DEMSA: a DT-enabled Middleware for Self-adaptive Smart Spaces

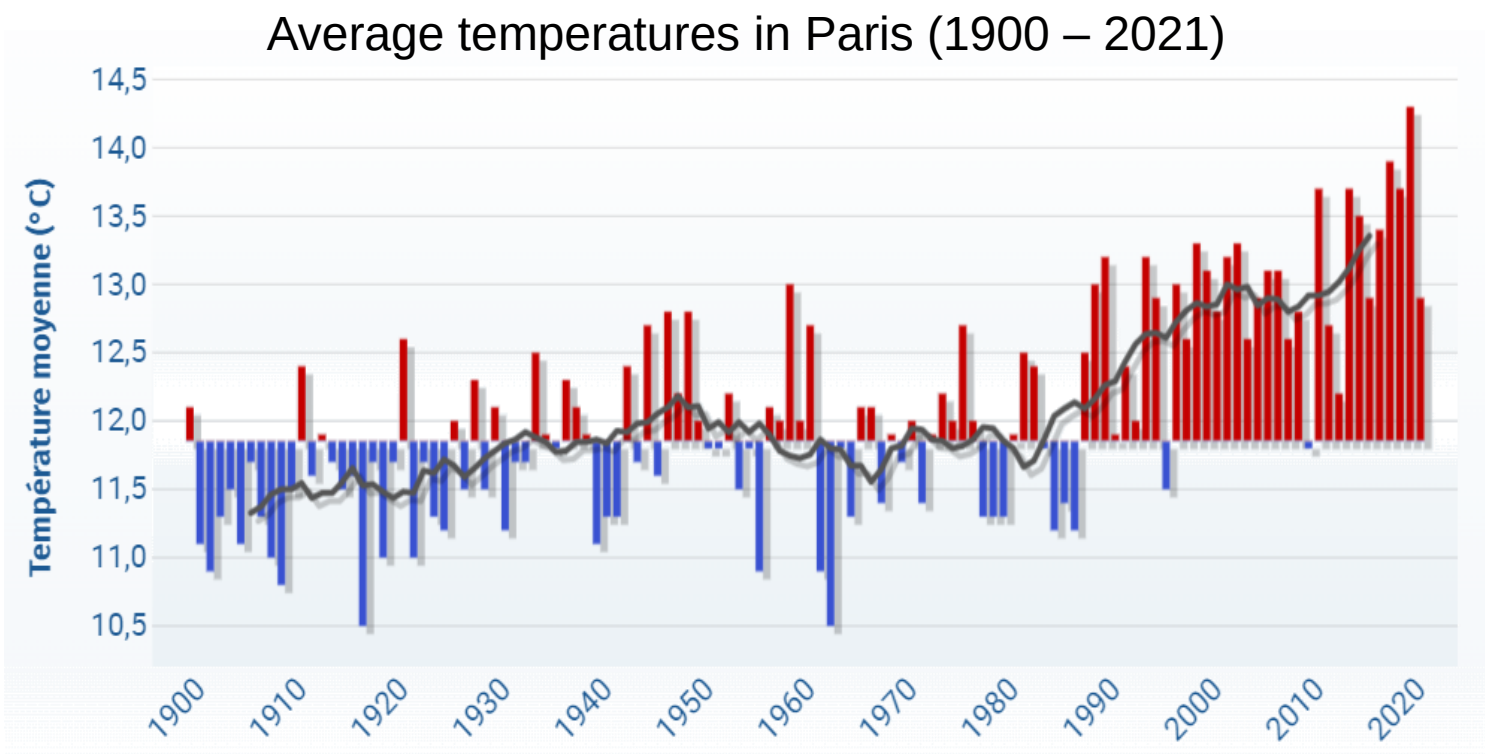
Jun Ma, **Georgios Bouloukakis**, Ajay Kattepur, Roberto Yus, Denis Conan

1st International Workshop on Middleware for Digital Twins (Midd4DT)

12 December, 2023

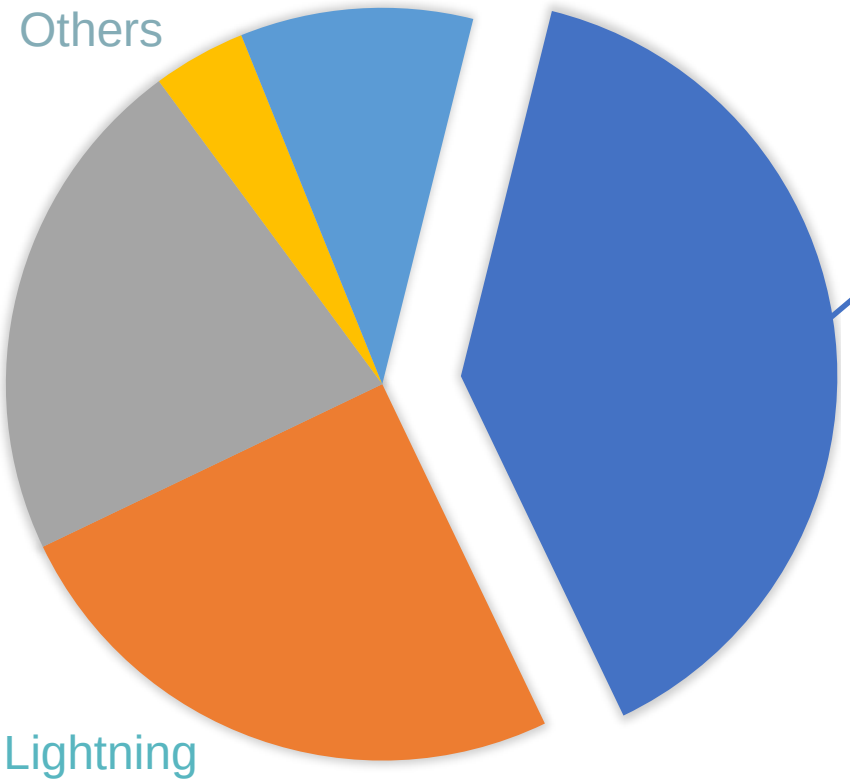
Climate change

- The global average temperature in 2020 is **1.2 degrees** warmer than in preindustrial times.



