Occupant-Centric Grid-Interactive Buildings

6. Occupant Centric Building Design and Operation

CE 397

Spring 2024

Prof Dr Zoltan Nagy

Tentative Course Outline / Schedule

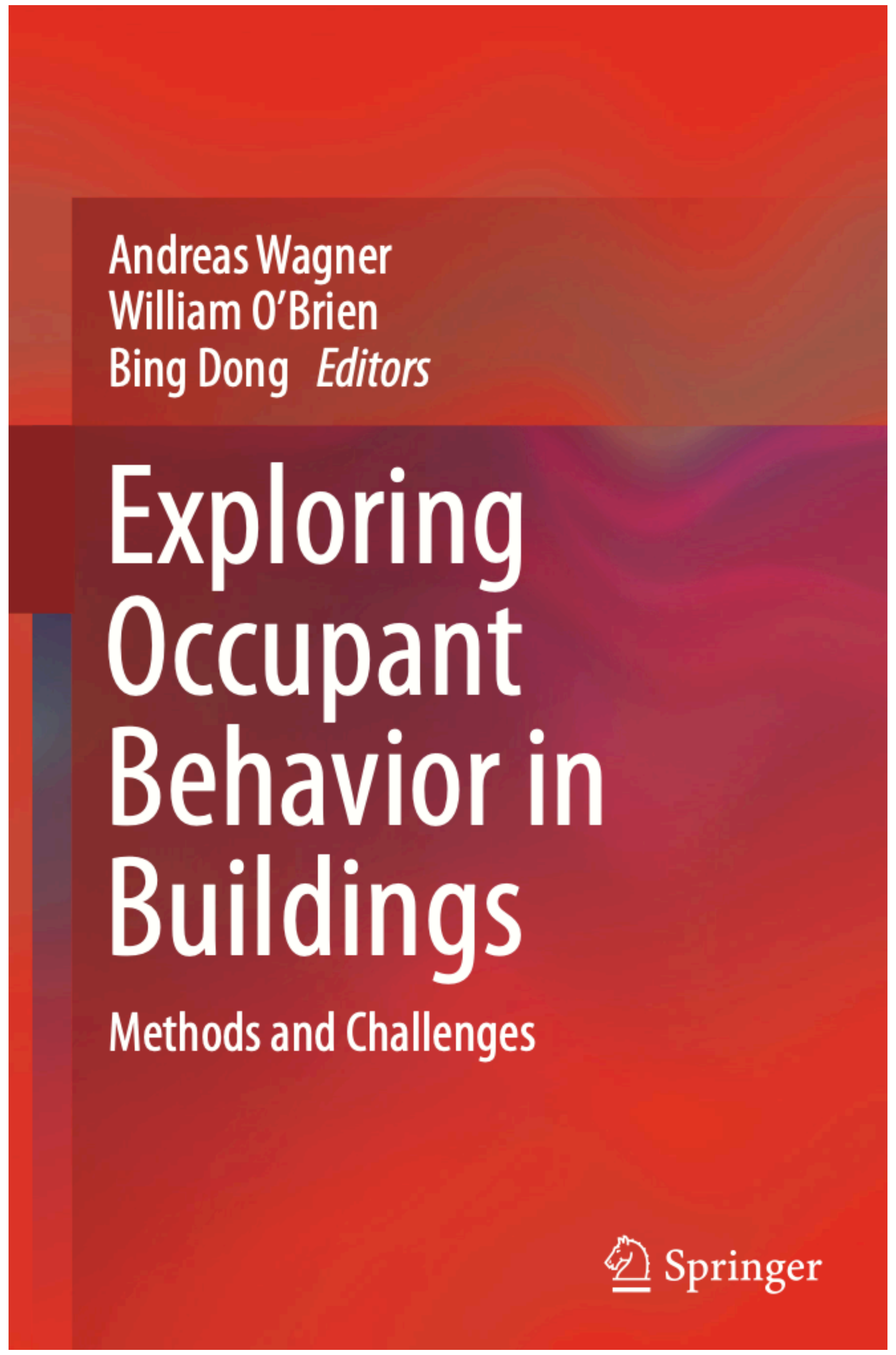
Week	Class	Topic	Guest Lecture
1	01/17	Introduction / Overview / Python	
2	01/24	Machine Learning I	
3	01/31	Machine Learning II	
4	02/07	Machine Learning III	Justin Hill (Southern)
5	02/14	Occupant Behavior Modeling	
6	02/21	Occupant Behavior Modeling	Tanya Barham (CEL)
7	02/28	Occupant Behavior Modeling	Jessica Granderson (LBNL)
8	03/06	Occupant Behavior Modeling	Hussain Kazmi (KU Leuven)
9	03/13	Spring Break	
10	03/20	Advanced Control & Calibration	Ankush Chakrabarty (MERL)
11	04/27	Calibration	Donghun Kim (LBNL)
12	04/03	Introduction to CityLearn	
13	04/10	Project Work	Siva Sankaranarayanan (EPRI)
14	04/17	Project work	
15	04/24	Project work	

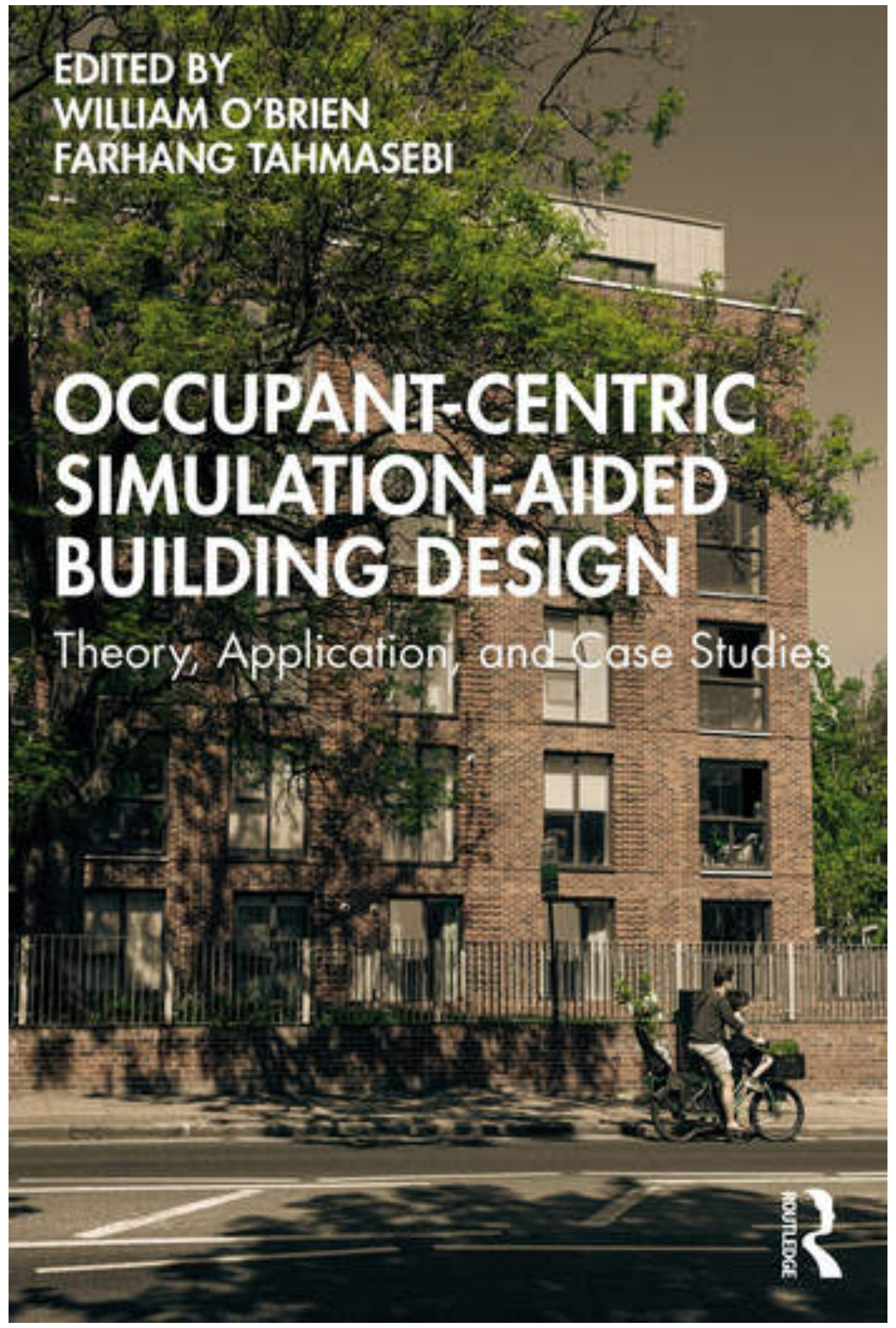
Plan for today

- Introduction
- Occupant Sensing
- Occupant Centric Performance Metrics
- Introduction to occupant modeling

Literature

- Book: Exploring Occupant Behavior in Buildings
- Book: Occupant Centric Design and Operation



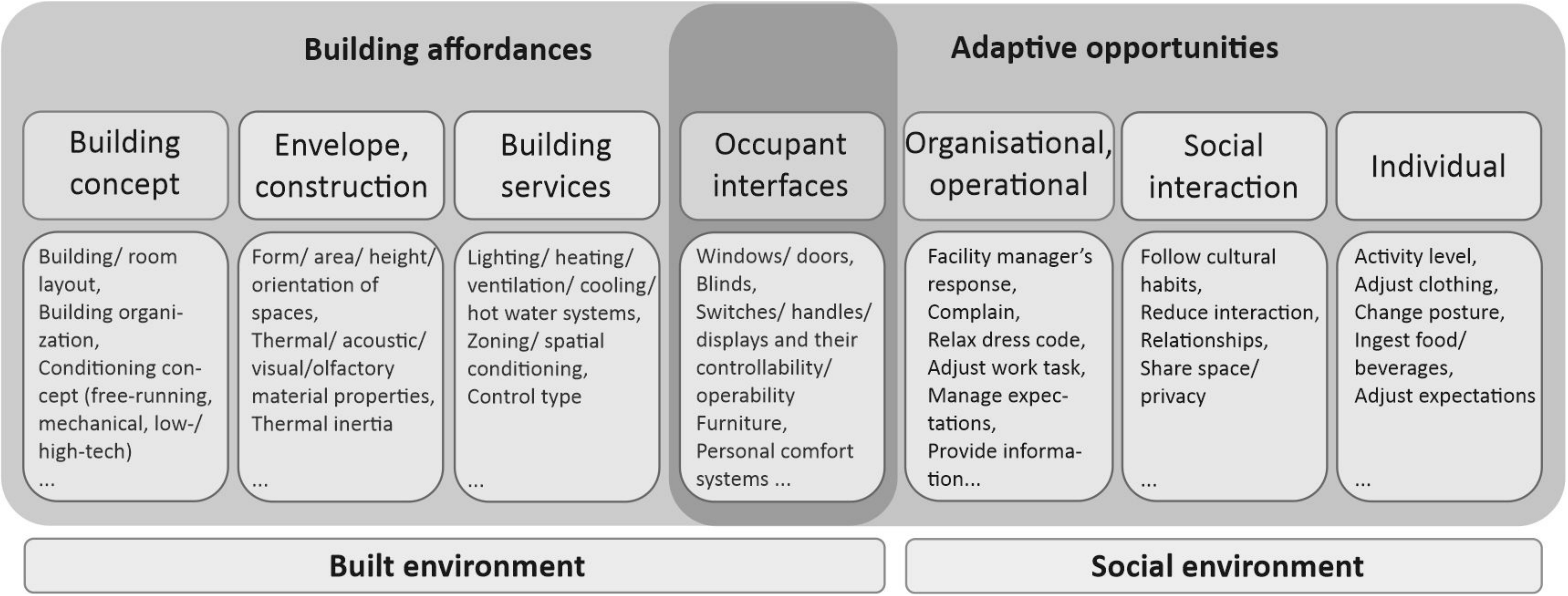


We shape our buildings; thereafter they shape us.

Who said this?


We shape our buildings; thereafter they shape us.
— Winston Churchill —
AZ QUOTES

Buildings need to be designed with adaptive opportunities in mind



Decisions undertaken in relation to construction entities and built spaces	**Examples of** design aims/requirements/considerations/decisions		
	Effects on occupants *within* the building	**Occupants' interaction *with* the building**	**Occupants' interaction *with the environment of the wider site,* through the building**
Building form and volume	Convey a sense of place; Display the status of the building owner;	Create exhilarating spaces; Ensure a feeling of 'coziness'; Minimize heating/cooling costs of the building	Help shape the street; Configure outdoor courtyards; Integrate with landscape
Building footprint on site and orientation	Provide places for children to play in the sun; Shape secluded spaces for people to interact outdoors and with each other	Provide clarity of access; Create useful outdoor spaces integrated with the street	Minimize environmental impact on the site; Protect from solar overheating; Lower impact on neighbors' right to light and sun; Take advantage of cooling breezes
Program distribution and orientation	Allow for flexibility in separating or joining rooms; Consider public/private interactions	Determine the relationship of noisy/ quiet, day/night spaces (e.g., isolate the bedrooms from the living area); Orientate spaces with regard to heating and cooling needs	Provide daylight, natural ventilation, and view to the outside for the main living spaces; Enable patients to see the day go by; Enable visual contact with nature
Form and area of building spaces	Provide office workers appropriate visual/aural contact with each other (e.g., open plan cellular/offices); Consider a mix of functions (e.g., bar, dance space, seating)	Provide an efficient and clear circulation inside the building (e.g., functionality, escape, and evacuation routes); Ensure that spaces support functions	Provide a sense of connection to the outside (e.g., shallow office spaces); Let sunlight into bedrooms in the mornings
Fire and evacuation routes	Provide for safe evacuation of building occupants	Provide safe routes to the outside; Ensure clarity on emergency access;	Provide the required access to external services (e.g., emergency vehicles, hydrants)
Floor to ceiling heights	Convey status; Provide views from the top (mezzanine)	Improve sound dispersion; Manage overheating (stratification)	Improve daylighting and sky views (e.g., large glazing); Facilitate segregated natural ventilation (e.g., above the occupant)
Heating and cooling system choice	Consider running costs for the client; Charge energy bills at room level (e.g., care homes)	Position systems to minimize furniture disruption; Reduce response time on conditioning the building; Consider passive heating and cooling strategies; Shift peak demand in relation to energy tariff	Minimize greenhouse gas emissions; Consider low energy technologies (e.g., heat pumps); Consider heat release and noise affecting pedestrians or outdoor recreation areas
Heating and cooling system demand	Ensure thermal comfort for the expected range of occupants (e.g., doctors and patients in hospital)	Ensure that temperatures and humidity are suitable for building contents; Provide 'thermal delight'	Minimize demands by taking advantage of the climate
Cooking system choice	Ensure that systems are appropriate to occupant's lifestyle (e.g., food type)	Provide appropriate ventilation system and cooking facility	Consider the environmental impact of fuel
Hot water system choice	Ensure that systems are appropriate to occupant's lifestyle (e.g., run a bath and do the dishes at the same time)	Ensure correct system sizing	Consider low energy technologies (e.g., solar hot water)
Ventilation system choice and demand	Consider different types of activities; Consider the number of occupants and type of occupancy	Consider occupant preferences (e.g., opening windows, HVAC, ceiling fans)	Consider natural/hybrid ventilation; Avoid outdoor noise; Filter outdoor air pollutants
Heating, cooling, and ventilation control type	Consider provision of shared and/or individual control	Consider provision of 'intelligent' controls; Ensure that controls are appropriate to occupants (e.g., elderly, children) and system type; Ensure that control are customized to activity;	Provide climate responsive/efficient controls (e.g., temperature sensors, Daylight responsive control)

