The Human-Dimension of Net-Zero Energy

Research at the SDE4 NZEB

Dr. Clayton Miller

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Department of
The
BUILT
ENVIRONMENT
WORLD RANKING
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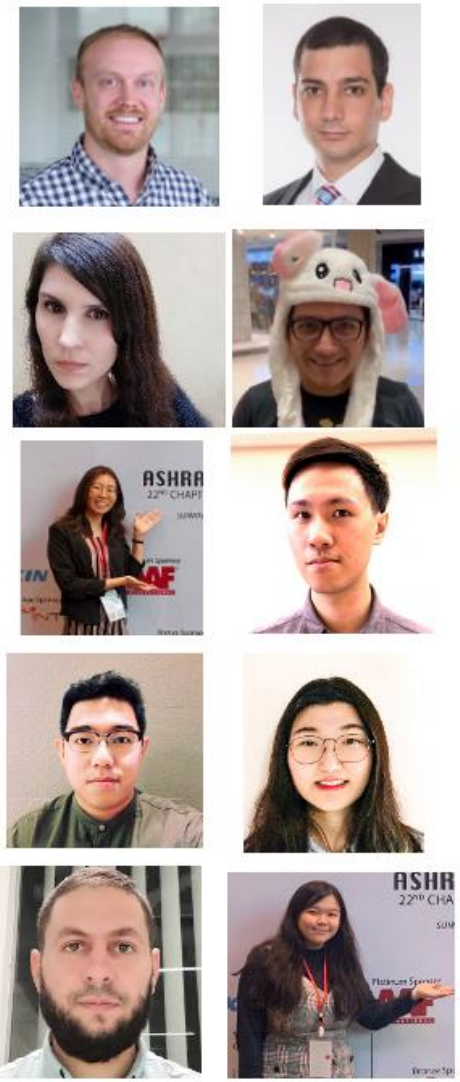
buds lab

building and urban data science

BUDS Lab is a scientific research group that leverages data sources from the built and urban environments to improve the energy efficiency and conservation, comfort, safety and satisfaction of humans.



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http://budslab.org/

Shameless Plug: edX Data Science for Construction, Architecture and Engineering

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Data Science for Construction, Architecture and Engineering

This course introduces data science skills targeting applications in the design, construction, and operations of buildings. You will learn practical coding within this context with an emphasis on basic Python programming and the Pandas library.

Estimated 7 weeks
4–6 hours per week

Self-paced
Progress at your own speed

Free
Optional upgrade available

There is one session available:

24,358 already enrolled! After a course session ends, it will be archived.

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https://www.edx.org/course/Data-Science-for-Construction-Architecture-and-Engineering

Net Zero by Design

Comfortable and Energy Efficient, Building Performance by Design

VISION

high-comfort
net-zero
energy building

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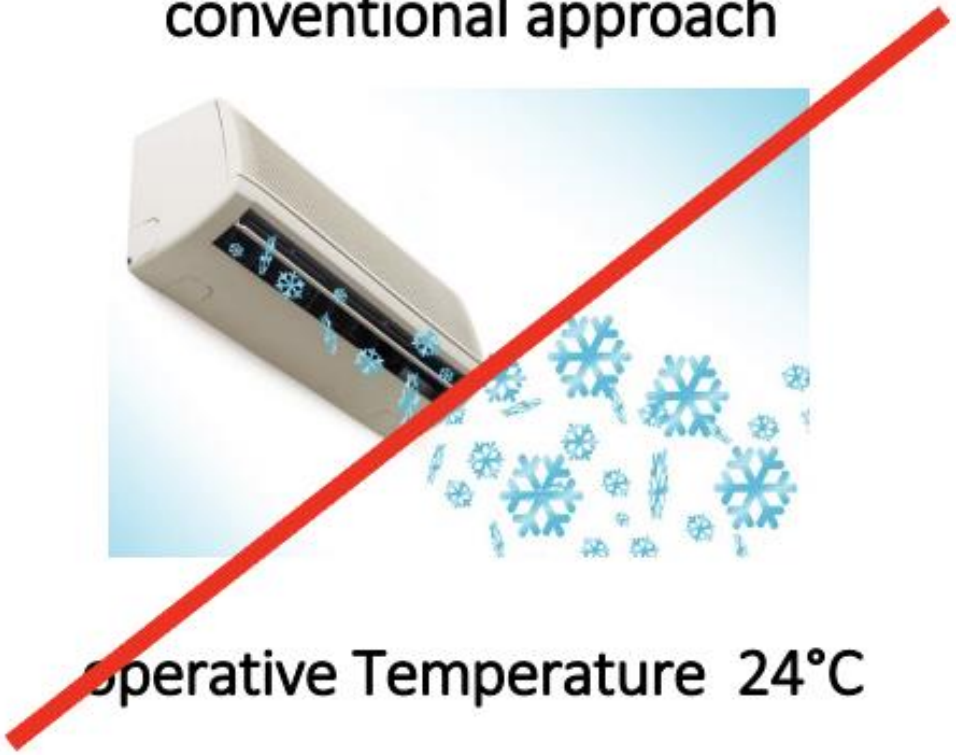
Slide Credit: Thomas Auer– Transsolar https://transsolar.com/