* Graphs from *Meteo France, The New York Time*

Energy consumption in Buildings

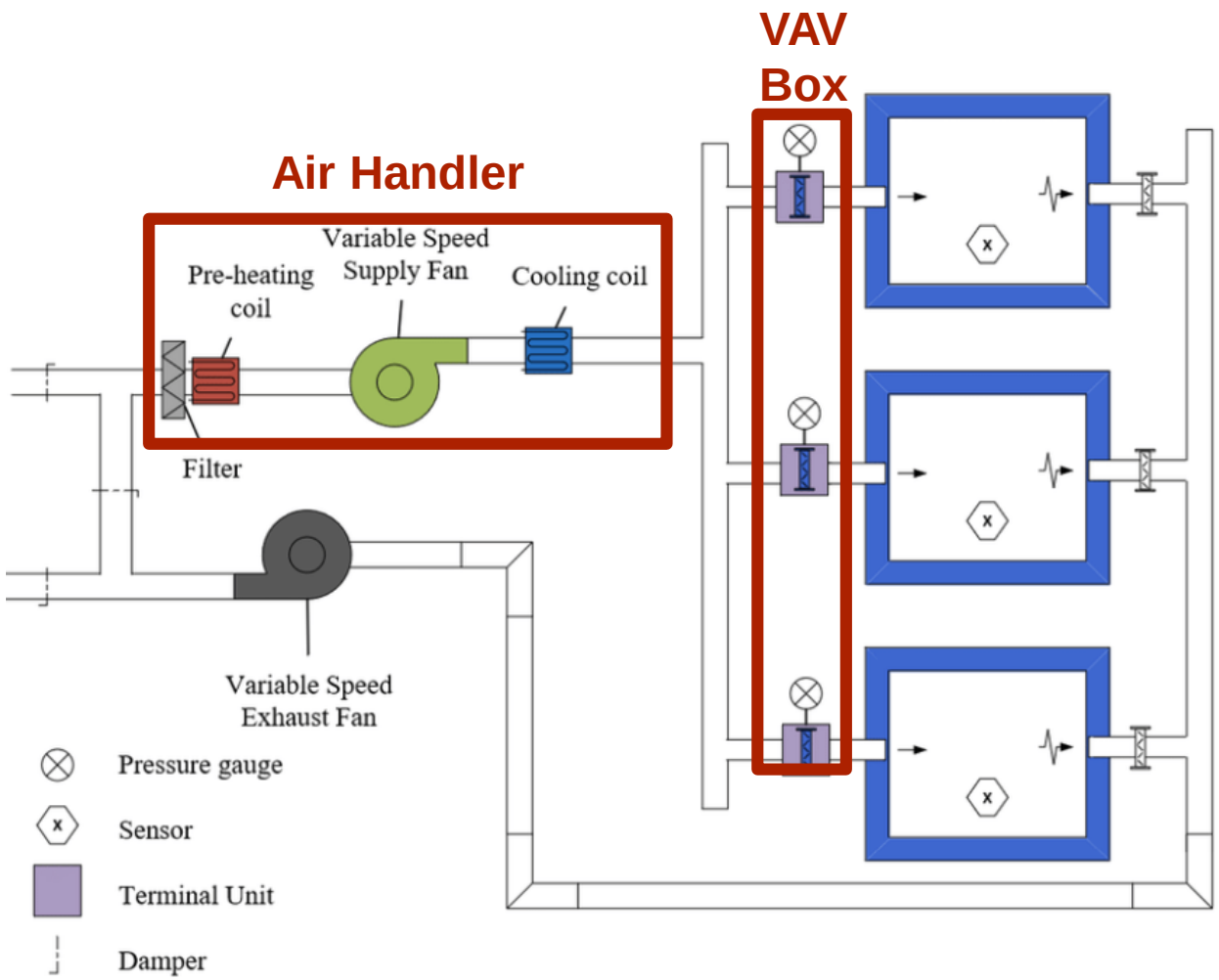


30-50%

Heating, Ventilation, and Air Conditioning (HVAC) system in buildings

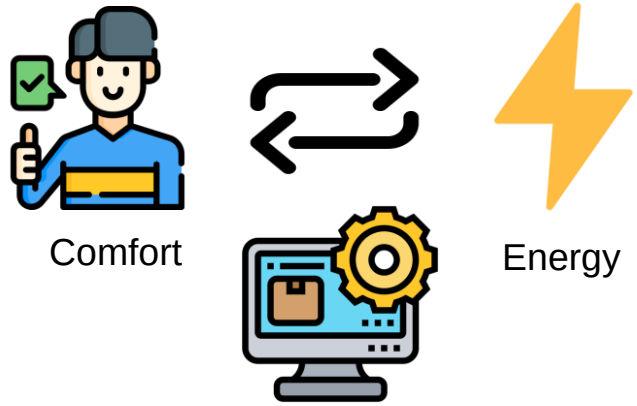
This work focuses on saving energy when using Heating, Ventilation, and Air Conditioning (HVAC) systems