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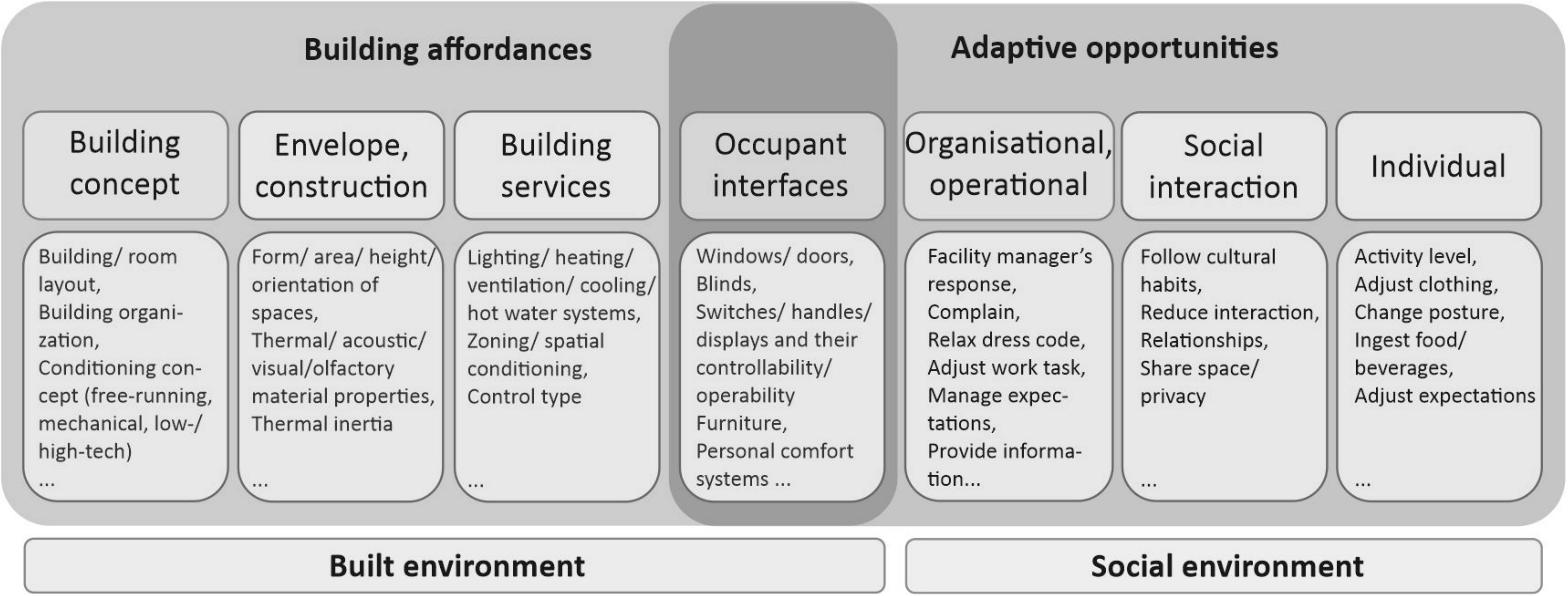
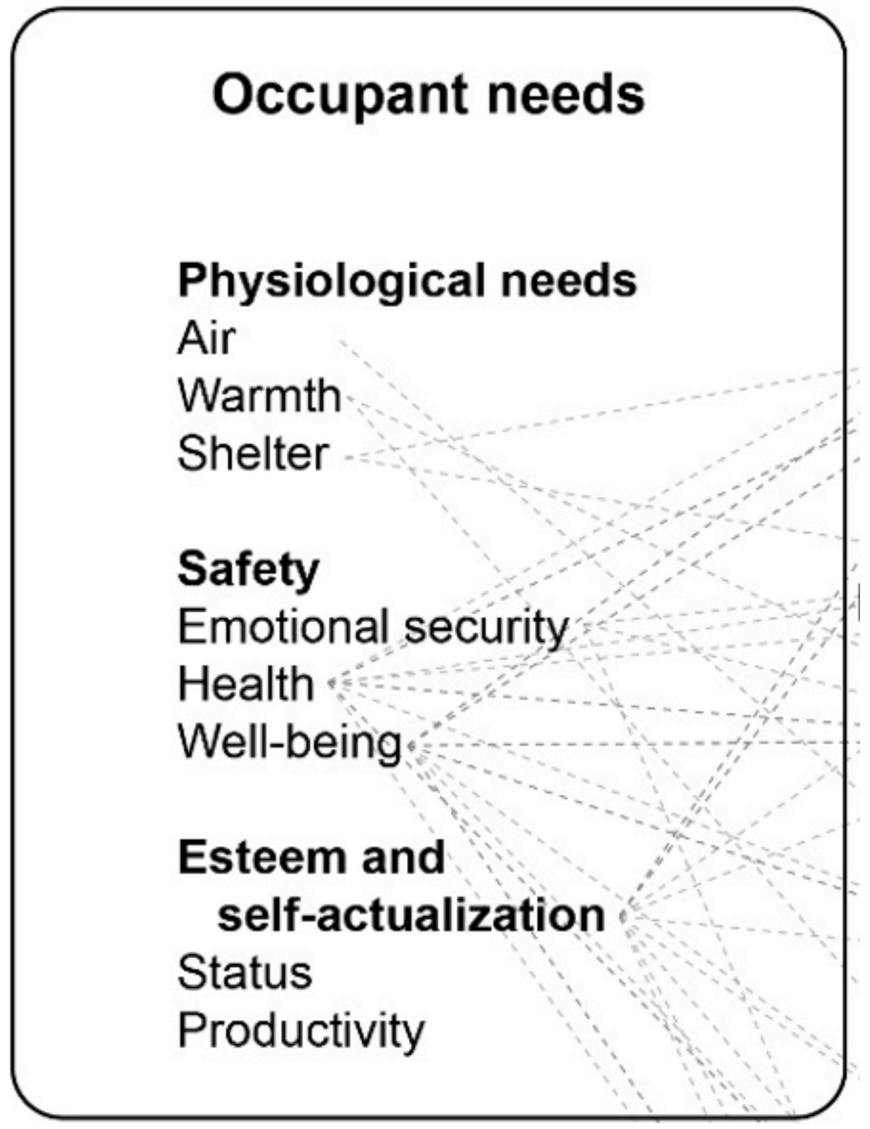
Let's take a look at this from the occupants' needs perspective



Human needs and the indoor built environment

Framework reflecting the design flow from human needs in relation to requirements for the indoor built environment to related design elements affecting the performance of buildings as related to the requirements. In reality, this is an iterative process and, once built, a building's elements will affect occupants' needs. Note that elements and connections are only examples for graphical reasons.



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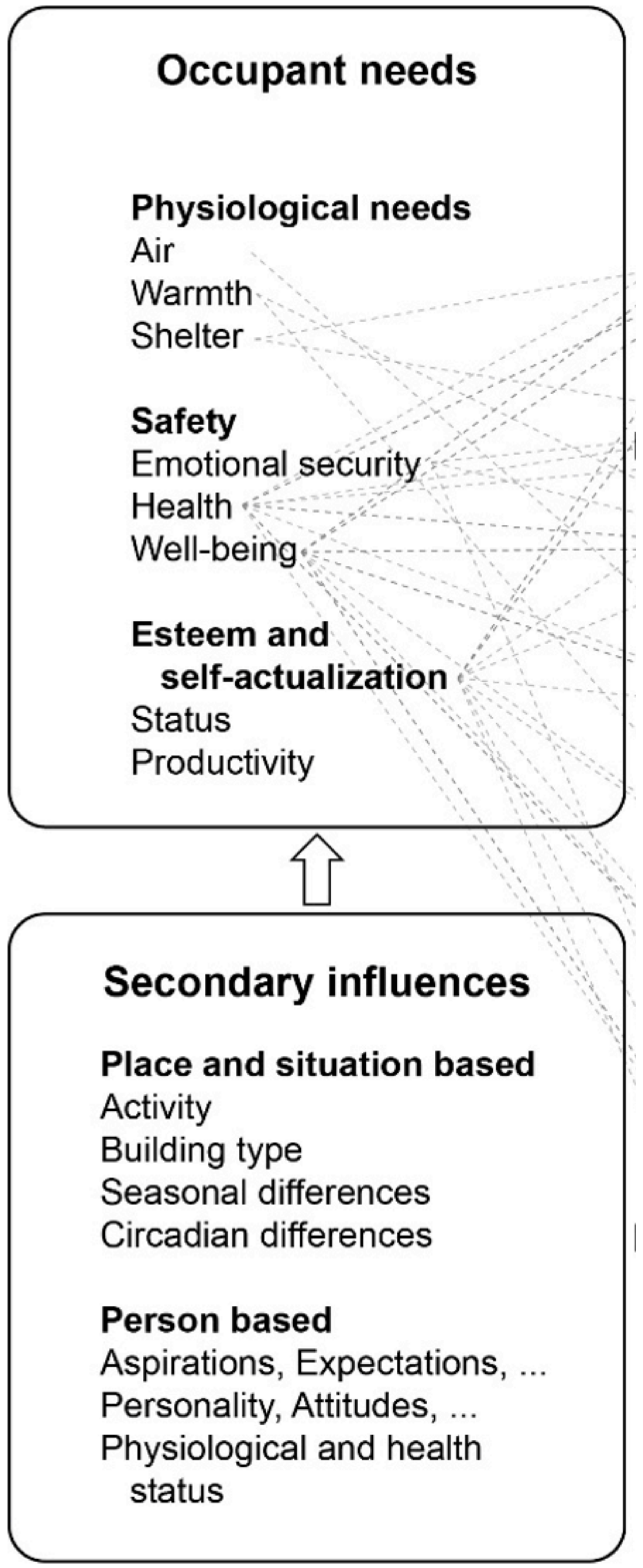

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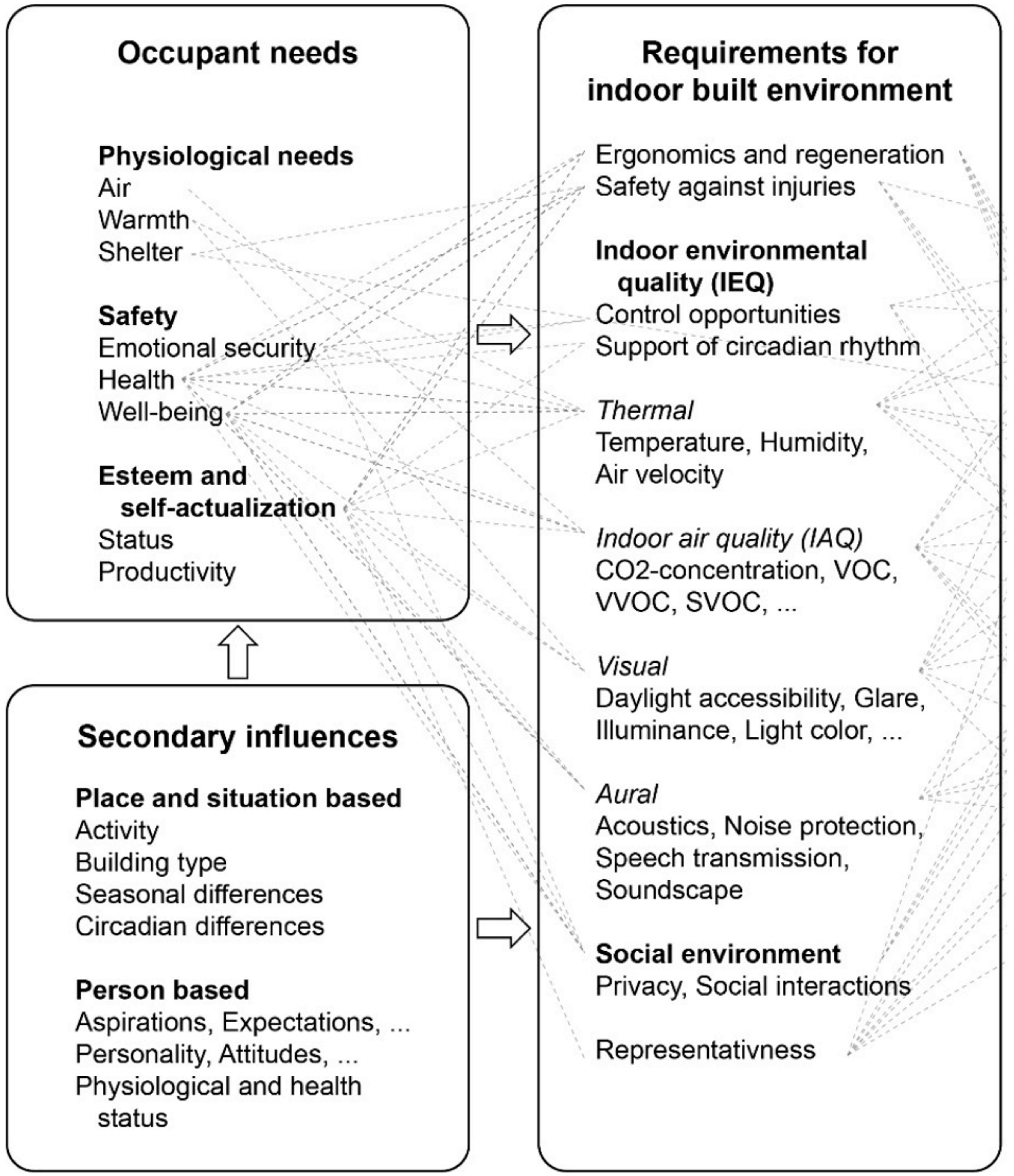