Net Zero by Design

Comfortable and Energy Efficient, Building Performance by Design

conventional approach



operative Temperature 24°C

adaptive comfort approach

operative Temperature 29°C
tempered air + elevated air speed

Slide Credit: Thomas Auer – Transsolar https://transsolar.com/

Net Zero by Design

Comfortable and Energy Efficient, Building Performance by Design

Photovoltaic
renewable energy

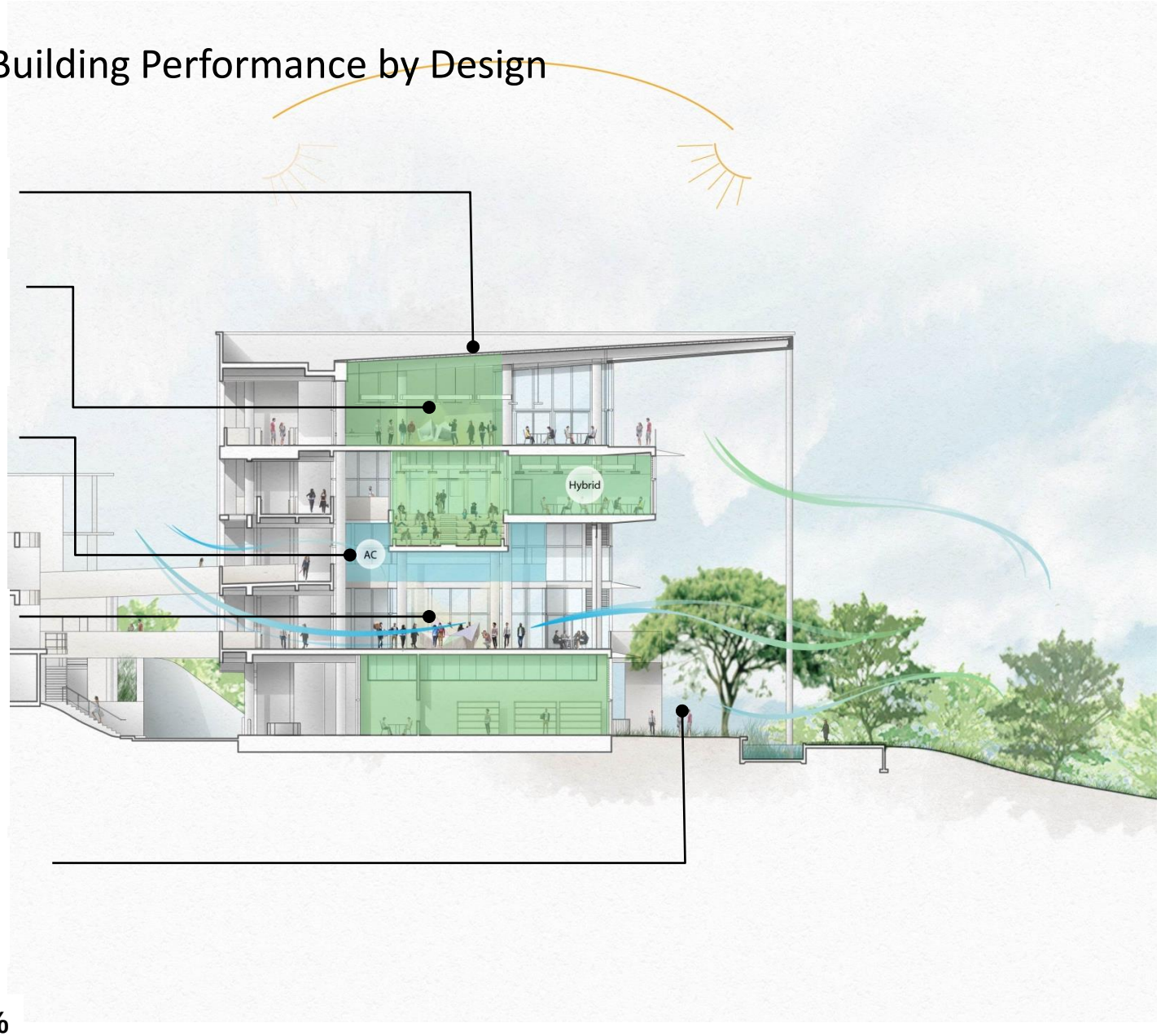
Hybrid Tempered, 26%
library, design studios
Theatrette, offices

