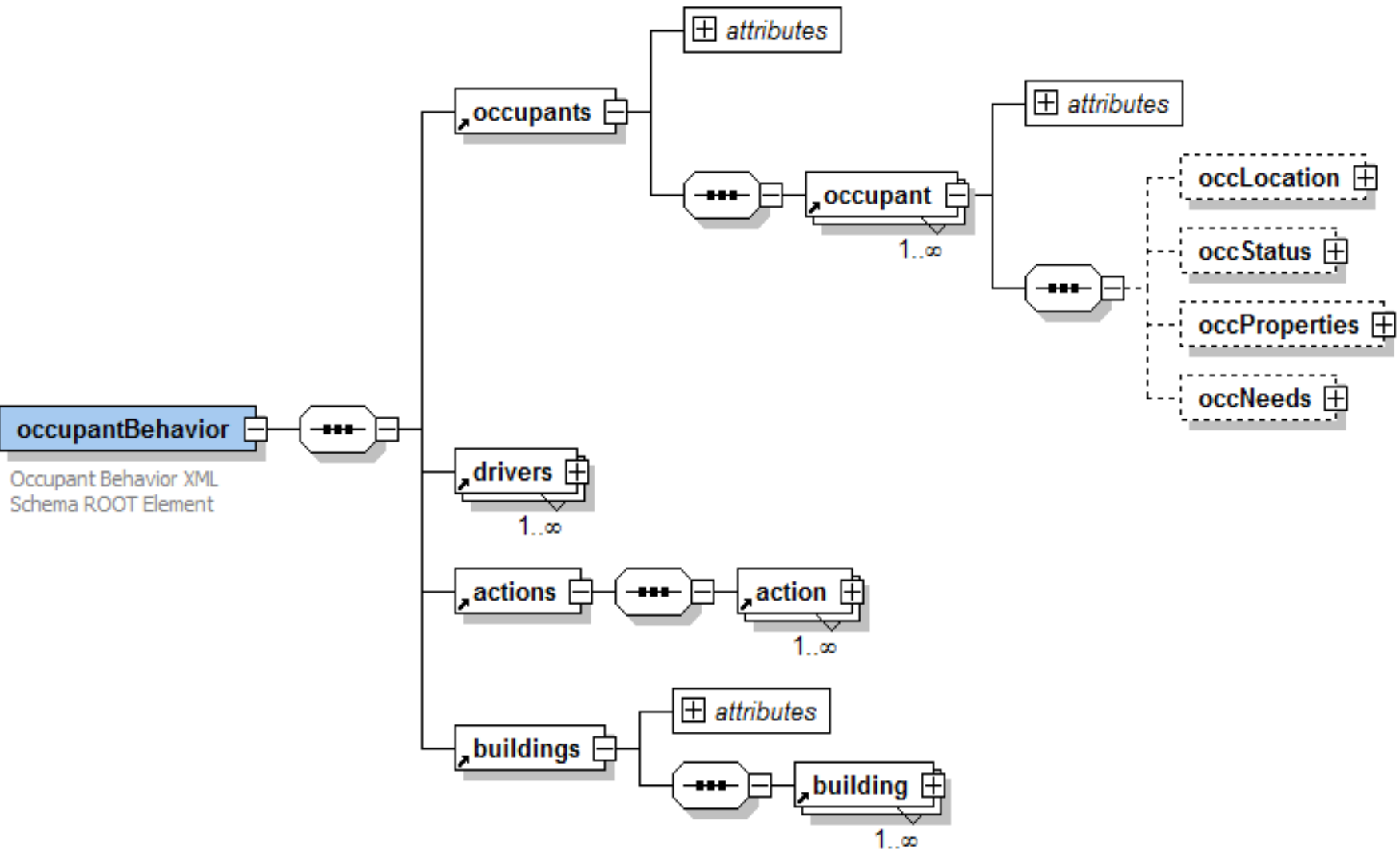
Driver:
Work plane illuminance

Need:
Visual comfort

Action:
Switch on

System:
Lights

The XML Schema - *obXML*



Various Approaches to Behavior Modeling

Three main approaches, e.g. using EnergyPlus:

1.Use schedules or predefined rules

2.Energy Management System (EMS)

3.Co-simulation via the FMI

Modeling approaches:

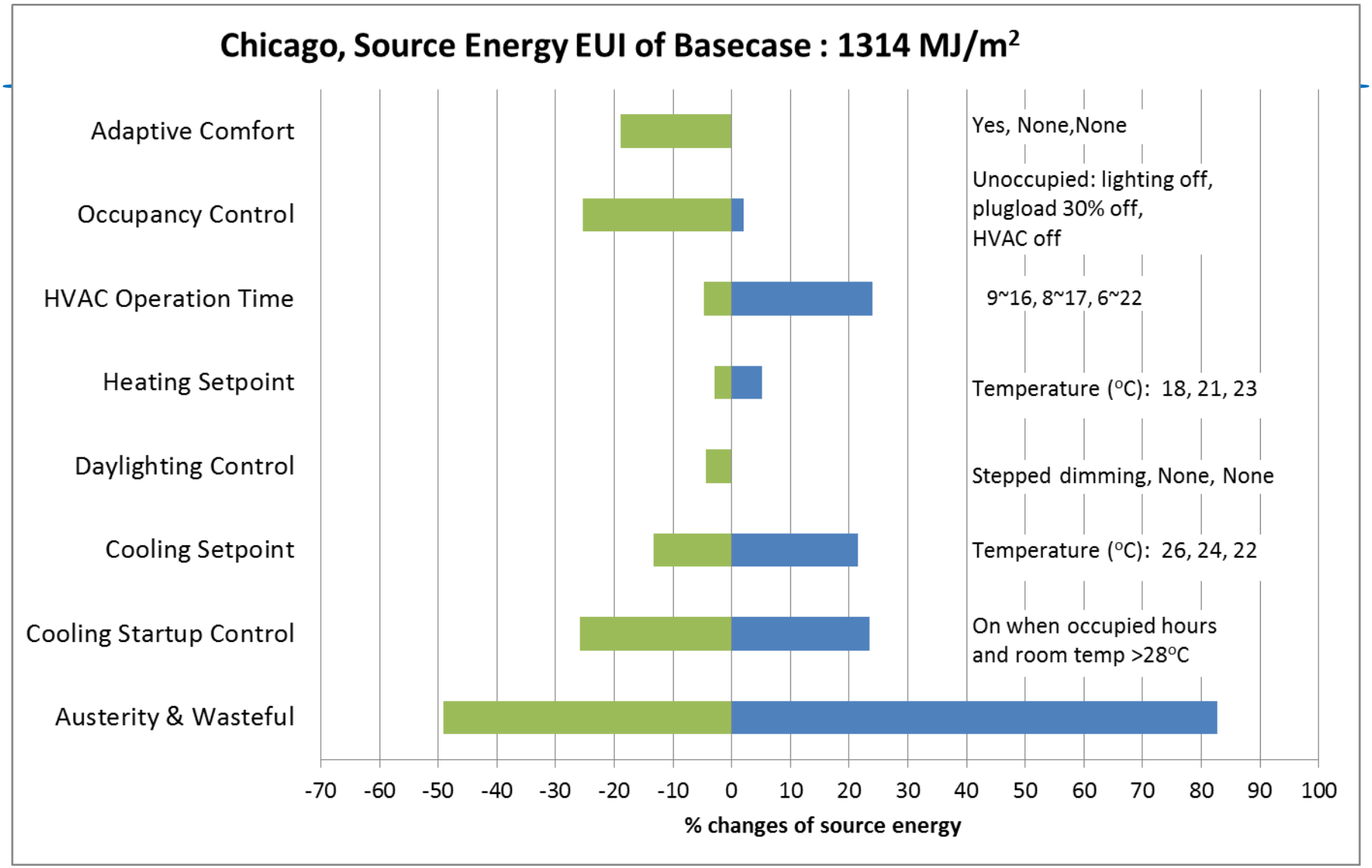
1.Implicit modeling: energy systems and components

2.Explicit modeling of occupant behavior: agent-based modeling

Occupant Behavior in Private Offices

Behavior	Austerity	Standard	Wasteful
Cooling Setpoint (°C)	26	24	22
Heating Setpoint (°C)	18	21	23
HVAC Operation Time (Cooling and Heating)	9:00am - 4:00pm	8:00am - 5:00pm	6:00am - 10:00pm
Occupancy Control	If unoccupied • Lighting: off • Plug-load: 30% off • HVAC: off	Scheduled	If unoccupied • Lighting: on • Plug-load: on • HVAC: on
Cooling Startup Control	Cooling starts when $T_{zone,\ air} \geq 28°C$ during occupied hours, once started maintains the cooling setpoint; Cooling off during unoccupied hours.	Follow fan schedule & cooling thermostat during 8:00am - 5:00pm	Cooling always on during 6:00am - 10:00pm
Daylighting Control	Stepped Dimming	None	None
Adaptive Comfort	Yes	None	None

Impact of Occupant Behavior on Energy Use in Private Offices



Modeling and Simulation of Occupancy in Buildings

Four types of occupancy models:

Building level – # of occupants

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

Space level – occupied status

- Is a space occupied?