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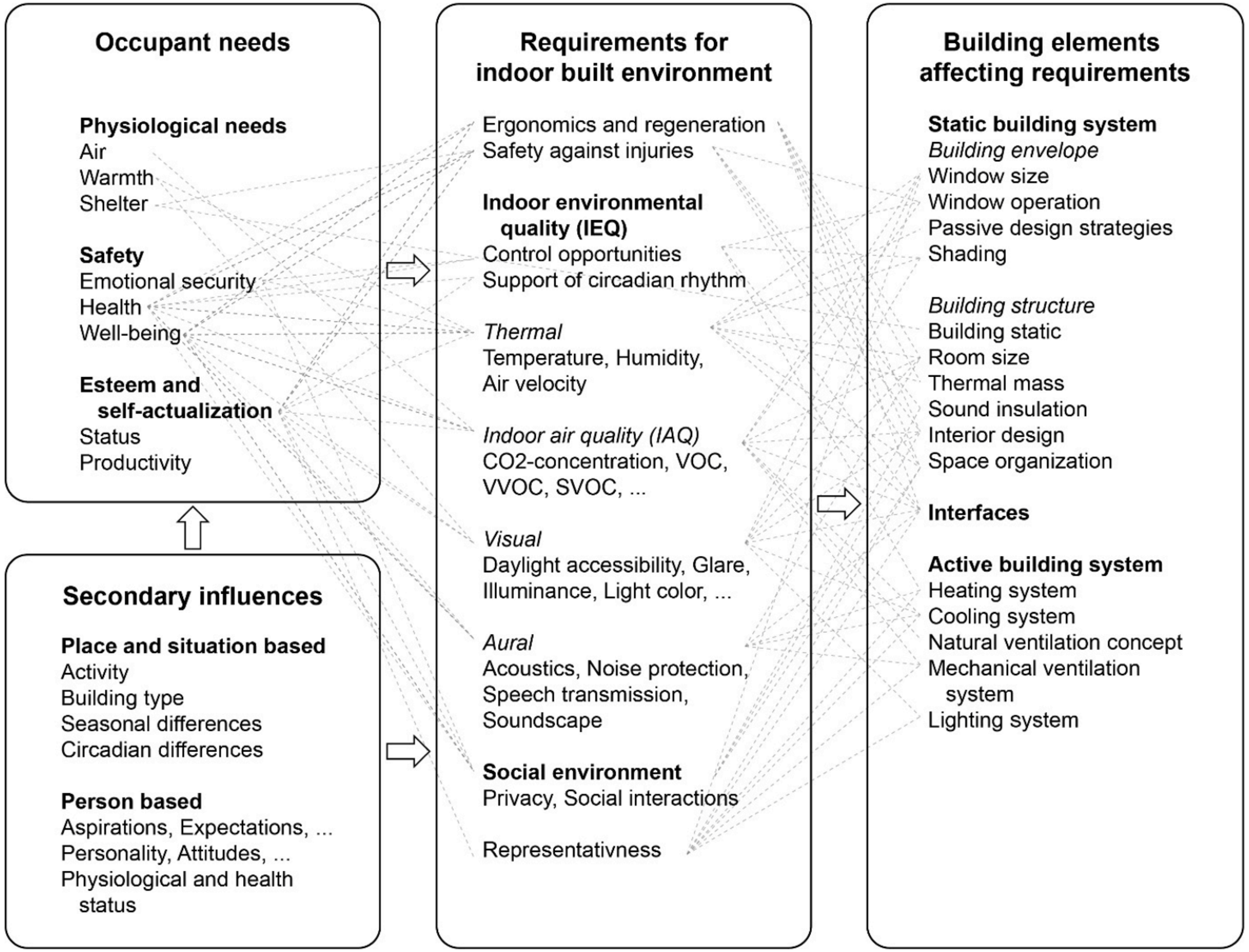
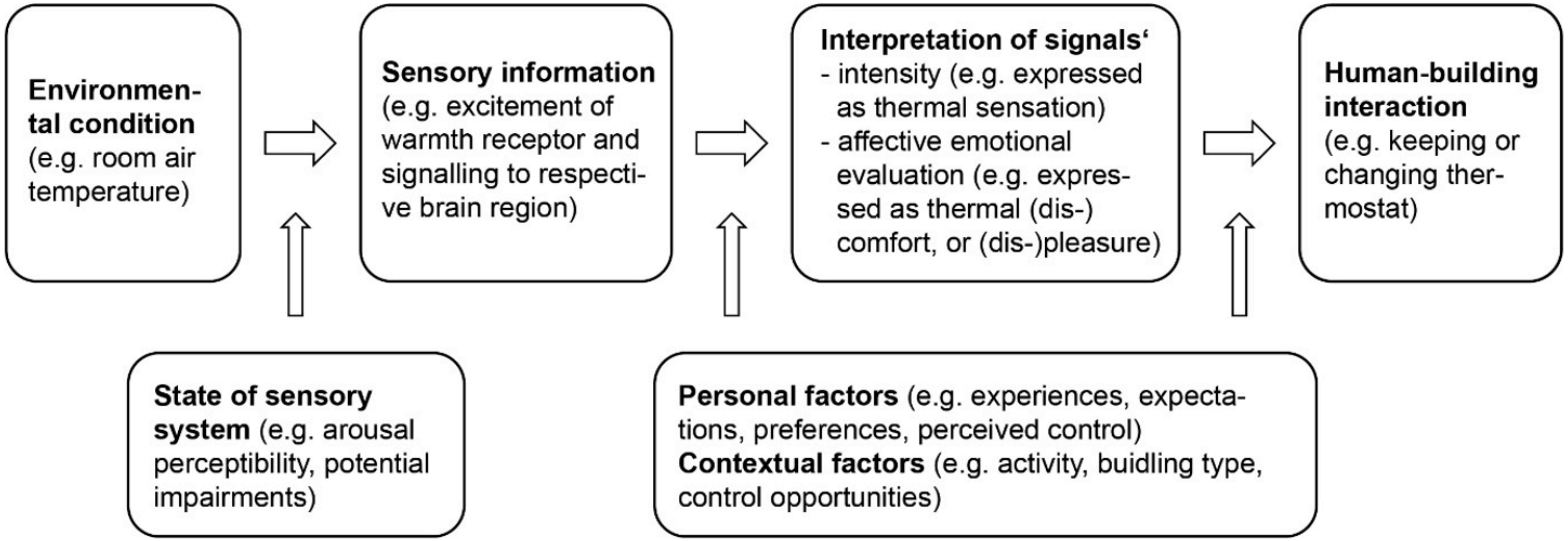


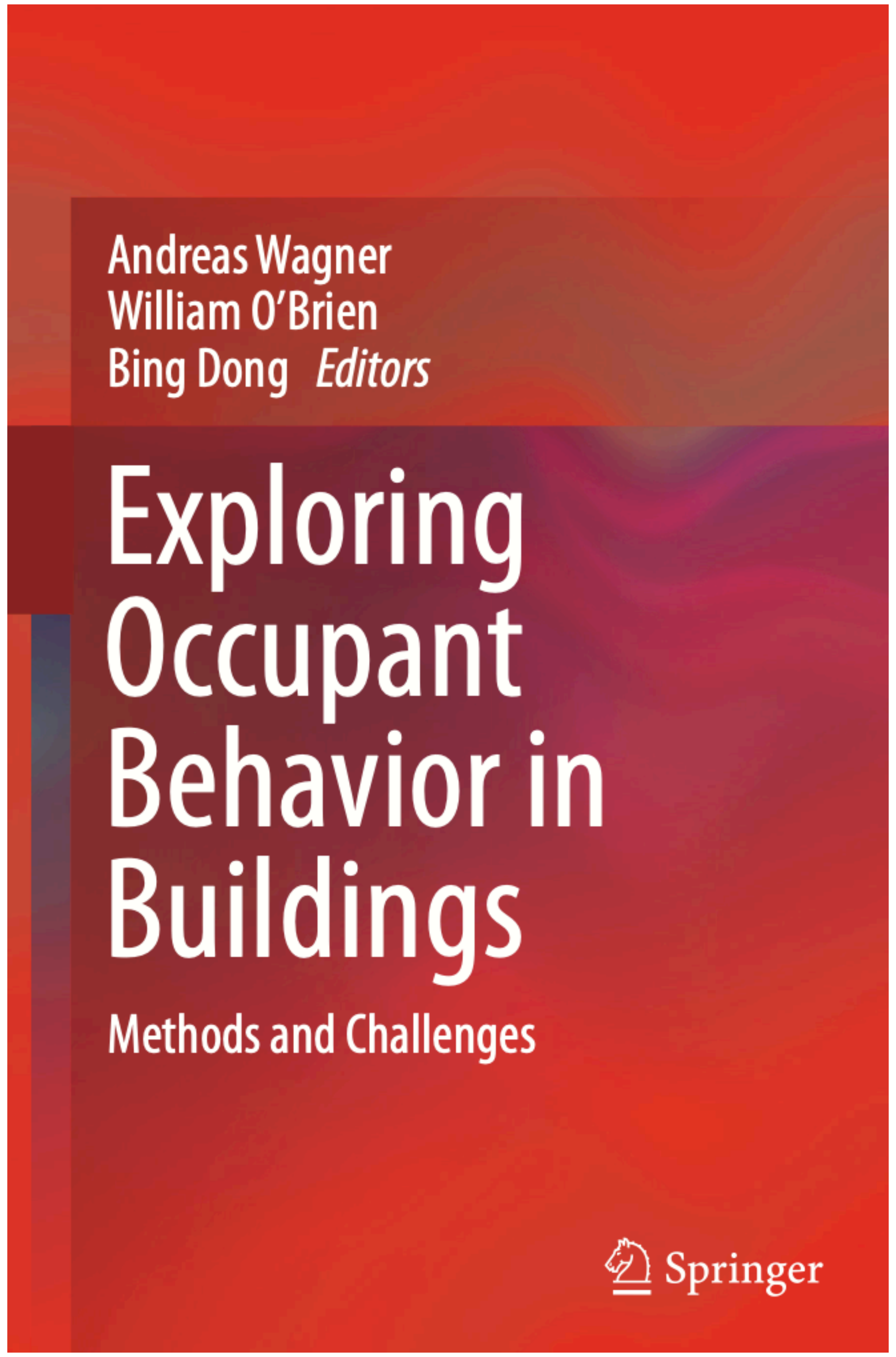
Sensory input and perception

- Schematic flow from environmental stimuli to human-building interaction



Sensing and Data acquisition

- Chapter 4



Data is crucial

Commonly used energy simulation tools often use synthetic schedules, lighting and plug loads, which can lead to large errors

some researchers found up to 600%

Gathering data on occupants (presence and behavior) can help reduce these modeling errors.

Not all methods are created equal

- There are 9 metrics by which we can evaluate sensing technologies:

Not all methods are created equal

- There are 9 metrics by which we can evaluate sensing technologies:
- Cost
- Power Type
- Data Storage
- Deployment Type (building type, room type, location, etc)
- Sensing range (min, max)
- Data sensed (binary, continuous, tracking)
- Data collection style (periodic, event-based)
- Accuracy/failure
- Demonstrated Applications

Group Work: What occupant sensing technologies do you know?

- Discuss with your neighbor
- 15 min
- Collect your answers on this google slide document

Group Work - Discussion

Occupant sensing technologies can be organized in 7 categories

- 1. Image based
- 2. Threshold / Mechanical
- 3. Motion Sensing
- 4. Radio-based
- 5. Environmental
- 6. Human in the loop
- 7. Consumption Sensing

1. Image based

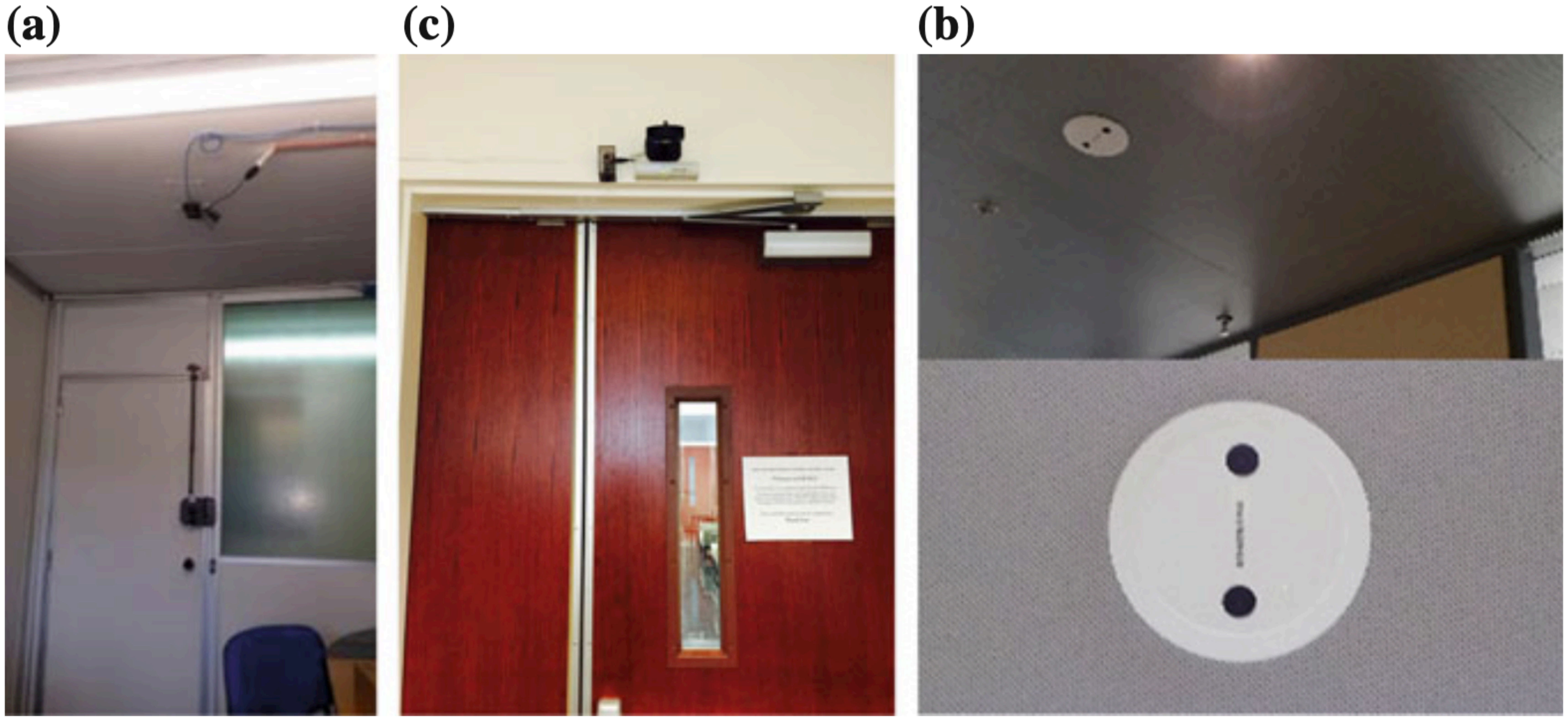


Fig. 4.1 Examples of various camera network deployment for occupant behavior studies. **a** Micro camera through RaspberryPI at University of Calabria (Italy) (Picture by Dafni Mora). **b** Stereo vision camera network at South Denmark University (Picture by Mikkel Baun Kjærgaard). **c** Commercially available camera network at UTSA (Picture by Bing Dong)