Background: HVAC System



Variable Air Volume (VAV) System

Trade-off

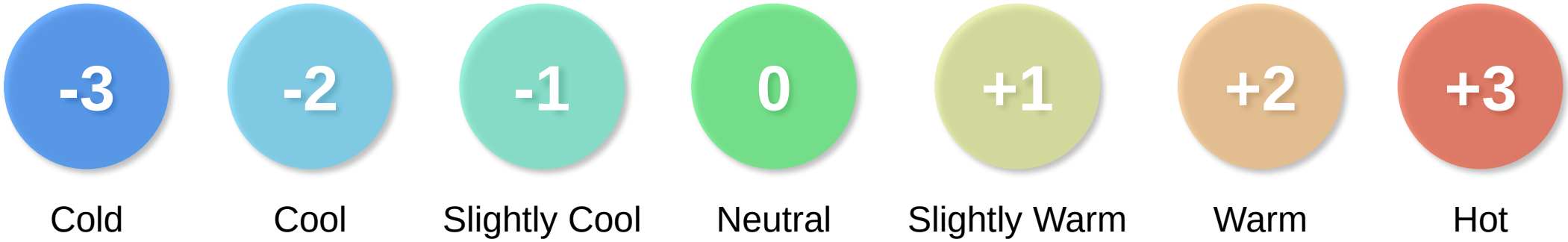


Measuring Thermal comfort

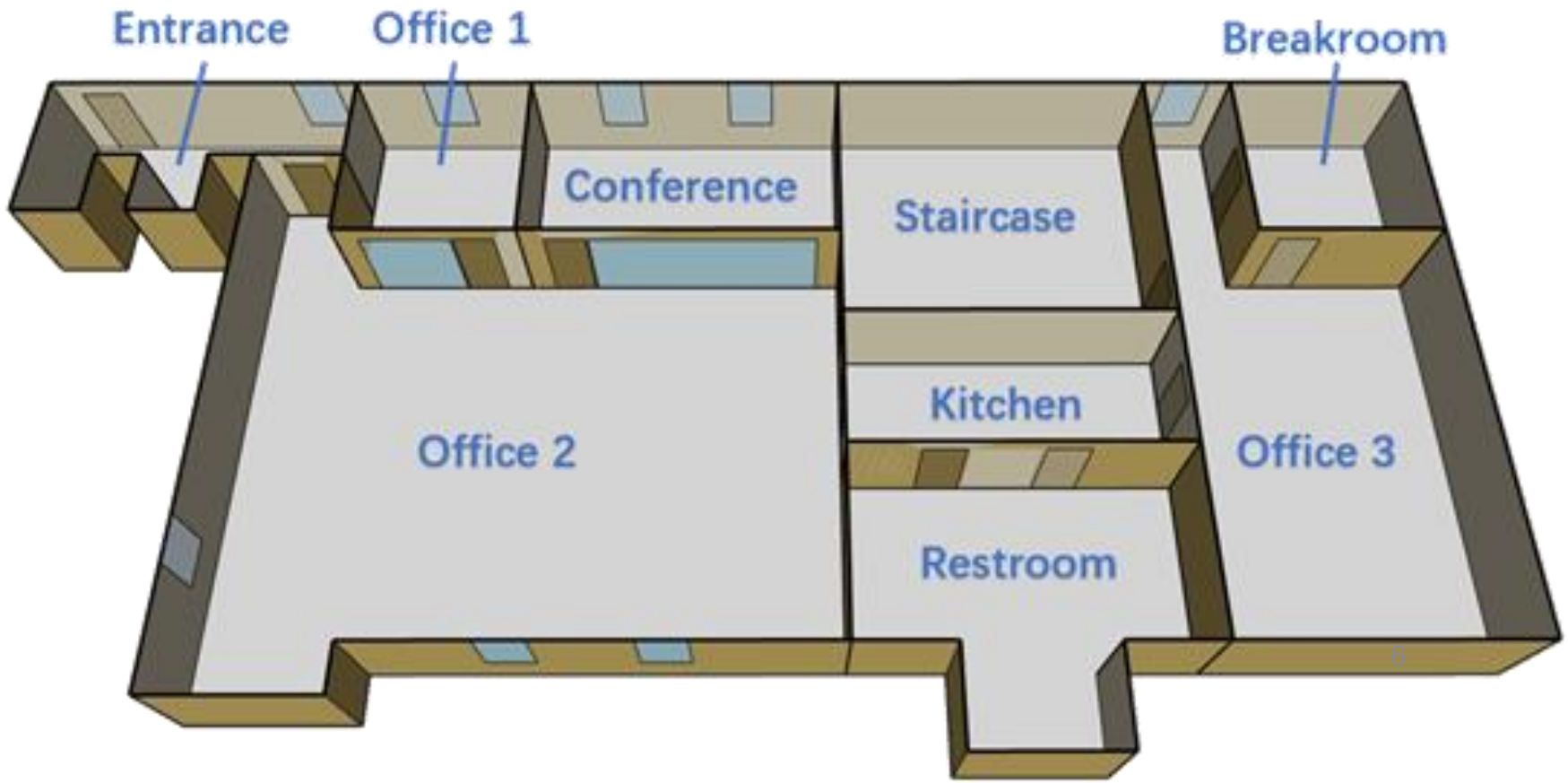
How to measure it?

- By extracting skin temperature
- By using body shape information
- By the environment (temperature, humidity, sunshine…)
- Let people speak

ASHRAE, the American professional association, proposes a widely-used 7-point thermal sensation scale