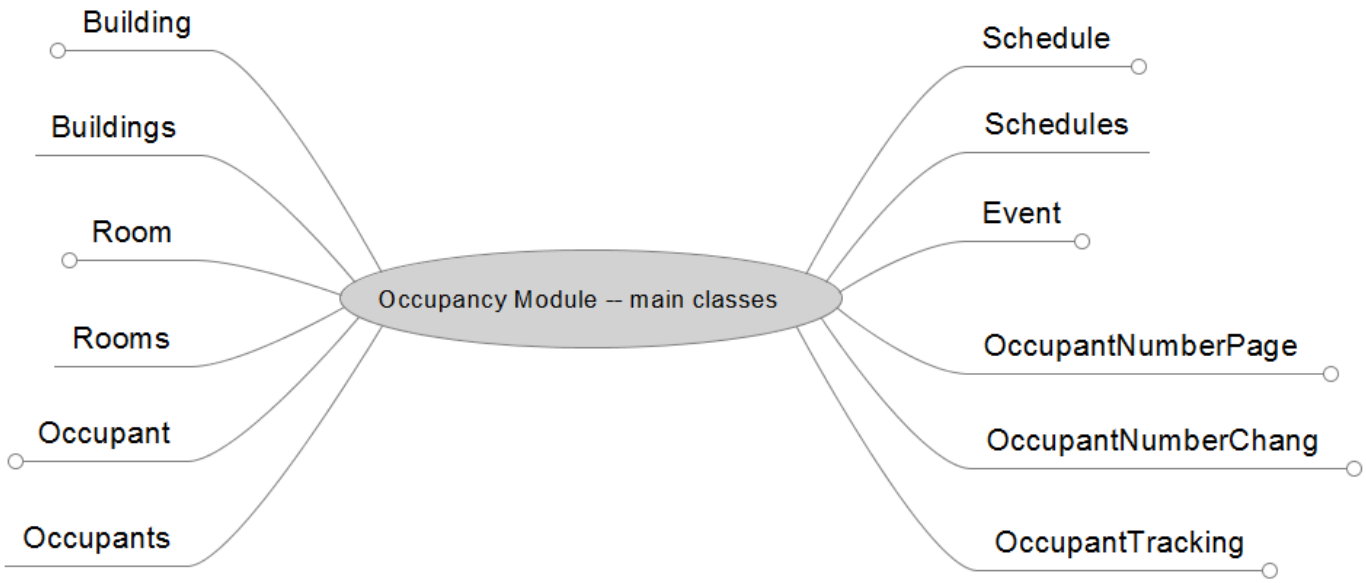
Space level – # of occupants

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

Occupant level - individual tracking

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

Software Module



- Run stand-alone as an executable file
- Called by other tools as a DLL
- Used as co-simulation with energy modeling tools, e.g. EnergyPlus

Application

occupancy visualization - mdified.py - C:\Users\fengxh\Dropbox\CERC Simulation\Behavior Module\Report\visualization\occupancy visualization - mdified.py

File Edit Format Run Options Windows Help

```
    # the csv file is only data, don't inclue the header line.
    csv = open(csv_path, 'r')
    lines = csv.readlines()
    csv.close()
    ln = lines[0].rstrip(', ')
    header = [v.strip() for v in ln.split(',')]
    lines = lines[1:] # remove the header line
    res = {}
    for k in header: res[k] = []
    for i in range(len(lines)):
        ln = lines[i].rstrip(', ')
        vals = [v.strip() for v in ln.split(',')]
        for i,k in enumerate(header):
            res[k].append(int(vals[i]) if vals[i].isdigit() else vals[i])
    return res

def main():
    # !- pygame parameters
    pygame.init()
    win_size = [1300,700]
    screen = pygame.display.set_mode(win_size, pygame.FULLSCREEN | pygame.HWSURFACE | pygame.DOUBLEBUF)
    pygame.display.set_caption("Occupant movement in office building")
    screen.fill(black) # Set the screen background
    clock = pygame.time.Clock()

    # !- occupant movement paramters
    # Loop for occupant movement (the whole)
    done = False
    # define spaces and scope
    for k,s in lstSpaces.iteritems():
        space = Space(k, s[0], s[1], s[2], s[3])
        if k==0: space.init_hotpos(1,16)
        elif k==12: space.init_hotpos(8,2)
        else: space.init_hotpos(4,4)
        scope[k] = space
    # define occupants
    lstAgents = []
    path = r'agent_location.csv'
    res = read_agent_locs(path)
    #n = len(res)-2
    steps, times, events = res['step'], res['time'], res['event']
```

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Questions?

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IEA EBC Annex 66

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