2. Threshold/Mechanical

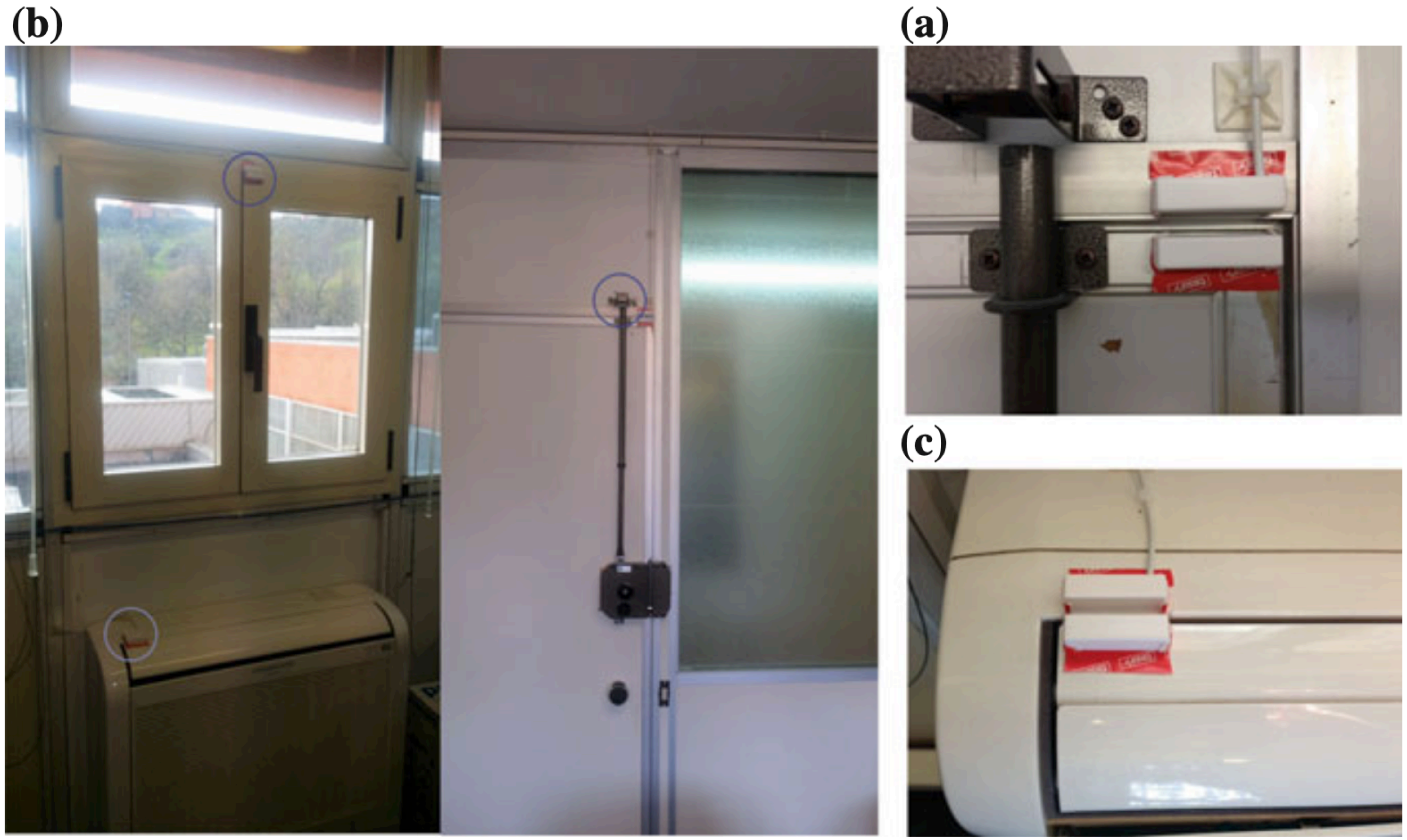
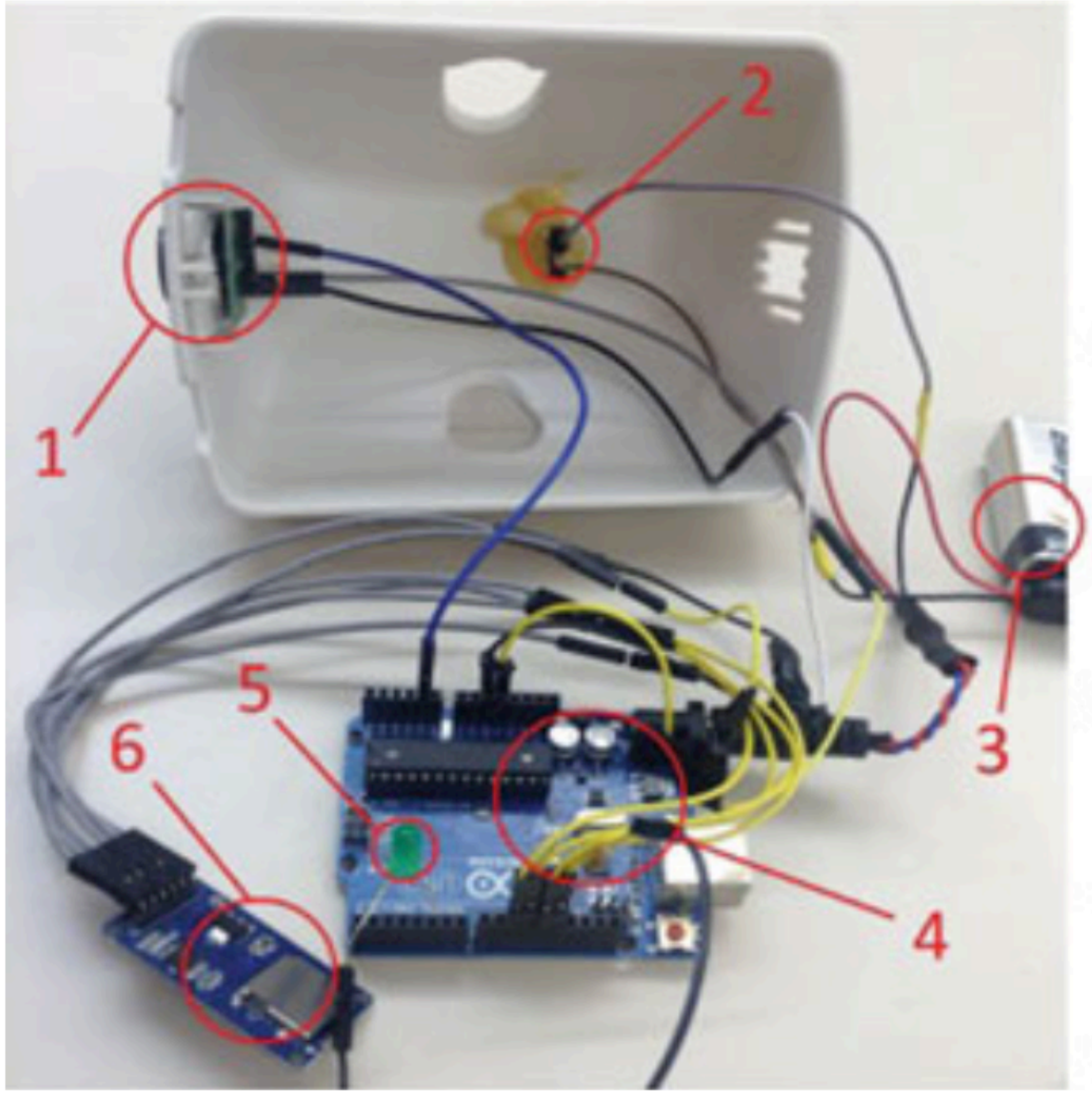


Fig. 4.2 Examples of threshold sensors (Pictures by Marilena De Simone). **a** Door contact sensor. **b** Window, door and air conditioning switching sensors deployment at University of Calabria, Italy. **c** Air conditioning switching sensor

3. Motion sensing

Fig. 4.3 Ultrasonic range sensor developed by UTSA, USA



1. Ultrasonic Range Finder
2. Switch (ON/OFF)
3. Battery
4. Micro-controller
5. LED
6. SD Card Reader

PIR sensor

4. Radio signal sensing

- electromagnetic waves in the frequencies from 10kHz to 300 GHz
- Radio Frequency Identification (RFID)
- WiFi/Bluetooth
- Ultra Wideband (UWB)
- Global Positioning System (GPS)

5. Environmental

- TVOC
- CO_2
- temperature
- acoustics
- in combination with other methods have been also used for occupancy detection and prediction

6. human in the loop

- Occupancy/behavioral data is collected with humans involved in the measurements
- directly observe people
- log interactions with systems (thermostat, blind use)
- wearables

7 Consumption sensing

- Water and electricity consumption have been found to correlate with occupancy

- Certain plug loads correlate with occupancy

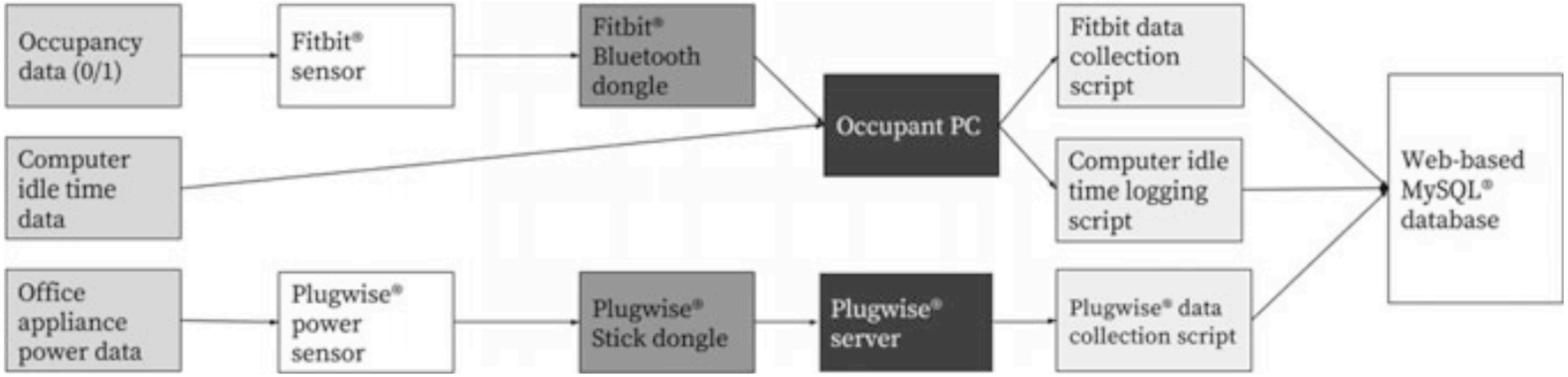


Fig. 4.8 Plug load meter data and ground truth data collection system architecture for learning occupant behavior (Zhao et al. 2014)

Occupant data acquisition

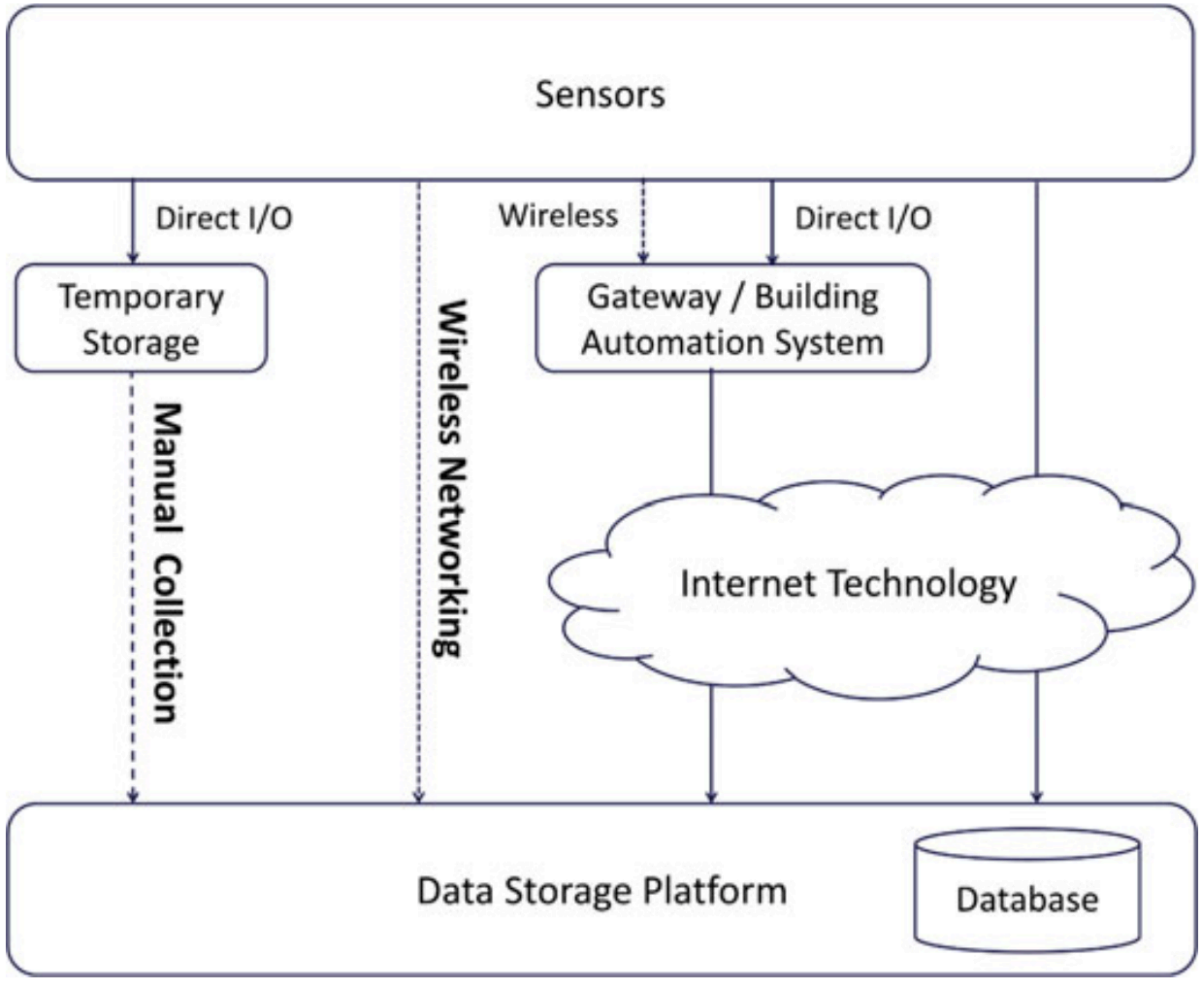


Fig. 4.9 Overview of the four different technical setups for acquisition of occupancy data (Figure by Mikkel Baun Kjærgaard)

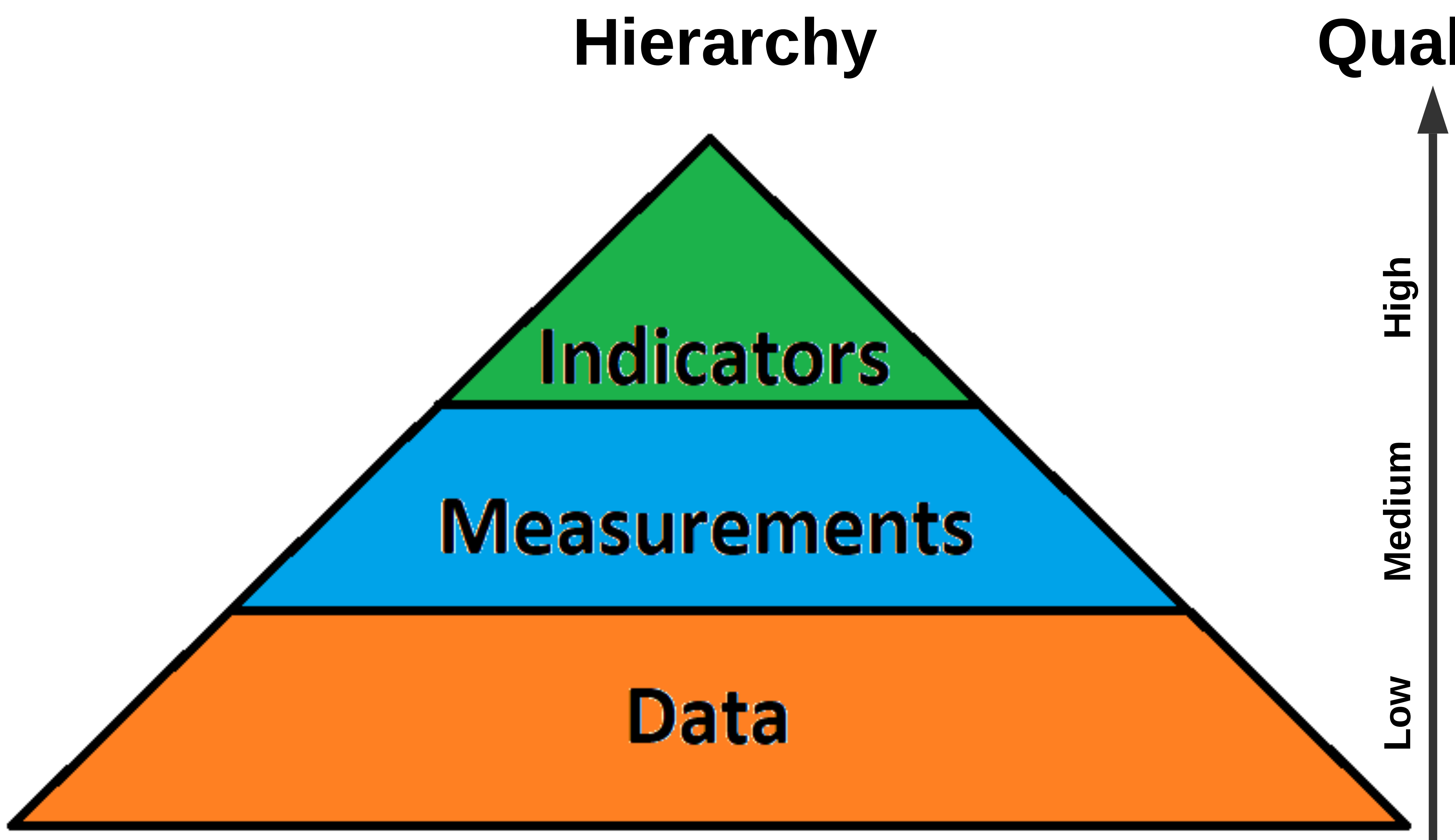
Break

What are Performance Metrics?

- What do you think?

- What are their characteristics?

Key Attributes of building performance metrics



Quality	Information
High	Combined values that clearly reflect the performance with easy-to-understand information
Medium	Measurements after cleaning and basic calculation that can track the trend of certain quantifies.
Low	Building characteristics or raw operational measurements.

Key Attributes of building performance metrics

- **Accessibility/reproducibility:** Metrics should be easy to obtain repeatedly with existing infrastructure and technologies and reasonable effort and cost. Specifically, the sources of data and how they can be measured should be straightforward.
- **Quantifiability:** Metrics should have a clear definition of either direct measurements or robust and straightforward formulas for calculating the values. For example, the metric definition should be clear about which sensor, meter, and building characteristics are needed for the calculation. Quantifiability is the fundamental of performance tracking, verification, and benchmarking.
- **Actionability:** Metrics should be target-oriented. They should provide actionable information to inform solutions to specific problems; for example, reducing lighting energy consumption per person by improving the lighting control.