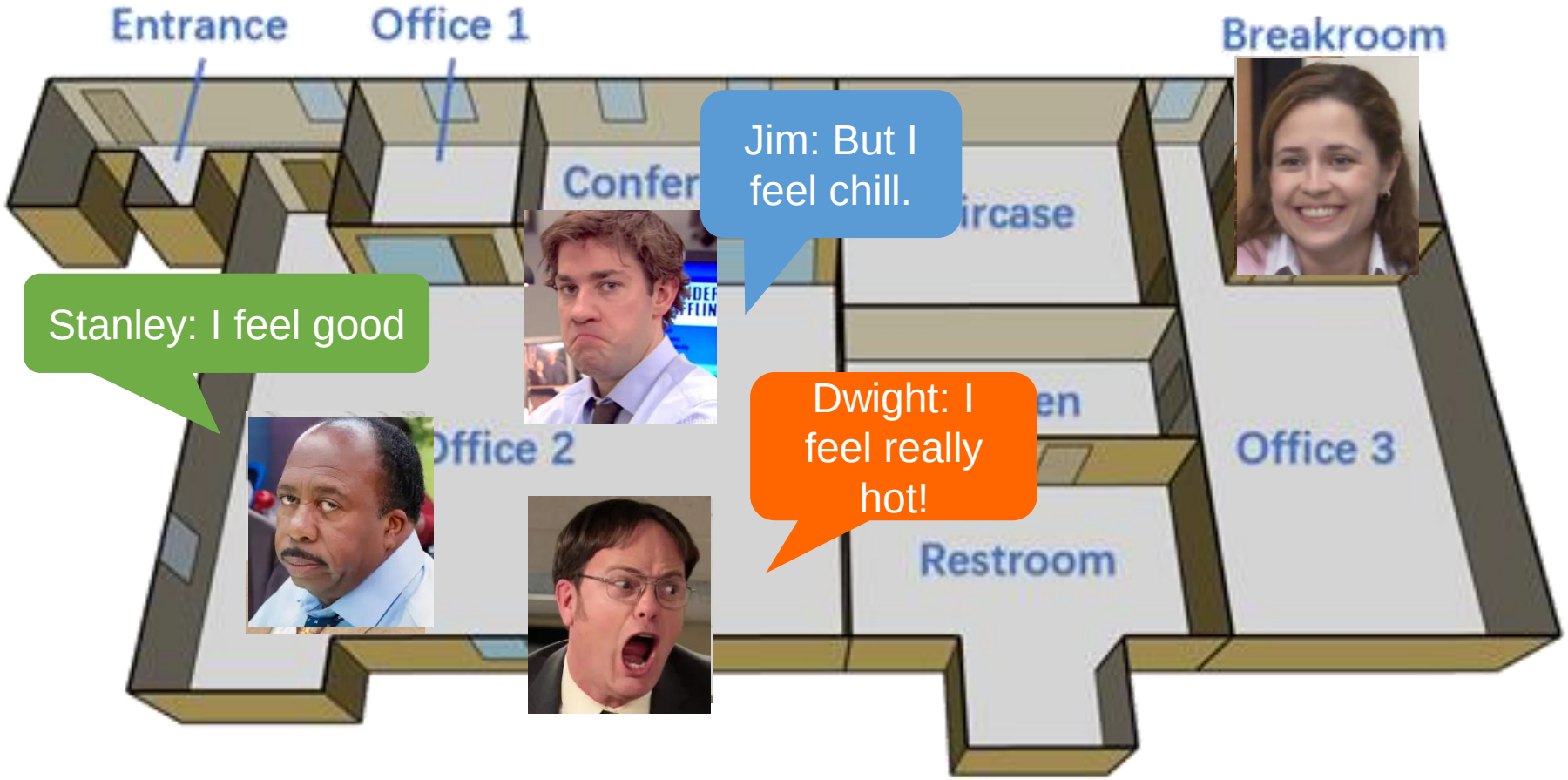


Case Study: Thermal Comfort Provision for Diverse Occupants



Case Study: Thermal Comfort Provision for Diverse Occupants

They can send their feedback using smart devices



Using Feedback to Control Building

Feedback

Thermal Comfort Provision System

Control Action

HVAC System

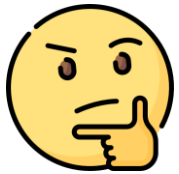
How to leverage feedback to balance Energy and Comfort?

Motivation: the Drahi-X smart building of IP Paris

The **Drahi-X** of IP Paris:

- 5000 m^2 of surface
- 12 electric zones and two floors.
- IoT devices: temperature sensors, motion detectors, smart plugs, HVAC systems
- Tablets in corridors of the building for occupant to provide feedback
- Existing BMS controls the HVAC and IoT devices

➢ Potential for occupant well-being and energy efficiency
  - Certain schedules of activities
  - Feedback to regulate HVAC
  - Different ***strategies*** for regulation over time



Exploit smart devices space knowledge to design an optimal *Thermal Comfort Provision System* in terms of comfort and energy consumption ?

Challenges on Thermal Comfort Provision System

1. **Diversity:**
   - literature focuses on overall comfort of individuals
   - individuals have diverse preferences
   - challenging to provide comfort in shared spaces

People's preferences → many factors age, fitness, their personality and their mood[1].

[1] *M. e. a. Schweiker, "Drivers of diversity in human thermal perception– a review for holistic comfort models," Temperature, vol. 5, no. 4, pp. 308–342, 2018.*

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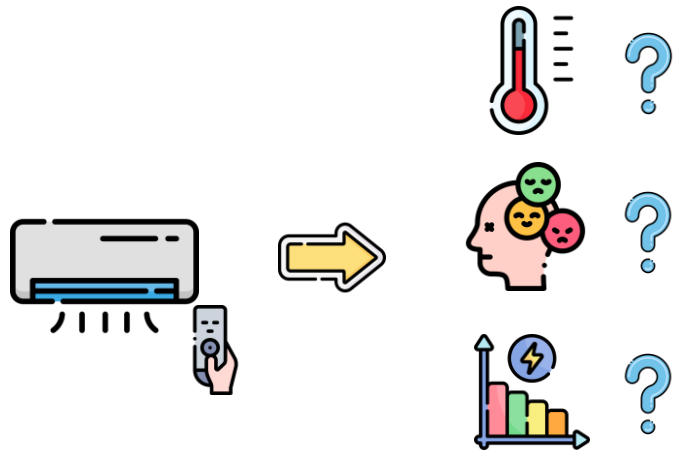
2. **Dynamicity:**
   - buildings scenarios are dynamic



changes → temperature, occupant comfort and energy consumption will be affected?

Challenges on Thermal Comfort Provision System

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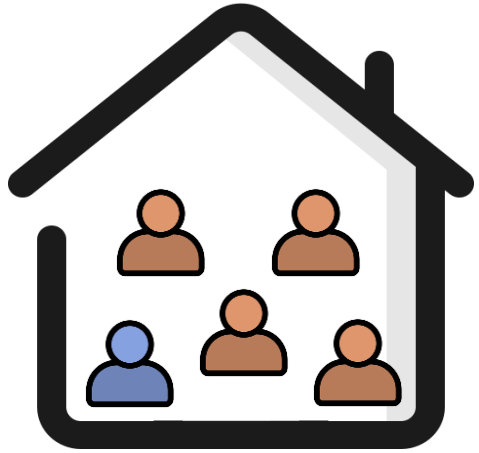
3. **Adaptivity:**
   - different strategies
   - challenging to select the optimal strategy



- warm preference is common
- setting colder temperature for fairness is not ideal
- forces the majority to compromise for the sake of equal treatment

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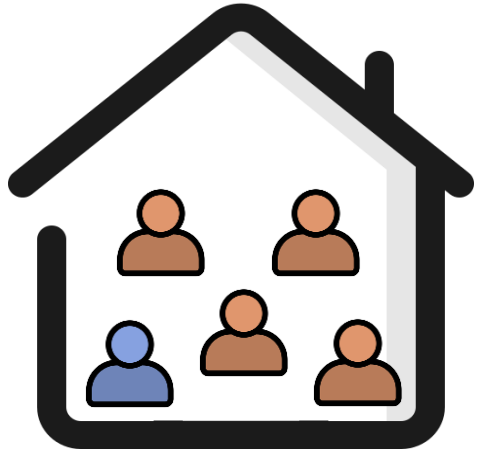
How to design a Thermal Comfort Provision system?