Full AC,17%
green building technology lab
energy lab, computer lab

Natural Cross Ventilated, 46%
with elevated air speed
social Plaza and social
interaction spaces
modeling areas, work shops
smart green home

Circulation
micro climate, wind
vegetation, green and blue

Mech and aux rooms 10%



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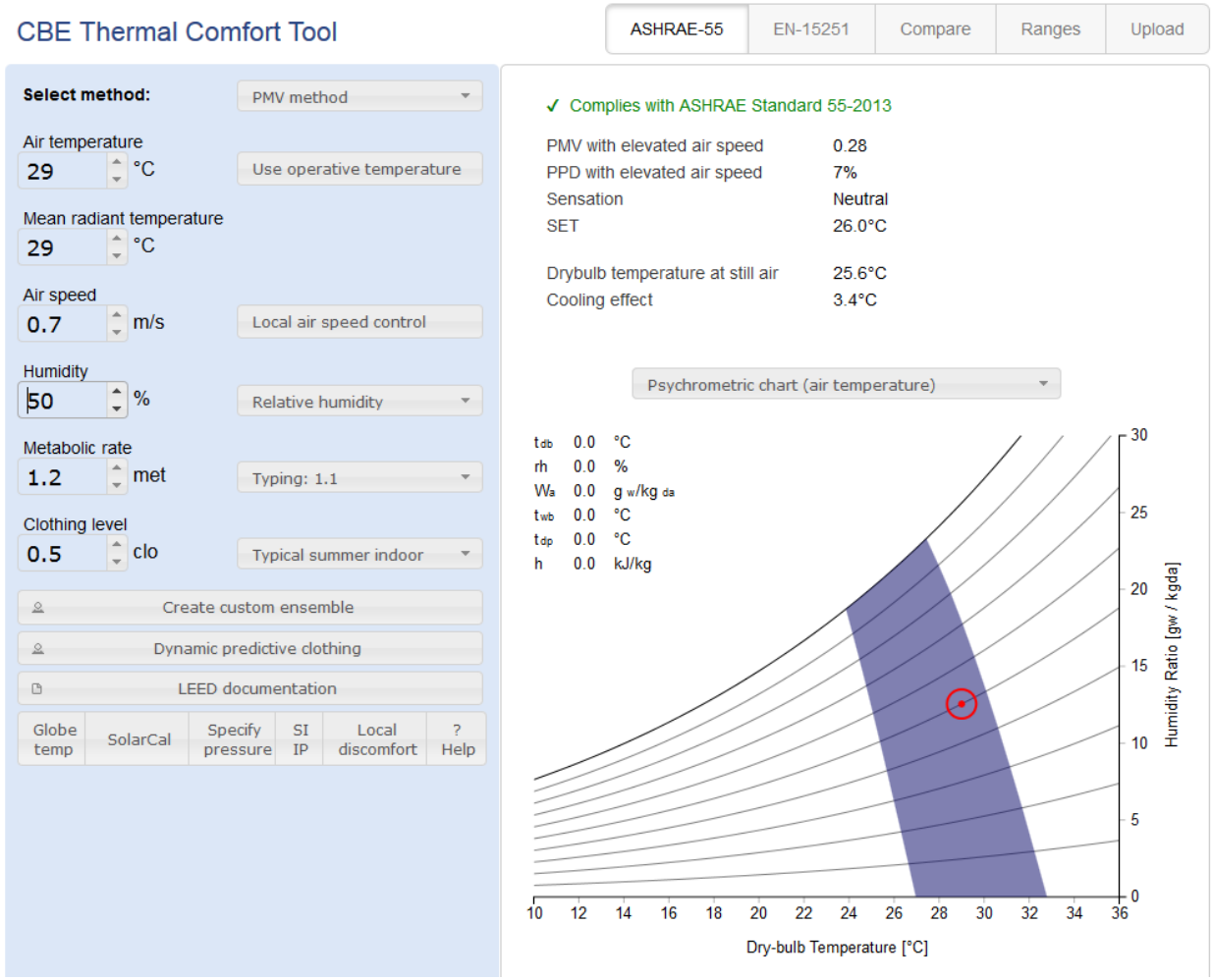
Thermal Comfort without elevated air speed

Comfort tool of Center for the Built Environment, University of California Berkeley