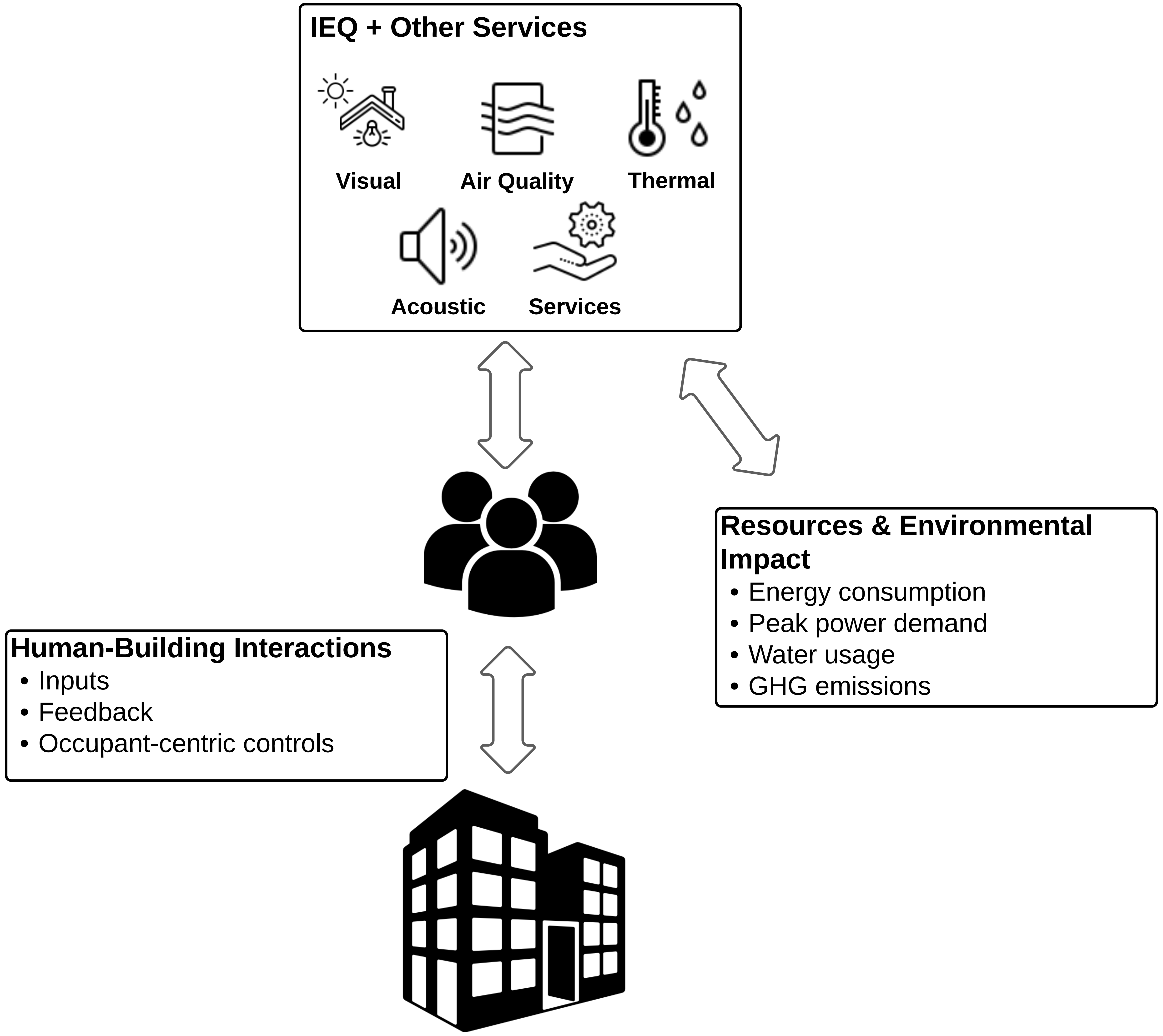
Key Attributes of building performance metrics

- **Comparability:** Ideally, metrics should be easy to compare across different scales, countries, building types, and other settings, to maximize utility. A good metric should be generic and not building-specific.

- **Unbiased:** Metrics should be fair and objective. For example, performance metrics normalized for real-time vs. designed occupant count may be misleading.

Occupant-Centric Metrics

- Occupants interact with buildings
- Buildings provide services
- Buildings & systems consume resources



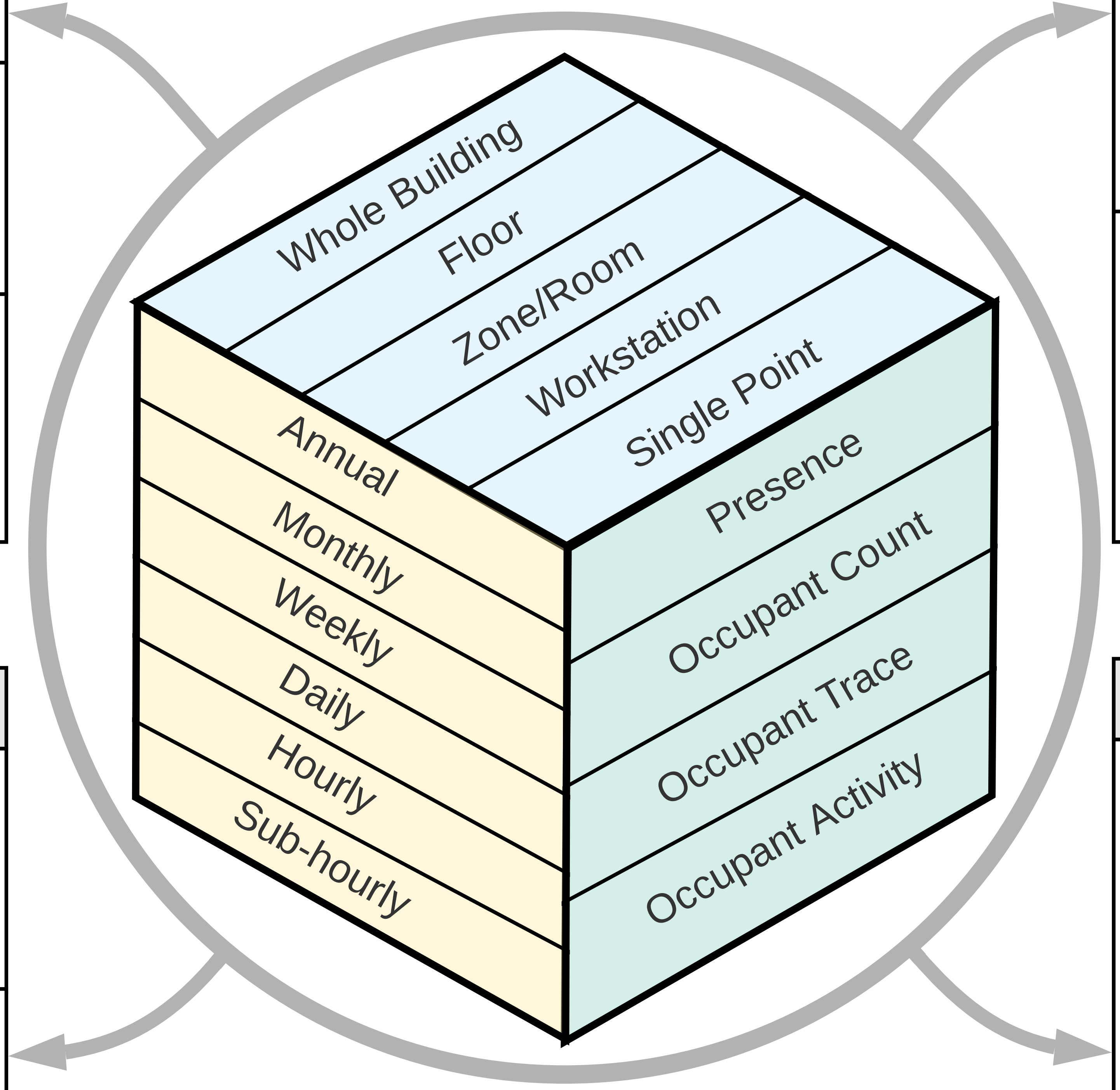
Diverse factors … when selecting metrics

Performance Factors

- Energy Related
  - Energy Efficiency
  - Demand Flexibility
- Indoor Envrionment Related
  - Improve Comfort
  - Avoid Hazard
- Emission Related
  - Reduce Emission
  - Reduce Waste

Quantifiability

- Via measurements
  - Sensor(s)
  - Meter(s)
  - Direct/Indirect
- Via simulations
  - Model Parameter(s)
  - Output Variable(s)



Normalization Factors

- Spatial
  - Floor Area
  - Number of Rooms
- Occupant
  - Number of Occupants
  - Equivalent Hours
- Weather
  - Degree Hours
  - Degree Days

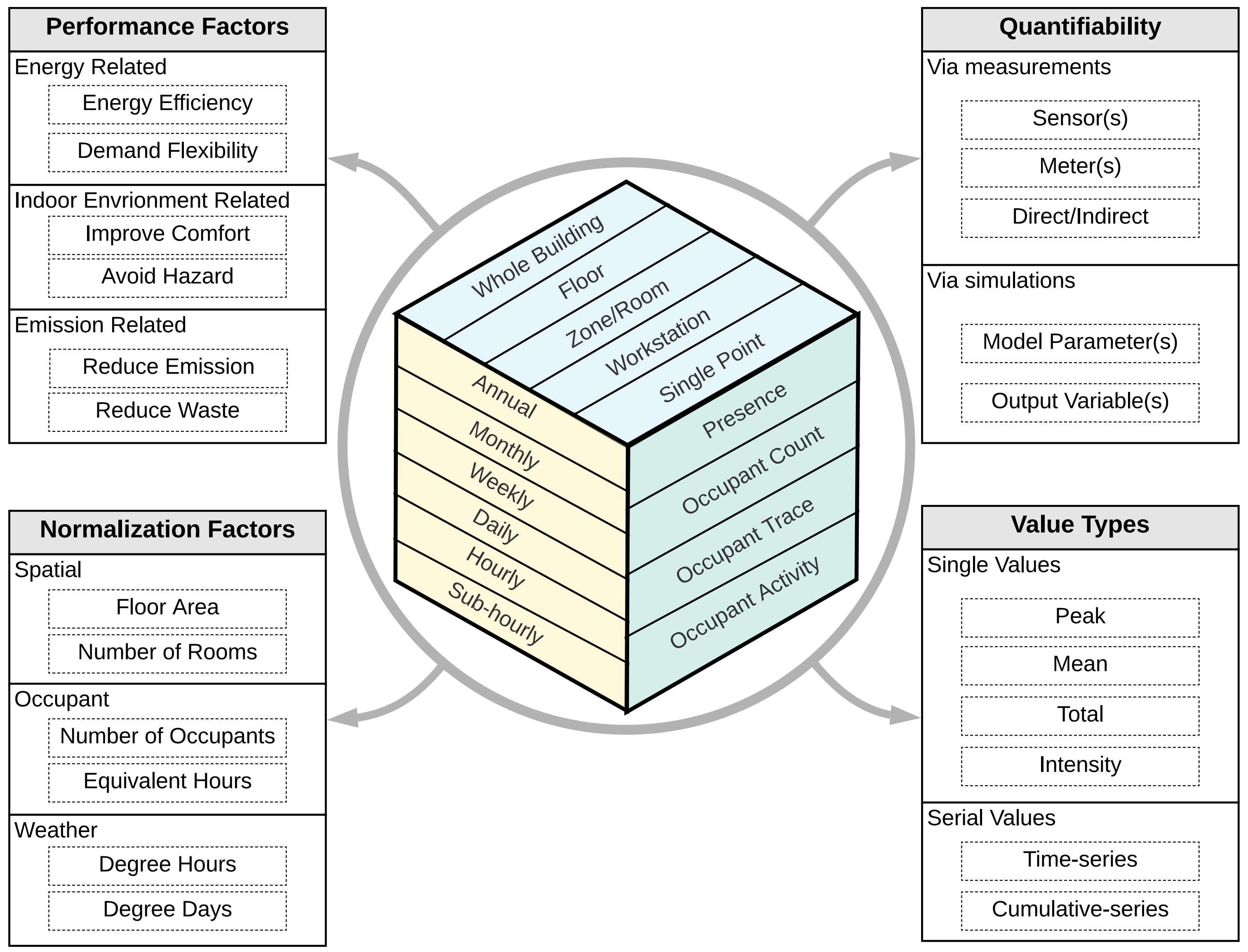
Value Types

- Single Values
  - Peak
  - Mean
  - Total
  - Intensity
- Serial Values
  - Time-series
  - Cumulative-series

Category	Sub-category	Metric Name	Metric Definition
Resource and environmental impact	Energy Use	kWh/OccupantHour	Annual total site energy use (kWh) / annual total occupant-weighted hours for the whole building
	Water Use	kg water/person	Annual water use (kg) / number of maximum occupants
	GHG Emissions	kg CO_2e/person	Annual CO_2 equivalent emission (kg) / number of maximum occupants
Building Services	Lighting	Underlit Occupancy Hours	The hours when the indoor light level is below the adaptive setpoints for a particular occupant when the room is occupied
	Thermal	Degree-Occupant-Hour Criterion (DOHC)	Sum of occupied hours multiplied by the number of occupants and operative temperature exceeding the corresponding comfort range
	Air Quality	Weighted CO_2 Exceedance * Occupant Hour	The sum of CO_2 concentration exceeding a reference level, multiplied by the number of occupants during each occupied hour, weighted by the range which the CO_2 concentration is in (e.g., higher weights when CO_2 concentration is unhealthy)
	Acoustic Quality	Global Index of the Acoustic Quality	A global index that is the weighted function of five partial indices, namely: reverberation index, intelligibility of speech index, uniformity of loudness index, external disturbance index, and music sound quality index
	Other services	Hoteling Potential	Minimum ratio of the required number of workstations to the number of employees if they relocate on a weekly or daily basis for 95% and 99% of the time
Human-Building Interaction	Controllability	Controllability of HVAC	Percent of occupants who can adjust thermostat settings for their local environment
	Controllability	Accessibility of operable windows	Percent of occupants who can open/close the operable windows
	Occupant and Response	Accessibility to Building Information	Percent of occupants who have access to building information (e.g., a dashboard to see energy use, demand, space use, and IAQ of their floor or space)
	Occupant Feedback	Mechanism to provide feedback	Can occupants provide feedback about their IEQ needs? Is there a periodic survey of occupant satisfaction?

Methods to quantify metrics based on measured data

- Metrics can be either directly measured or calculated using measured data



Data Type	Example
Occupancy information	Occupant presence/absence and/or people count at the space or whole-building level
IEQ parameters	Air temperature, humidity, CO_2 concentration, volatile organic compounds, illuminance level, and acoustic level
Resource usage	Energy use of the whole building or major end uses including lighting, HVAC, plug-in equipment, and service water heating. Water use for the whole building or broken down into HVAC (cooling tower), drinking, and other uses (washing, flushing toilet, etc.)
Environmental impacts	GHG emissions and solid waste associated with building services
Human-building interaction measurements	Percent of occupants able to interact with building systems and components, e.g., open/close windows, adjust thermostat settings, open/close shades, turn on/off or dim lights, turn on/off plug-in equipment, occupant feedback system

Methods to quantify metrics based on measured data

- Occupancy information is essential for occupant-centric metric calculations.

- Methods to measure occupant presence of absence are differentiated by implicit or explicit counting.