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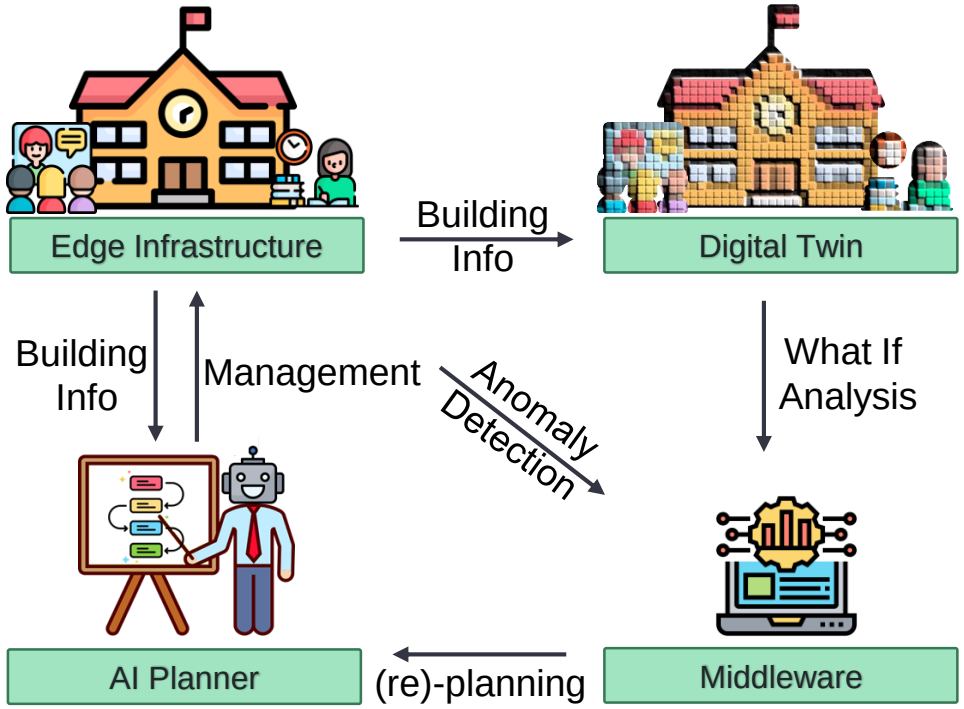
Proposed solution: DEMSA

➢ DT-enabled Middleware for Self-adaptive Smart Spaces

Real physical environment:
- Real-time monitoring (through IoT devices)
- Smart energy management (e.g., HVAC)



Digital Twin, digital replica of:
- Building's architecture
- Devices, Systems, etc.
- Inhabitants

Automated Planning for:
- Semantically representing DT
- Temporal plans with strategies for HVAC regulation

Middleware for:
- Synchronizing DT co-simulations
- Self-adaptation based on AI temporal plans and building conditions