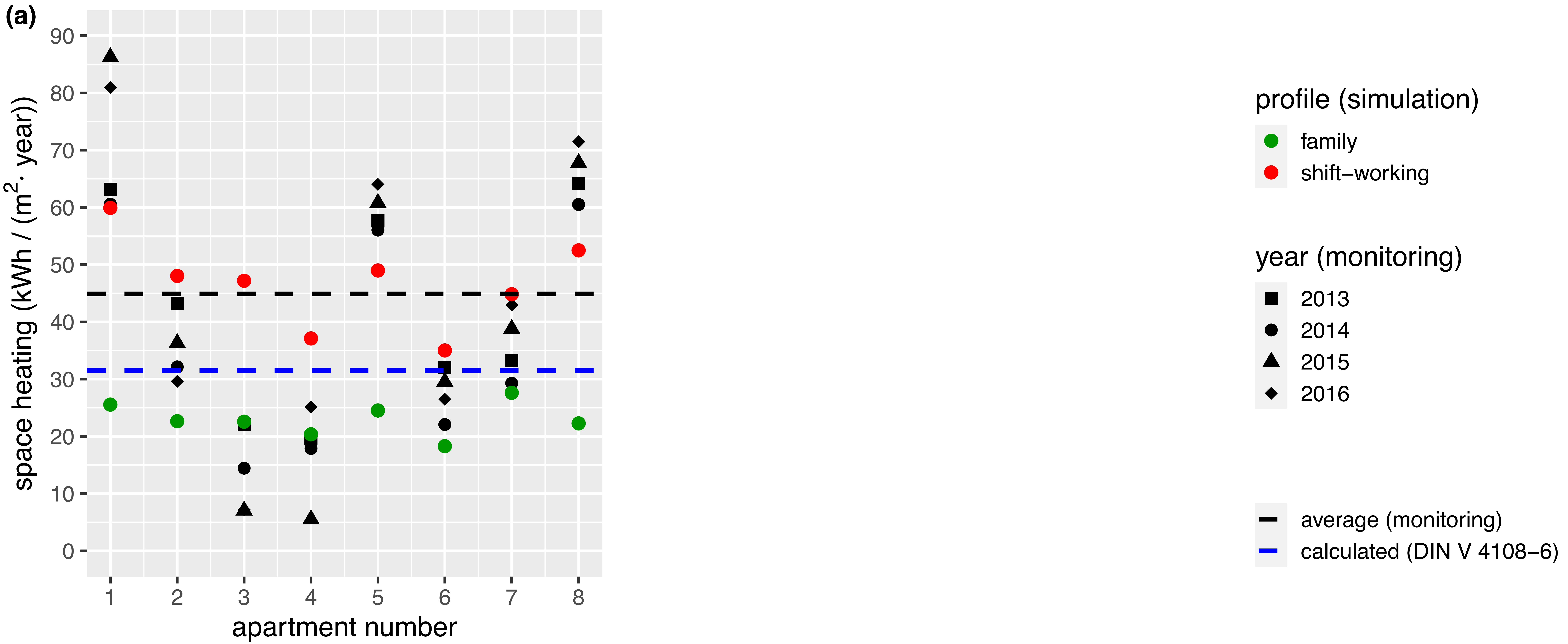
- Implicit methods measure occupancy indirectly. Examples?

- Explicit methods measure occupancy directly. Examples?

Case study compares traditional to occupancy centric metrics

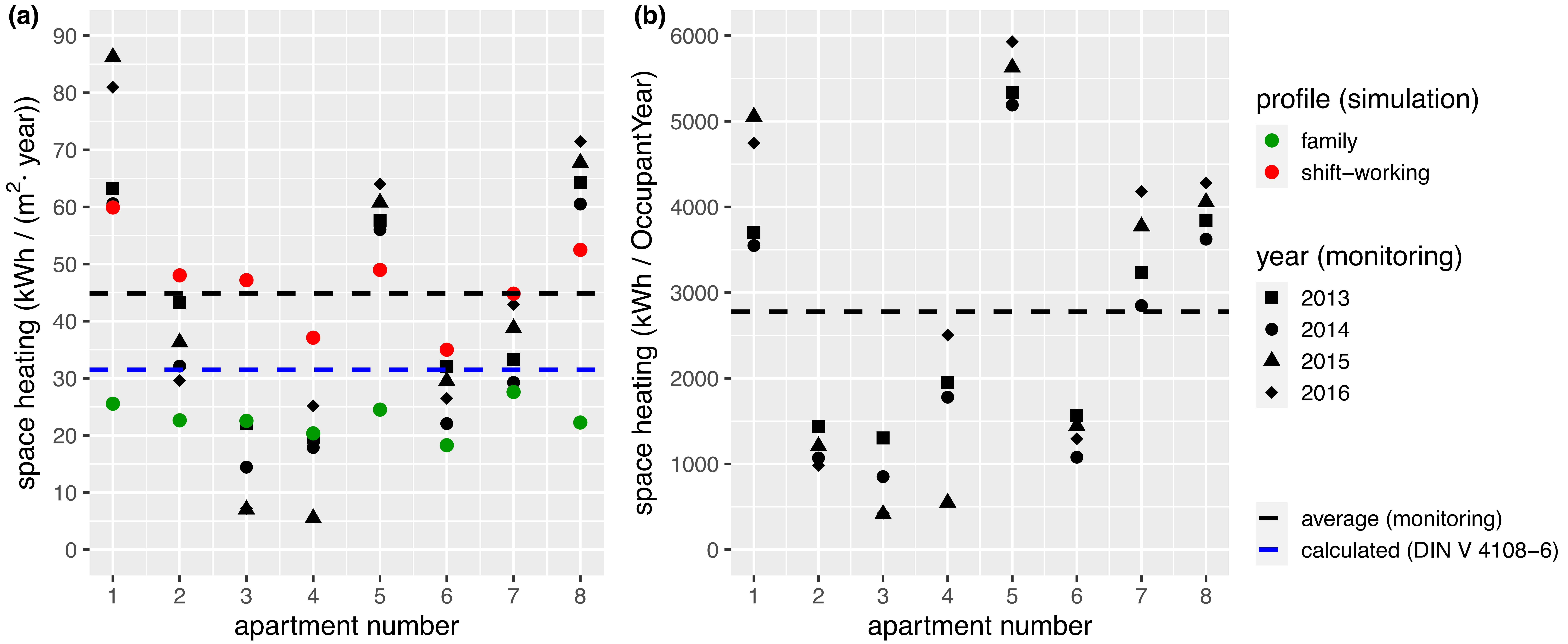
- High efficiency residential buildings in southern Germany
- Objective was to compare calculated energy demand based on standards (energy certificates, etc) and the actual monitored consumption
- consumption data is thermal energy (space heating and DHW) and electricity for appliances
- study ran from 2013 to 2016
- energy was normalized by heating degree days

Case study compares traditional to occupancy centric metrics



*Thermal energy for space heating in the example building with eight units: kWh/(m2 * year) (left) and kWh/OccupantYear (right). Both metrics are weather normalized. (Hahn et al. 2020)*

Case study compares traditional to occupancy centric metrics



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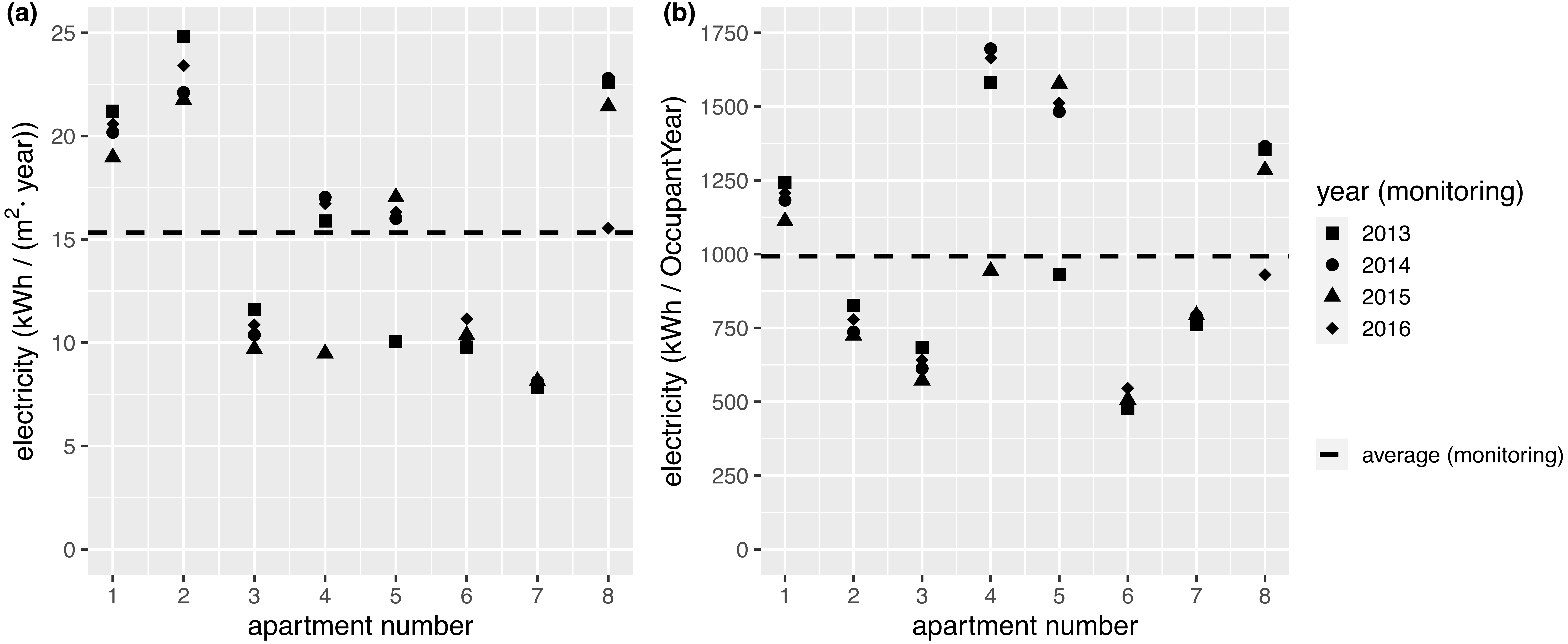


Annual electricity use of the example building with eight units: kWh/(m2 * year) (left) and kWh/OccupantYear (right). (Hahn et al. 2020)

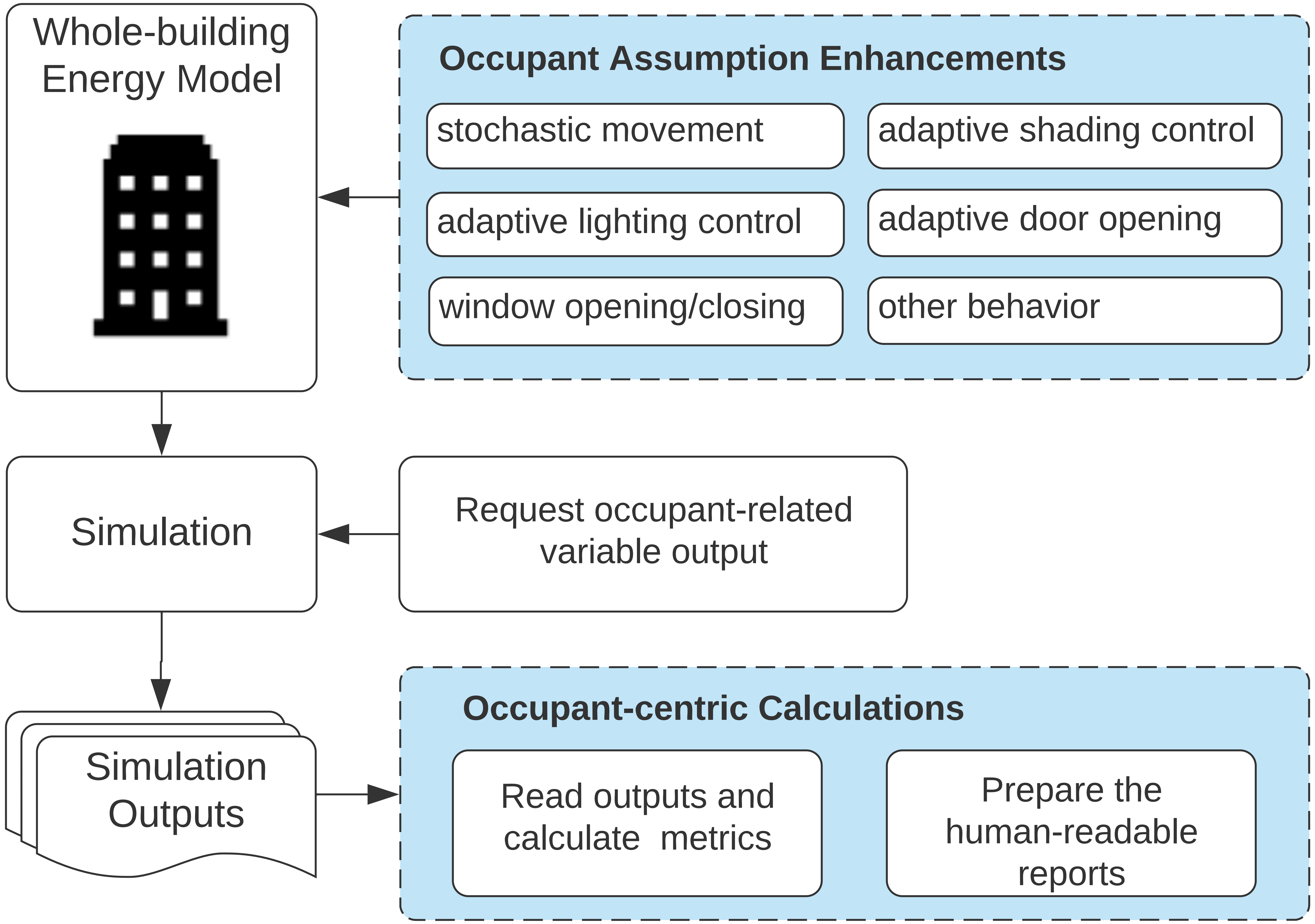
Methods to quantify metrics based on Simulation

- Building performance simulation (BPS) provides an approach to quantify the impact of occupants.
- Recent advances make it possible to model relatively realistic occupant behavior.
- In addition post-processing of the results is necessary.

Occupant Behavior Modeling	Recent Advancements	Benefit
Presence/Movement	1. Occupancy estimation and prediction with easy-to-measure environmental parameters, Wi-Fi connections 2. Stochastic occupant movement modeling	Provides high temporal and spatial resolution of occupancy information and helps users convert them into occupancy schedules for simulations.
Actions	Modeling of the adaptive behaviors 1. Window operation 2. Solar shading operation 3. Lighting operation 4. Thermostat adjustment 5. Appliance use 6. Clothing adjustment	Provides insight into occupants' individual IEQ preferences and helps users calculate occupant-centric metrics with respect to realistic occupant demand

Methods to quantify metrics based on Simulation

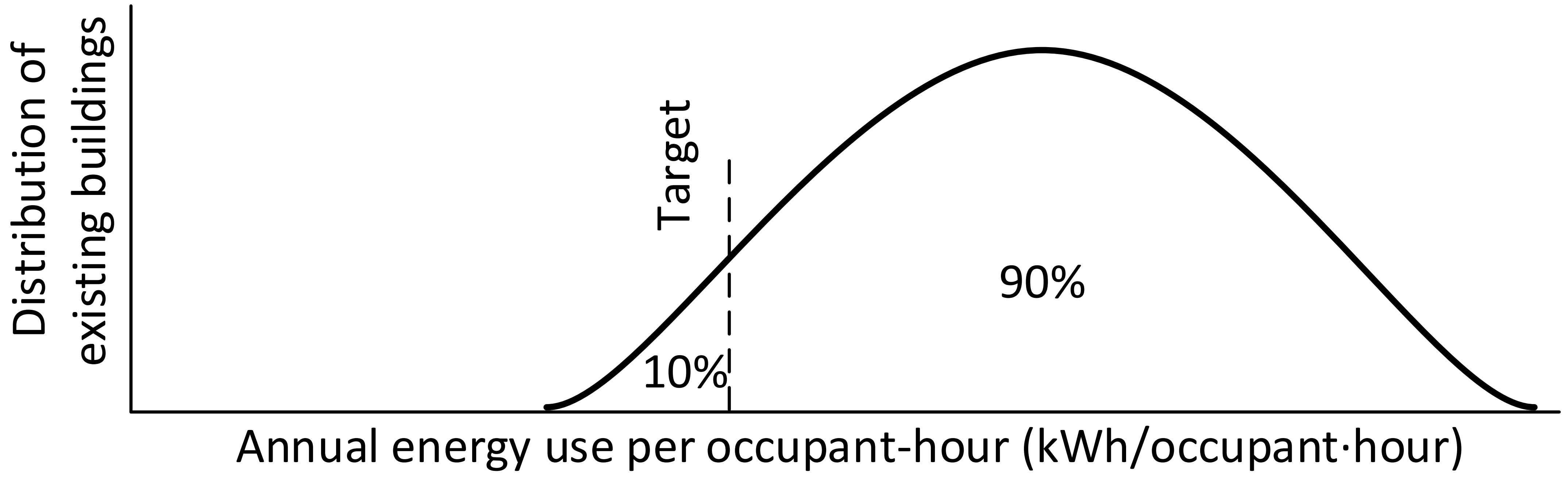
- Traditional BPS approach is augmented with occupant assumptions
- The stochastic nature of occupant behavior often requires multiple simulations.
- The simulation results are analyzed using occupant-centric metrics.



Setting targets of occupant centric metrics

- Two approaches:

- - **Top down**: A high-level metric is broken down into smaller parts. For example, Canada's residential building sector consumes about 1,600 petajoules (PJ) (1,600×1015 J) total, or about 42 gigajoules (GJ) per person (Government of Canada 2020). This value could be used as a starting point for a target, e.g., 21 GJ per person (or a 50% reduction from the current housing stock).



Setting targets of occupant centric metrics

- Two approaches:
- - **Bottom up**: start with individual occupants and their needs and may aggregate these up to the building level. For instance, we might consider the daily water needs for occupants and then use this information to estimate building-level water use (e.g., 100 occupants times 50 liters (L)/day of water leads to expected water use of 5,000 L/day).
-

Occupant requirements

- **Space**
  - Office space: 10 m^2 from 8 am to 6 pm on weekdays + 10% of 30 m^2 conference room 2 h/day
  - Parking: 1 space or 1 bicycle parking space
- **Water**
  - Hand/dishwashing/ toilet/drinking: 80 L/day
- **Lighting**
  - Office 10 m^2 at 500 lux, 5 W/m^2 = 500 W·h
  - Conference room 3 m^2 at 500 lux, 5 W/m^2 = 30 W·h
- **Plug loads**
  - Personal equipment
    - Computer monitor: 50 W for 10 hours
    - Laptop computer: 30 W for 10 hours
  - Shared equipment
    - Centralized printer 10% share: 500 W for one hour, 10 W for 23 hours
    - Refrigerator 5% share: 0.05 kWh/day
    - Coffeemaker 25% share: 0.03 kWh/day
- **Ventilation**
  - Outdoor air: 2.5 L/s + 0.3 L/s/m^2 × 13 m^2 = average of 6.4 L/s
- **Comfort**
  - Desk fan: 10 W for 10 hours = 100 W·h

Setting targets of occupant centric metrics

- Top-down methods easier to apply. But occupancy estimates must be made for real or designed occupancy.

- Bottom-up methods are more challenging to generate. But they follow more closely the intent of occupant-centric performance metrics.

- In some cases, resources are also required when no occupants are present.

Introduction to occupant modeling

Introduction

- Occupants can profoundly impact building performance

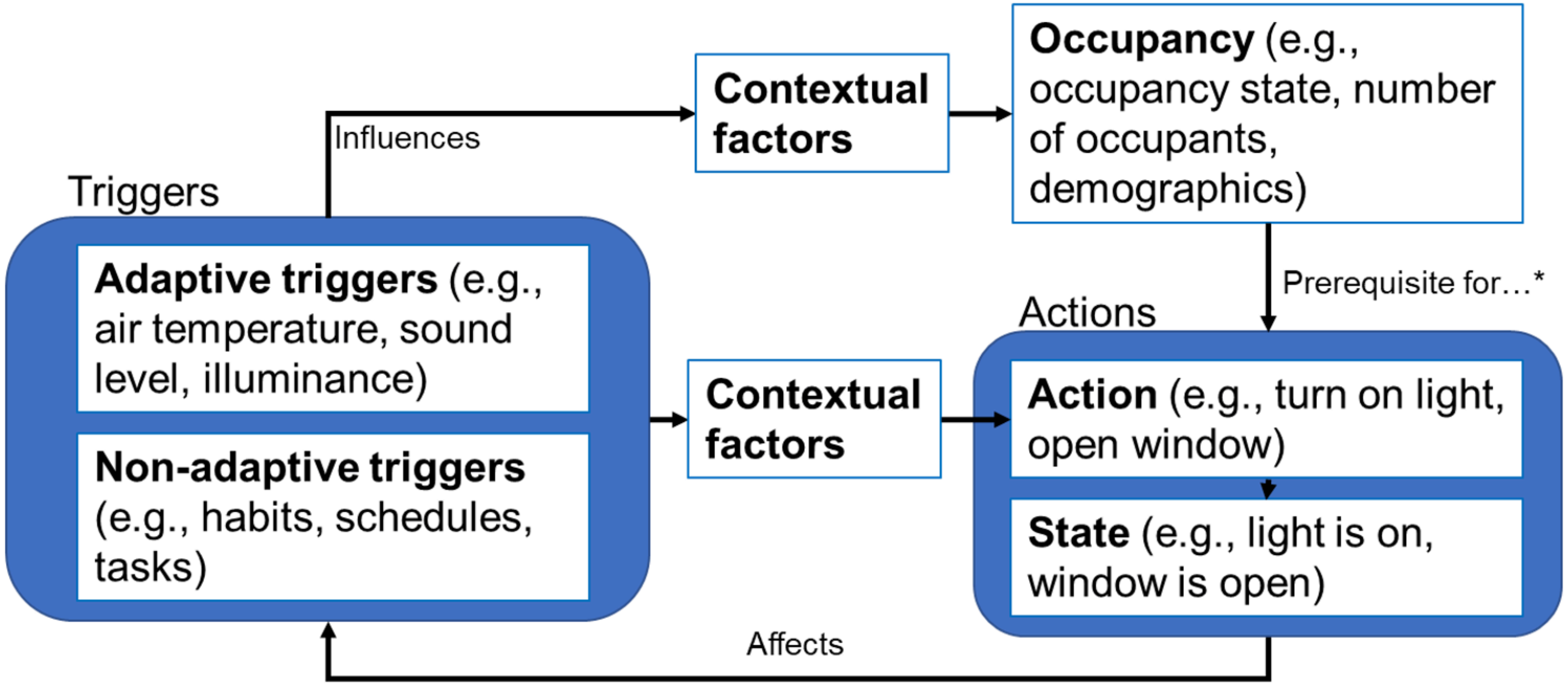
- **Performance Gap** =
  Predicted Energy Use - Measured Energy Use

- Performance Gap can be larger for high performance buildings - Why ?

Introduction

- Inaccurate characterization of occupants in the building design process can lead to
- increase performance gap
- poor design decisions
- Can you think of examples (design assumptions) that may negatively impact a building's performance?

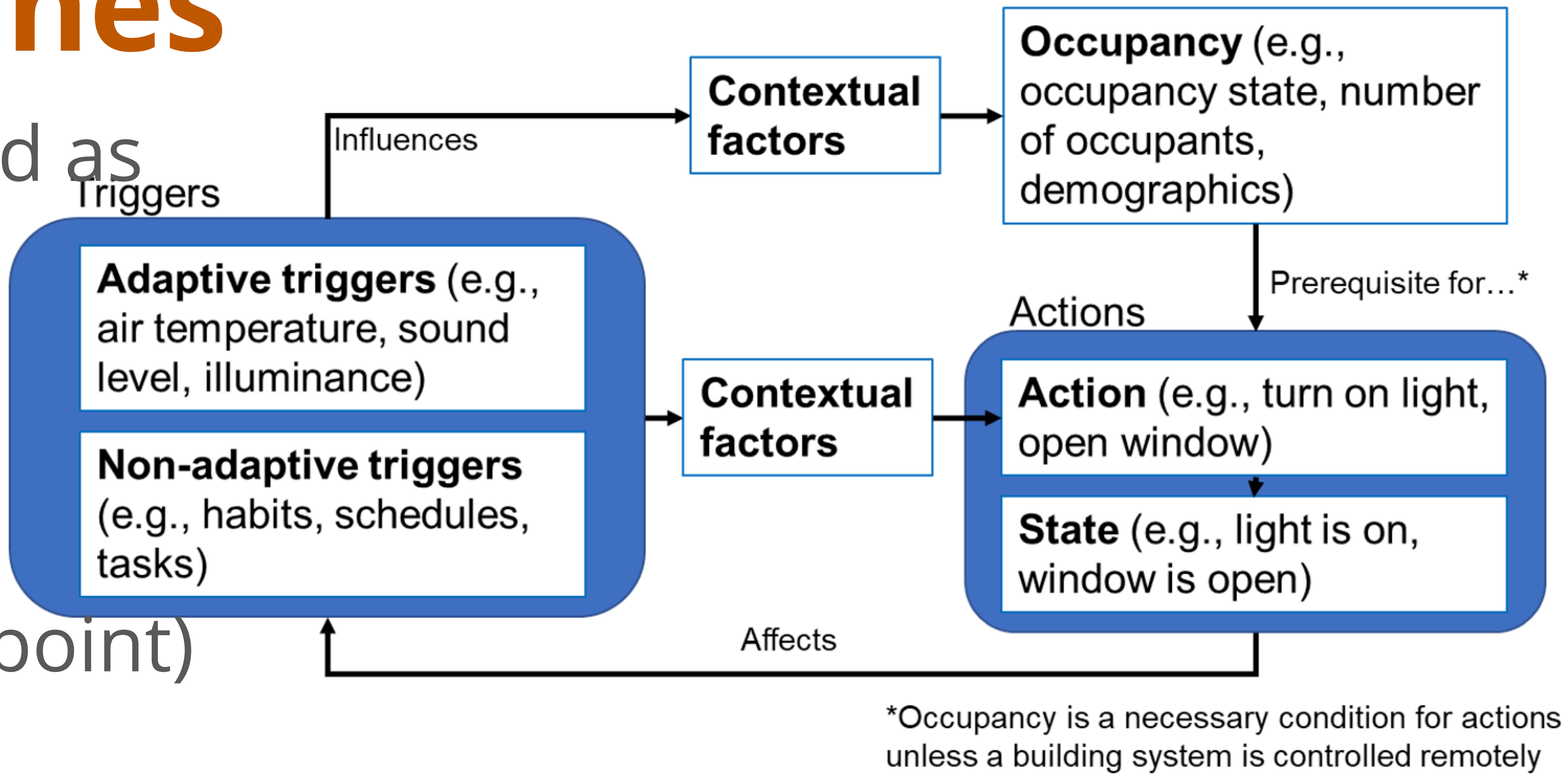
Occupancy & Occupant Behavior



*Occupancy is a necessary condition for actions unless a building system is controlled remotely

Occupancy Modeling Approaches

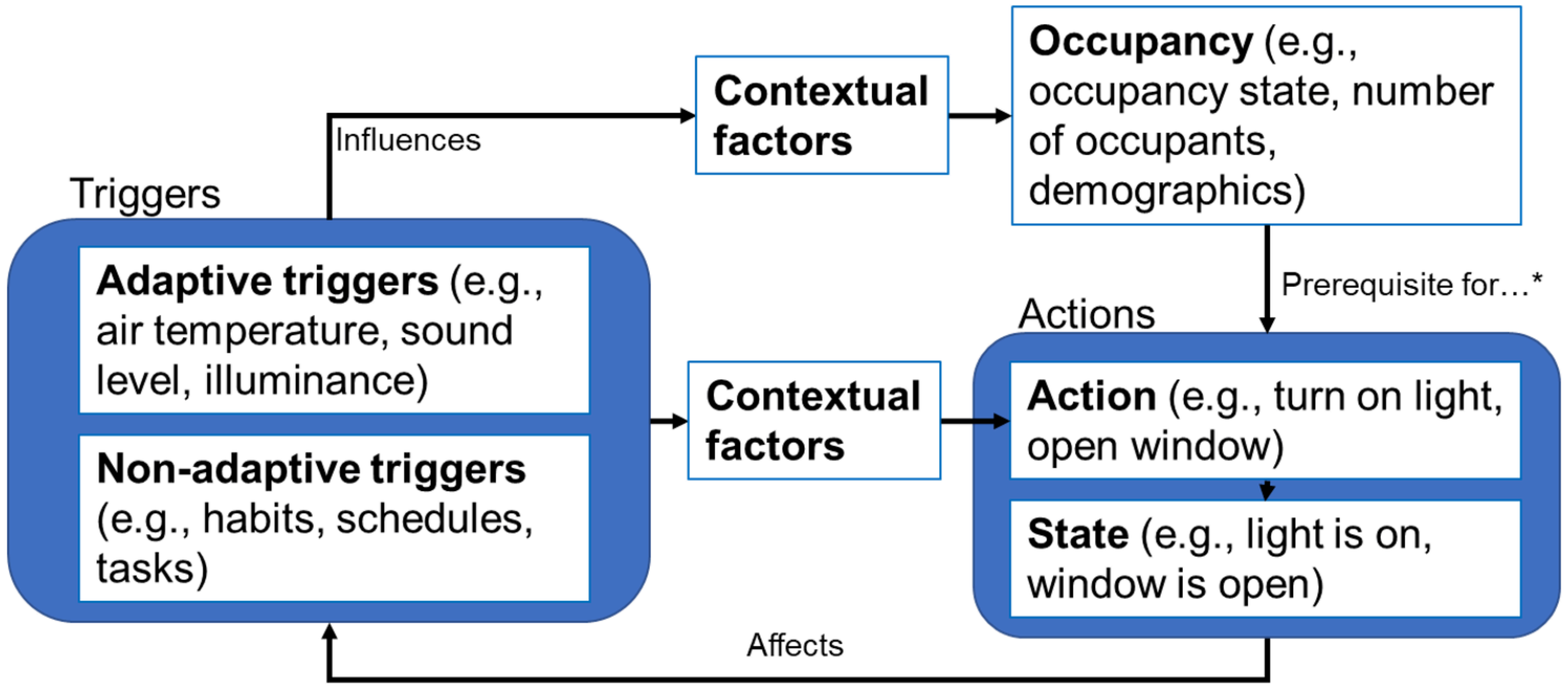
- Occupant's presence and behavior can be modeled as
- - actions (ex: turning systems on/off)
- - states (ex: state of a light switch, thermostat set-point)



- An **action changes the state**, which then normally remains constant until a new action is taken (exceptions exist).
- A **state has more than two levels** and options (example: window open/close or percent closed)

Occupancy Modeling Approaches

- Objective of Occupant Modeling is
- predict occupant actions/interactions with building systems, or
- predict resulting state of the building systems.
- Accurate prediction is difficult, but predicting long-term trends is feasible if sufficient data is available to make generalized models.
- Generalizable predictors and models challenging to create due to human and contextual diversity. (climate, cultures, building types, systems)



*Occupancy is a necessary condition for actions unless a building system is controlled remotely