➢ **How to evaluate DEMSA?**

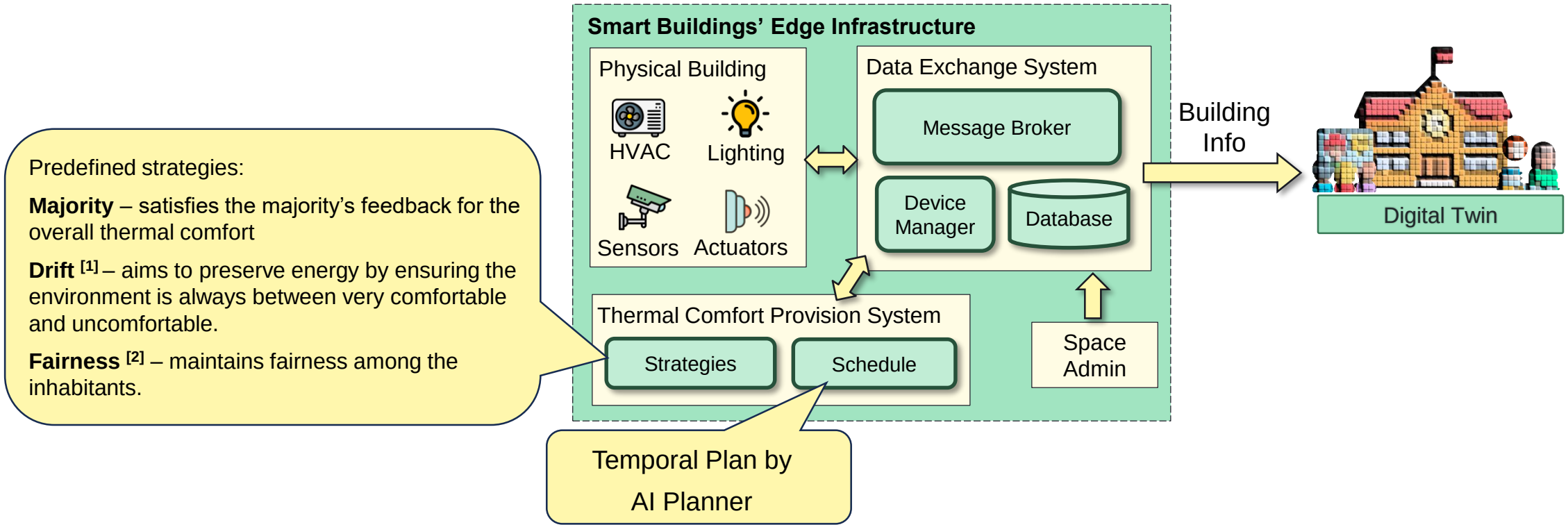
DEMSA Evaluation Metrics

1. Energy Consumption (EC) :
   - amount of energy consumed in the building

2. Thermal Comfort (TC) :
   - #people feel comfortable based on feedback

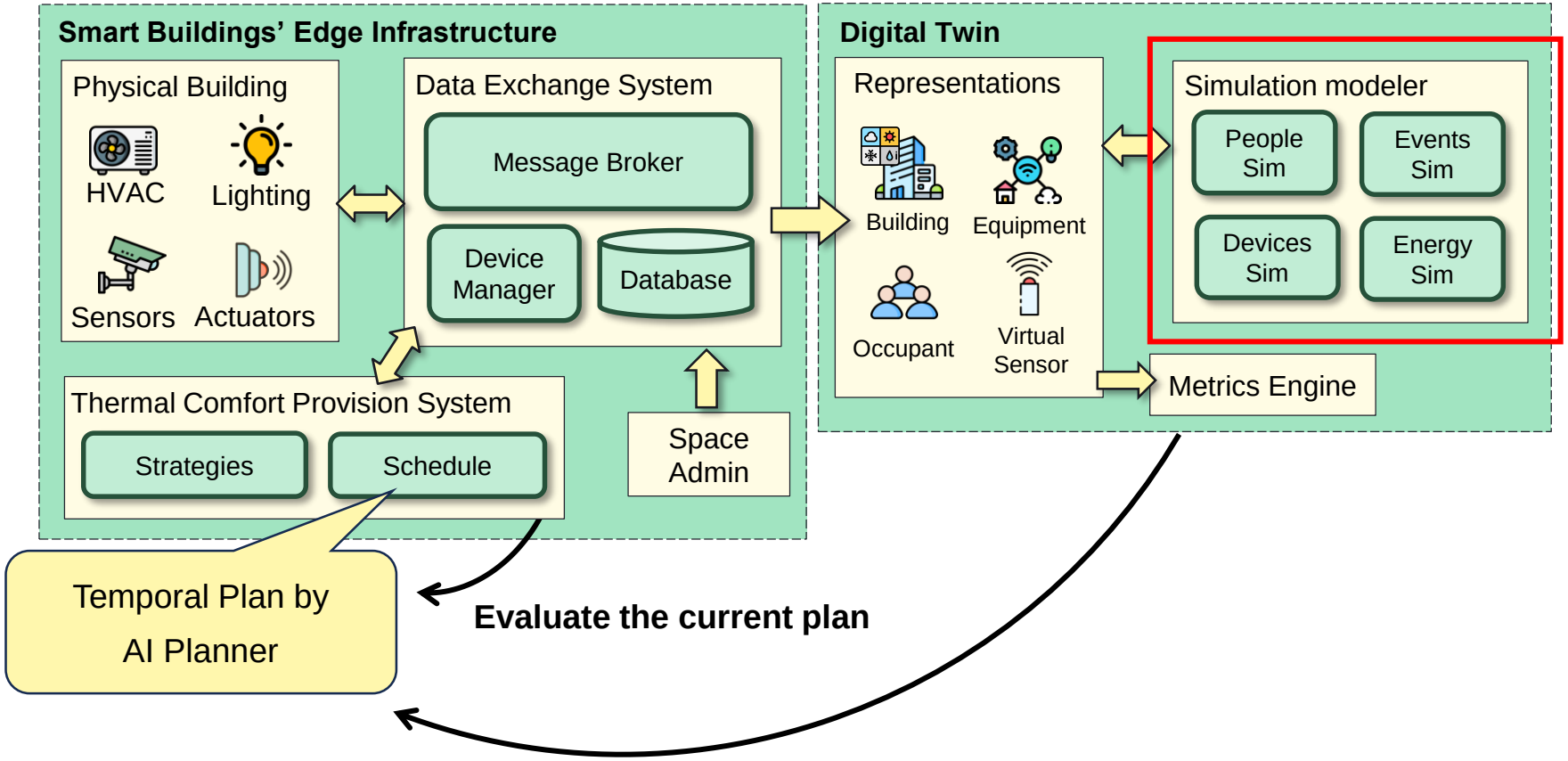
3. Equality (EQ) **:**
   - equality level -- if individuals treated fairly

DEMSA -- Smart Buildings' Edge Infrastructure



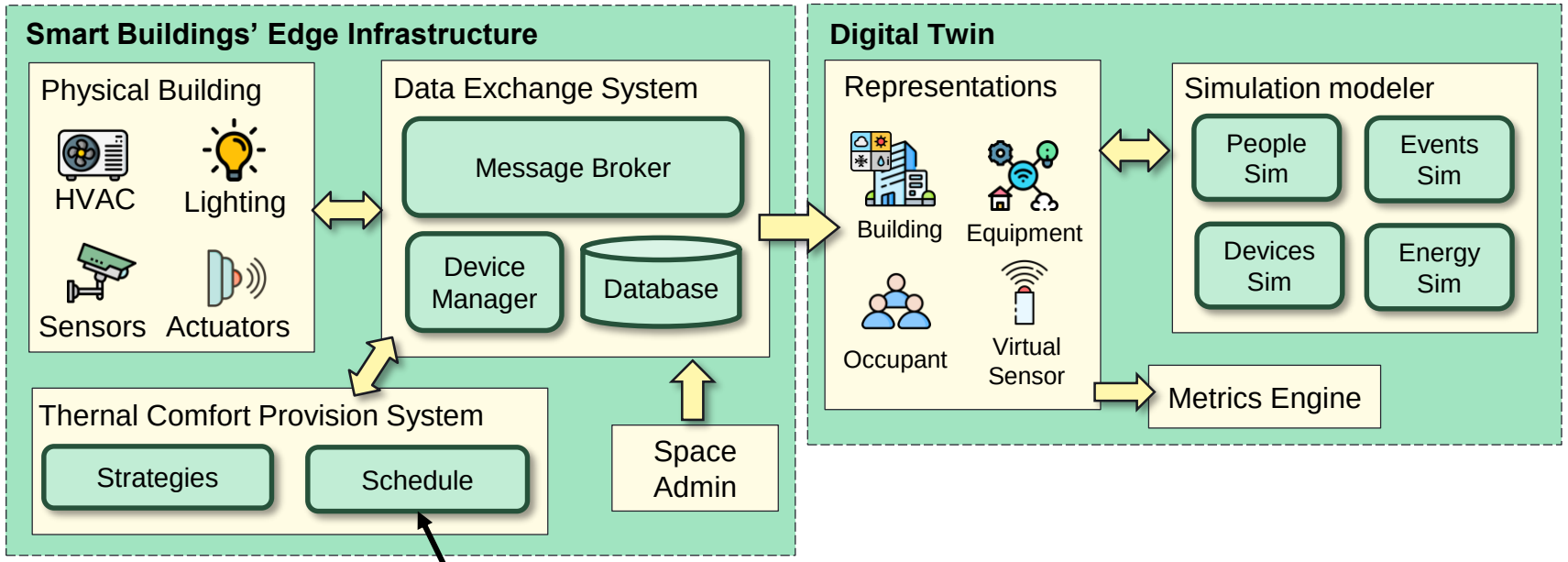
[1] *Sean Purdon et al. 2013. Model-free HVAC control using occupant feedback. In LCN Workshops*
[2] *Eun-Jeong Shin et al. 2017. Exploring fairness in participatory thermal comfort control in smart buildings. In ACM BuildSys*