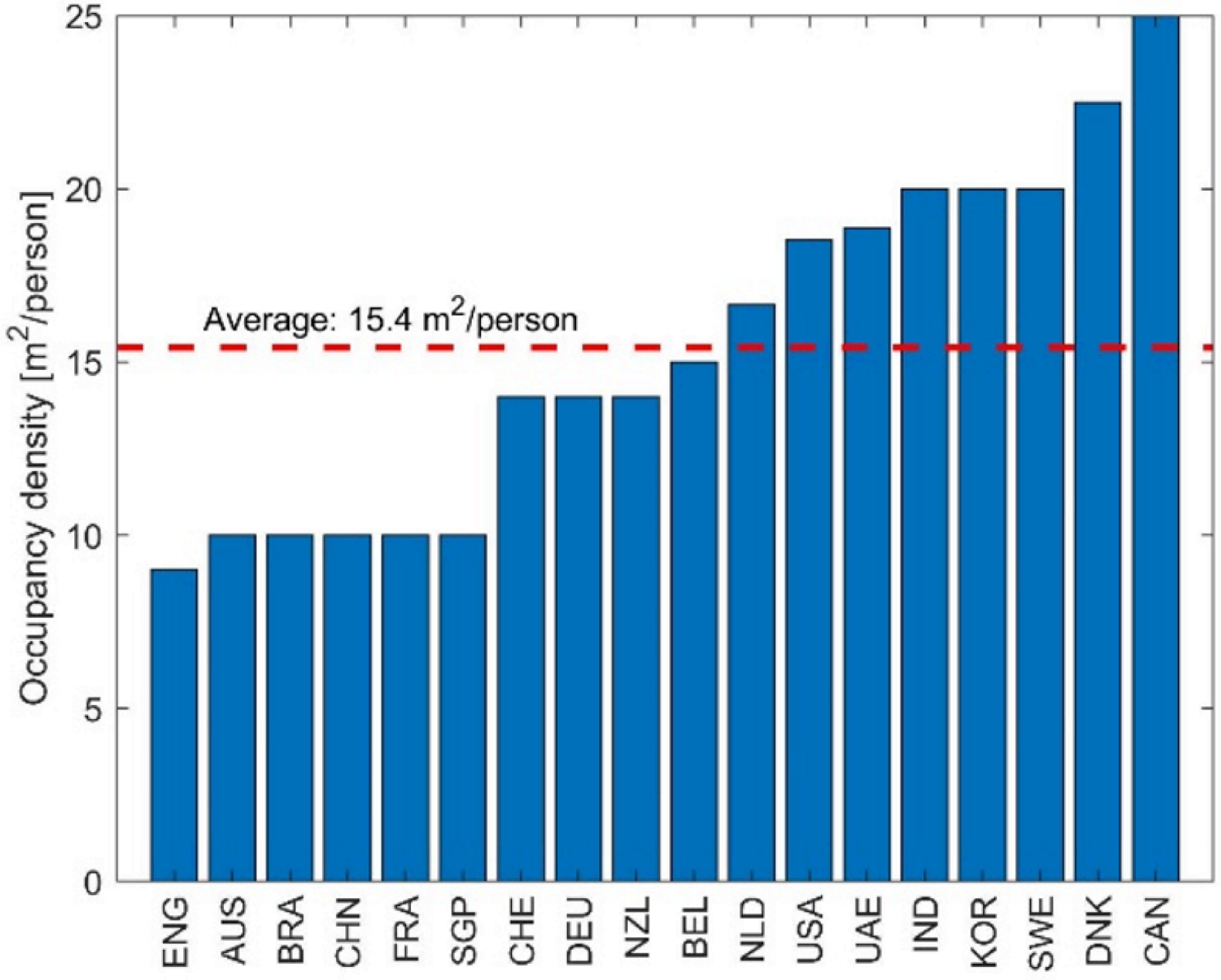
Traditional Occupant Modeling

- Today's state of the art modeling approaches are legacy applications of the early days.

- Building Performance Simulation (BPS) (EnergyPlus) tools specific a diversity schedule:
- Time-based schedules and densities to represent occupancy.

Domain	Common modeling approaches/assumptions
Occupancy (presence)	Daily diversity schedules (hourly resolution) with a corresponding density (e.g., m^2 per occupant), usually specified for different building or space types
Plug-in equipment and appliances	Daily diversity schedules with a corresponding power density (e.g., watts per m^2)
Operable windows	Windows are closed
Lighting	Daily diversity schedules or daylight-controlled (otherwise turned on with occupancy) with a corresponding lighting power density (e.g., watts per m^2)
Window blinds/ shades	Always open/non-existent (considered furnishing) or closed during glare events (e.g., above 1000 lux, as per IES LM 83 (IESNA 2012))
Water appliances (e.g., showers, toilets, sinks)	Hot water volume or energy per day per person or per floor area (e.g., L/person/day)
Thermostats	Daily setpoint schedules with possibility to turn off systems or use a temperature setback for unoccupied and/or overnight periods
Clothing level	Seasonal schedule (e.g., 0.5 clo in summer and 1.0 clo in winter (ASHRAE, 2020))

Example (Traditional modeling)



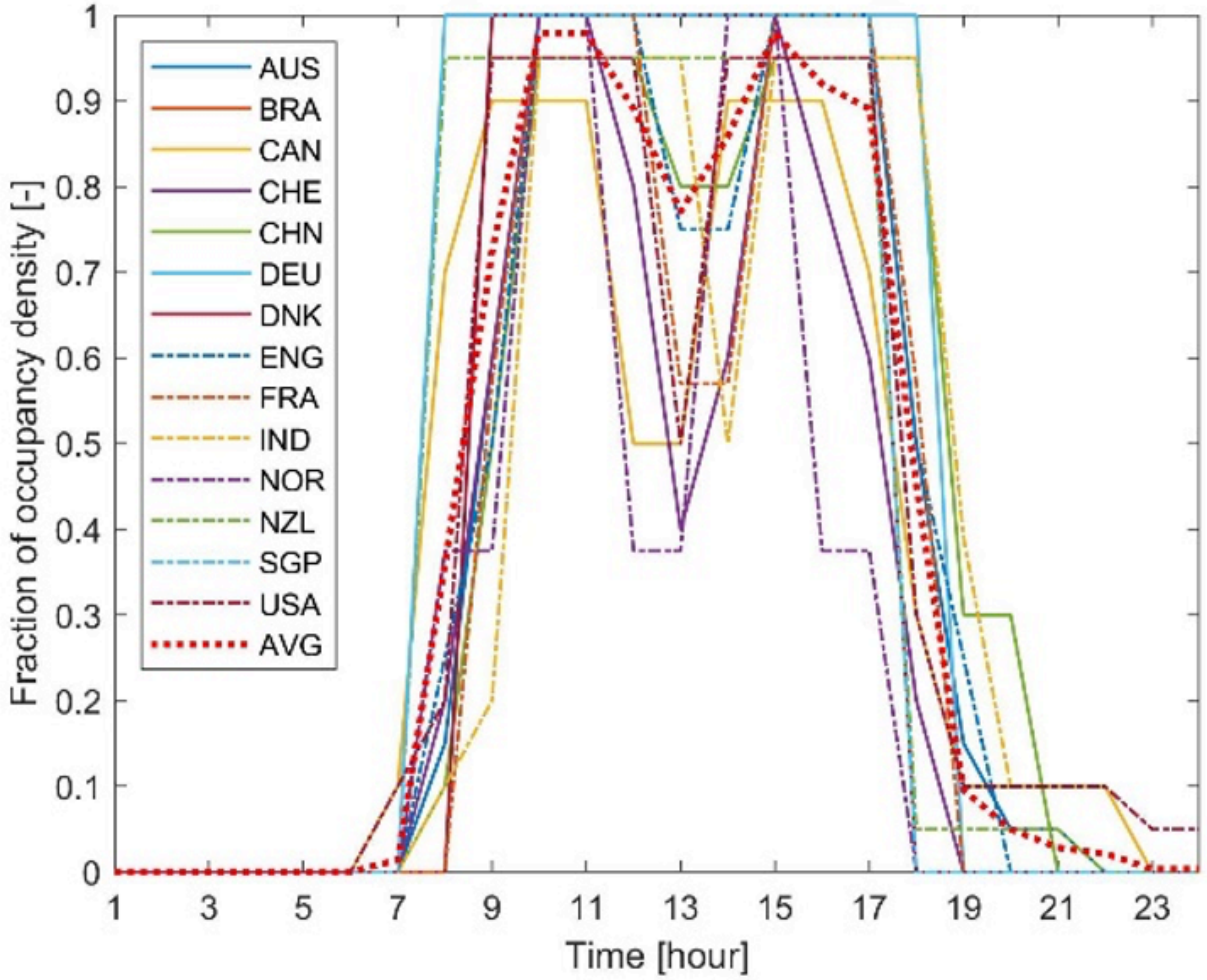


Figure 6-2: Example comparison of occupancy levels and schedules for office buildings in 15 different countries

Traditional Occupant Modeling

- Pro:
- simple (mathematically)
- consistent (same results each run)
- transparent (for BPS user and client)

Cons:

- ?

Traditional Occupant Modeling

- Pro:
- simple (mathematically)
- consistent (same results each run)
- transparent (for BPS user and client)

Cons:

- no recognition of two-way human building interaction
- deterministic, ie, does not consider possible range of interactions
- separated occupant related domains
- rather coarse and abstract, makes it easy to avoid 'dealing with occupants'

Advanced occupant modeling

- one or more of the following possible and desirable traits
- - **Stochastic:** A randomness to consider the reality that occupants' individual decisions are often diverse, unpredictable, and inconsistent
- - **Dynamic**: The recognition that conditions (e.g., air temperature) alter the way occupants behave and locate themselves within a space.
- - **Data-Driven**: The trait that occupant models are generated based on measurements.
- - **Agent-Based**: The acknowledgement that occupants interact with buildings and/or each other through a series of decisions that are likely a result of one or more conditions

Stochastic models

- stochastic = probabilistic
- make use of stochastic processes to reproduce occupancy and a variety of behaviors
- results in probabilistic distribution of predicted results
- many models have been used

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- stochastic = probabilistic
- make use of stochastic processes to reproduce occupancy and a variety of behaviors
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Model type	Typical purpose	Application
Binomial model	Data analysis (e.g., to understand which factors influence occupants to execute an action) and stochastic modeling (e.g. to simulate a human operations in building performance simulation software)	A model for predicting binary outcomes (e.g., yes/no, awake/asleep, open/closed, opening action/closing action)
Markov Chains	Stochastic modeling with time dependencies (e.g., to model an event that is more likely to happen at particular time of day, or particular day of week)	A model for predicting outcomes with *n* states, where *n* can be an integer and represent, for example, specific locations in a building, occupant presence (e.g., present and awake, present and asleep, absent), or position of a window (open, half opened, closed), e.g., at different time of the day

binomial model

- Well established
- Analyze/model binary variables (on/off, yes/no, up/down)
- Often called *logistic regression*
- example: state of a window (open/close), state change of a window (from closed to open)

binomial model

- Well established
- Analyze/model binary variables (on/off, yes/no, up/down)
- Often called *logistic regression*
- example: state of a window (open/close), state change of a window (from closed to open)

p(x). expresses the probability function for a certain event to happen

$$p = \frac{1}{1 + e^{-(\propto + \beta x)}}$$

$$ln\left(\frac{p}{1-p}\right) = \propto + \beta x$$

example window state change depending on an explanatory variable x (ex temperature)

$$ln\left(\frac{p}{1-p}\right) = \propto + \beta_0 x_0 + \beta_1 x_1 + \cdots + \beta_n x_n$$

Example Window opening

- Binomial modeling with multiple explanatory variables to 300 monitored windows to generate 300 different models.
- For each window, the author determined which of the measured explanatory variables had a major influence on the probability of a change of window state and which did not.
- The variables were then classified depending on the number of times they appeared in the 300 models, where the more frequent the variable, the more important it was considered.
- Calì, Davide, Rune Korsholm Andersen, Dirk Müller, and Bjarne W Olesen. 2016. “Analysis of occupants' behavior related to the use of windows in German households." *Building and Environment* no. 103:54-69.

Example W

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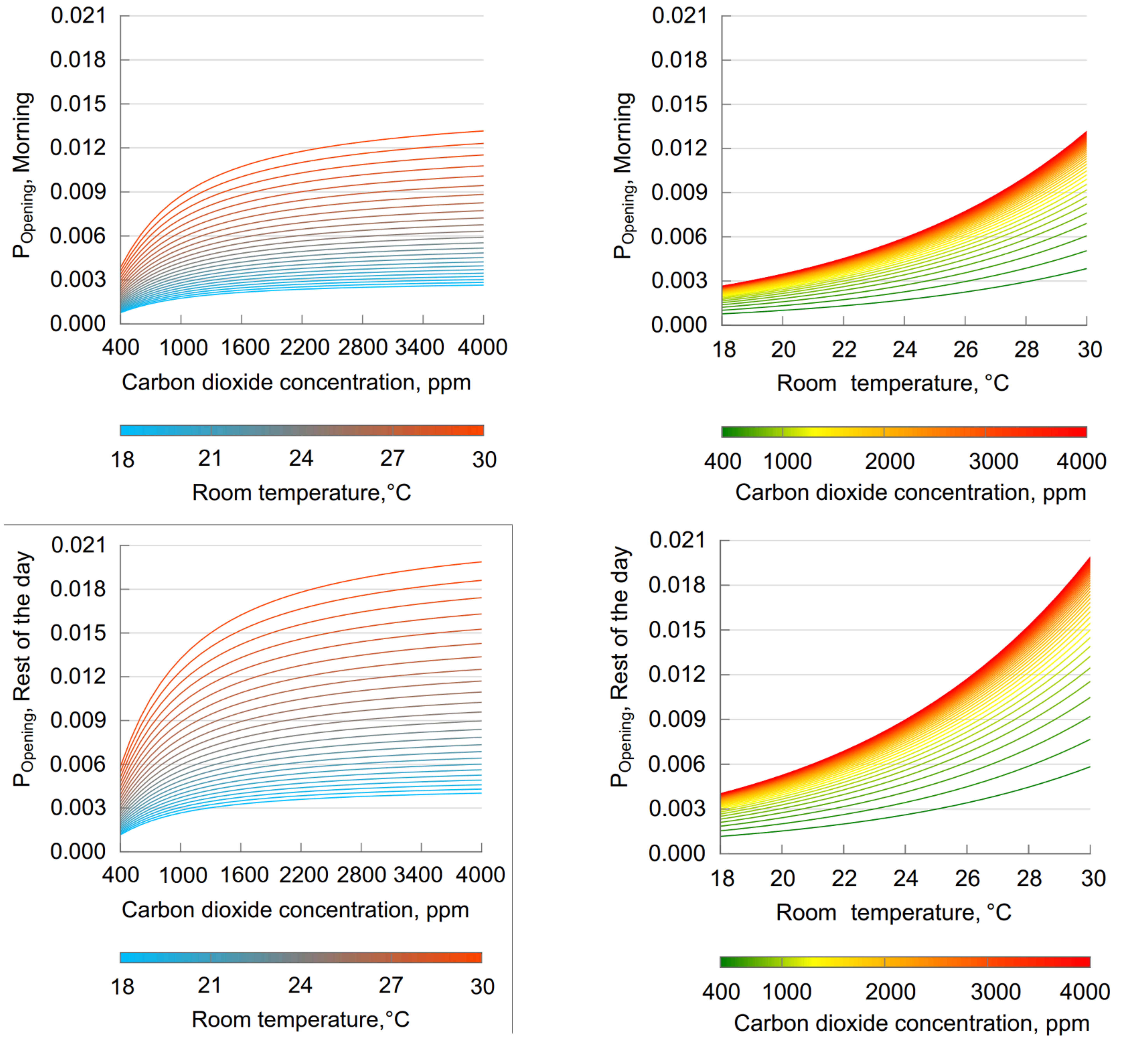

Figure 6-3: Probability of opening action of a window in a living room of a specific apartment (Calì 2016) at three different times of day, within the next 60 seconds.

Analysis vs Predictive Modeling

- Binomial models can be used for both analysis and predictive modeling
- For analysis we are more interested in the impact of drivers (x). Typically we fit a logistic regression model to experimental data.
- For predictive modeling, we have the model coefficients and we evaluate the model within, for example, a building simulation model. The model is called at each time step.

$$p = \frac{1}{1 + e^{-(\propto + \beta x)}}$$

$$ln\left(\frac{p}{1-p}\right) = \propto + \beta x$$