DEMSA -- DT for IoT-enhanced Spaces



- Prediction of EC, TC EQ
- What-if-analysis – e.g., feedback from 70%

DEMSA – AI planner



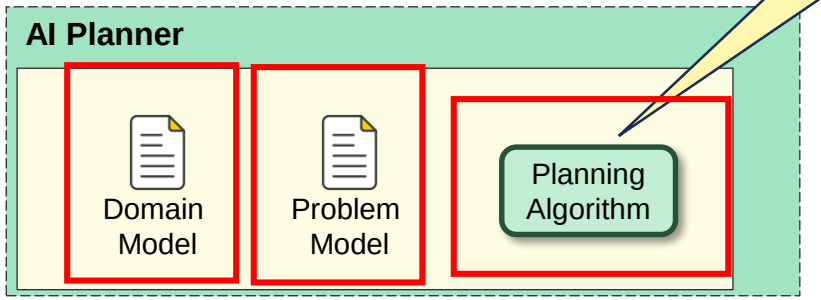
Domain model:

- Representation of Building: objects, actions, conditions, goals
- Same domain may be paired with multiple problem instances

Problem Model

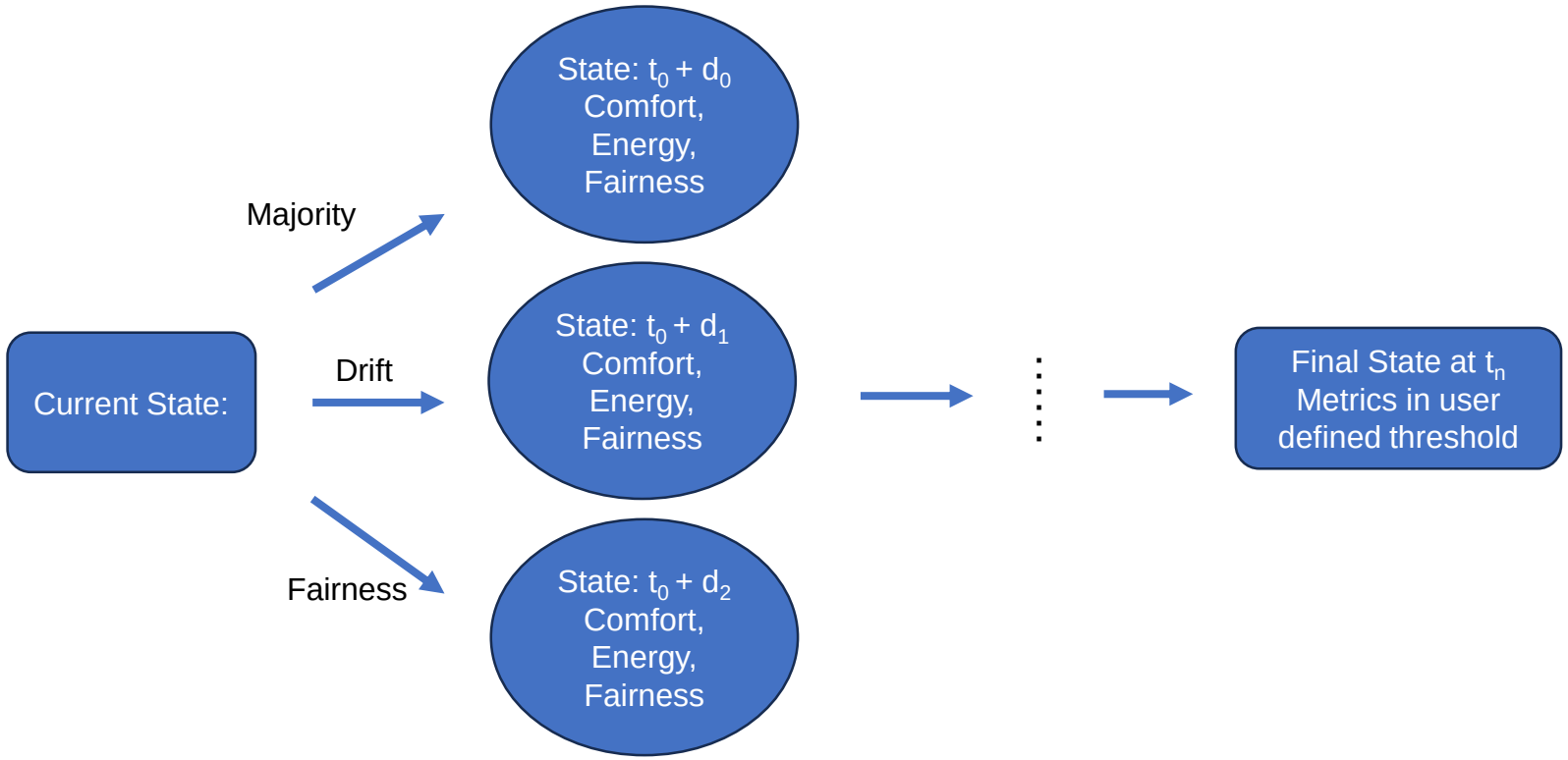
- Ground problem instantiated based on specific goals and metrics

t1: fairness strategy room1
t2: drift strategy room1
t3: fairness strategy room1
t4: majority strategy room1



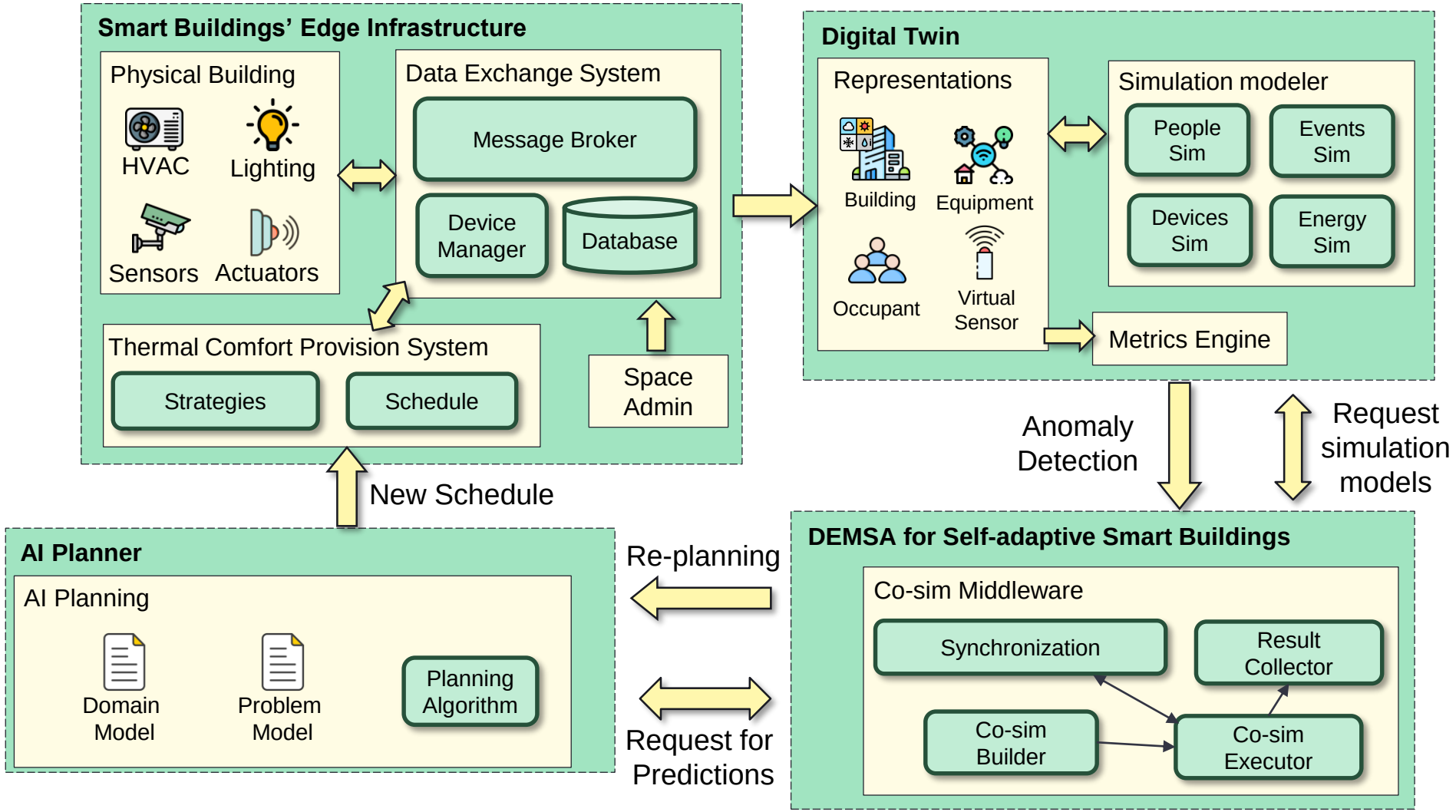
- Systematically explores combinations of actions for (near)-optimal sequences
  - transform the initial state into the goal state

DEMSA -- Self-adaptive Buildings using Automated Planning



1. Detect the current state
2. Generate schedules based on predictions
3. Evaluate the performance using co-simulations
4. Select the best schedules

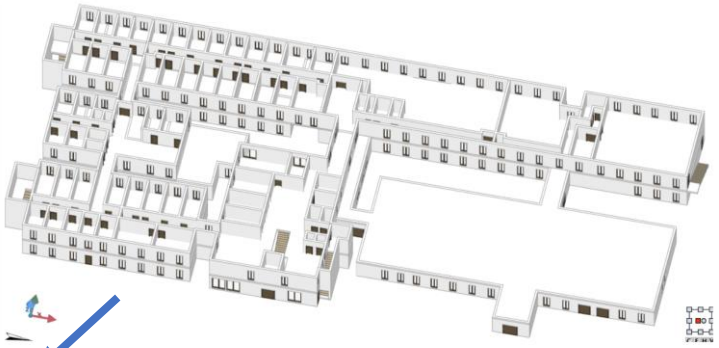
DEMSA for Self-adaptive Smart Buildings



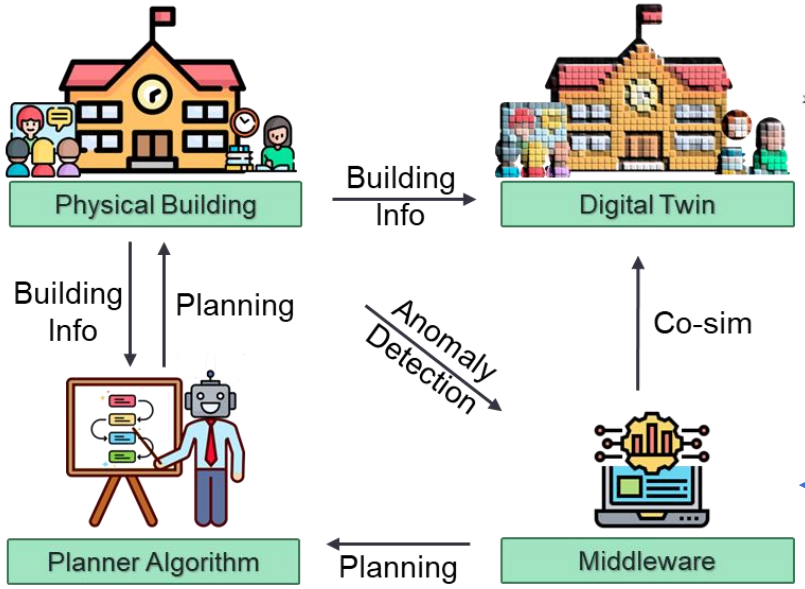
Current Status of DEMSA and Future Work

In the future we plan to:
1. Digitize the occupants and devices in Drahi-X building
2. Develop an automated simulation generator for Digital Twins
3. Implement the AI Planner
4. Evaluate and improve the performance of the system

- Implemented the DT component using small office building (The Office) [1]
- Created the 3D model of Drahi-X using IFC models



- Access to real BMS, and HVAC systems in Drahi-X building.
- Access to Ericsson smart buildings in Sweden



- developed a benchmark [1] to evaluate performance of thermal comfort provision systems.

- Implemented the middleware for co-simulation of building energy simulator, occupant movement and sensation simulators [1].

[1] *Jun MA, Dimitrije Panic, Roberto Yus, Georgios Bouloukakis. "Co-zyBench: Using Co-Simulation and Digital Twins to Benchmark Thermal Comfort Provision in Smart Buildings", Technical Report, 2024*

Conclusion

DEMSA middleware for enabling:

- Thermal Comfort Provision system for regulating temperature using diverse strategies.
- A DT system for enabling “what if analysis” via a co-simulation module
- Temporal scheduling of Edge infrastructures for balancing comfort and energy consumption
- The DEMSA middleware for self-adaptive Edge infrastructures using people and spaces’ feedback.

Thank You!
Questions?

Energy for Climate Interdisciplinary Center

https://www.e4c.ip-paris.fr

Di Hydro EU project

Research Group at Télécom SudParis

https://satrai.telecom-sudparis.eu