Operative Temperature	29°C
Air speed	0.15 m/s
PMV	1.2

Slide Credit: Thomas Auer – Transsolar https://transsolar.com/

Thermal Comfort with elevated air speed



Comfort tool of Center for the Built Environment, University of California Berkeley

Operative Temperature	29°C
Air speed	**0.7 m/s**
PMV_{eas}	0.3

Slide Credit: Thomas Auer – Transsolar https://transsolar.com/

Key Wellness and Sustainability Categories of SDE4

- W — WATER
- WL — WELLNESS
- TA — TROPICAL ARCHITECTURE
- HC — HYBRID COOLING
- NZE — NET ZERO ENERGY
- BD — BIOPHILIC DESIGN

The Age-Old Question in the Built Environment

What do occupants want?

How do we understand what makes them feel satisfied/be productive in their indoor environment?

How does this impact the Net-Zero Energy Paradigm?

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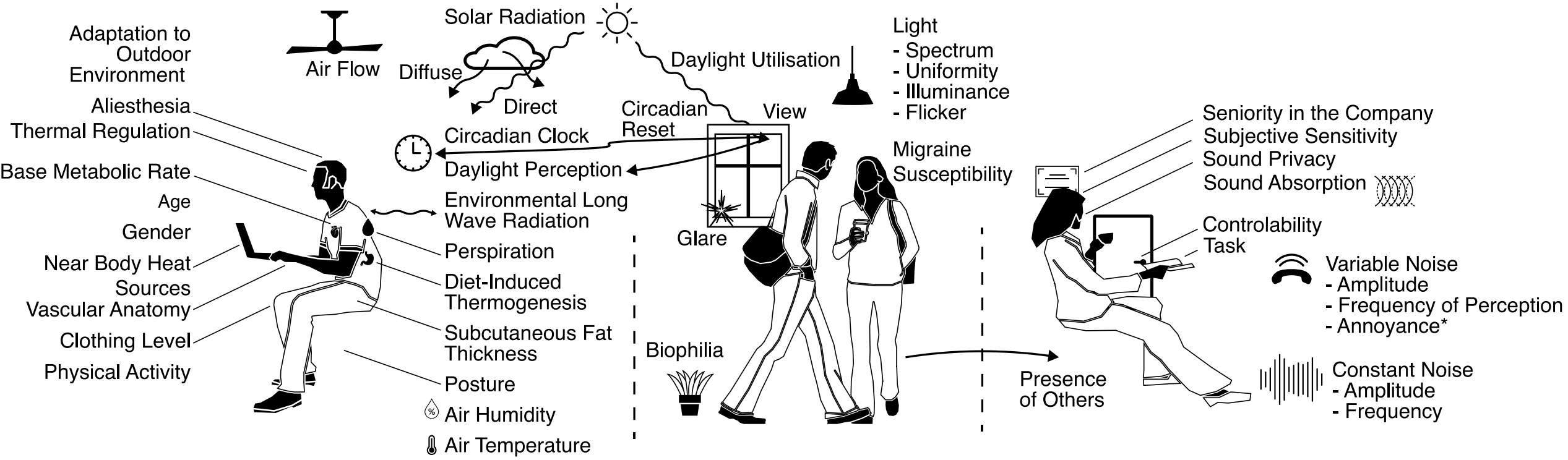
There are so many factors to consider…

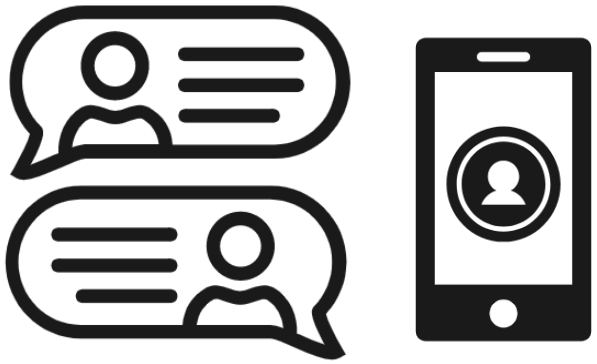
Can we create effective ways to measure or infer all of these environment, physiological, psychological, and behavioral attributes?



Jayathissa, P., Quintana, M., Abdelrahman, M., & Miller, C. (2020). Humans-as-a-Sensor for Buildings—Intensive Longitudinal Indoor Comfort Models. *Buildings*, *10*(10), 174. https://doi.org/10.3390/buildings10100174

Digitization of human perception in a scalable way!

Social media companies capture human perception using innovation in the way they collect information:



They create digital platforms that provide value to users

And capture specific preference feedback in that context

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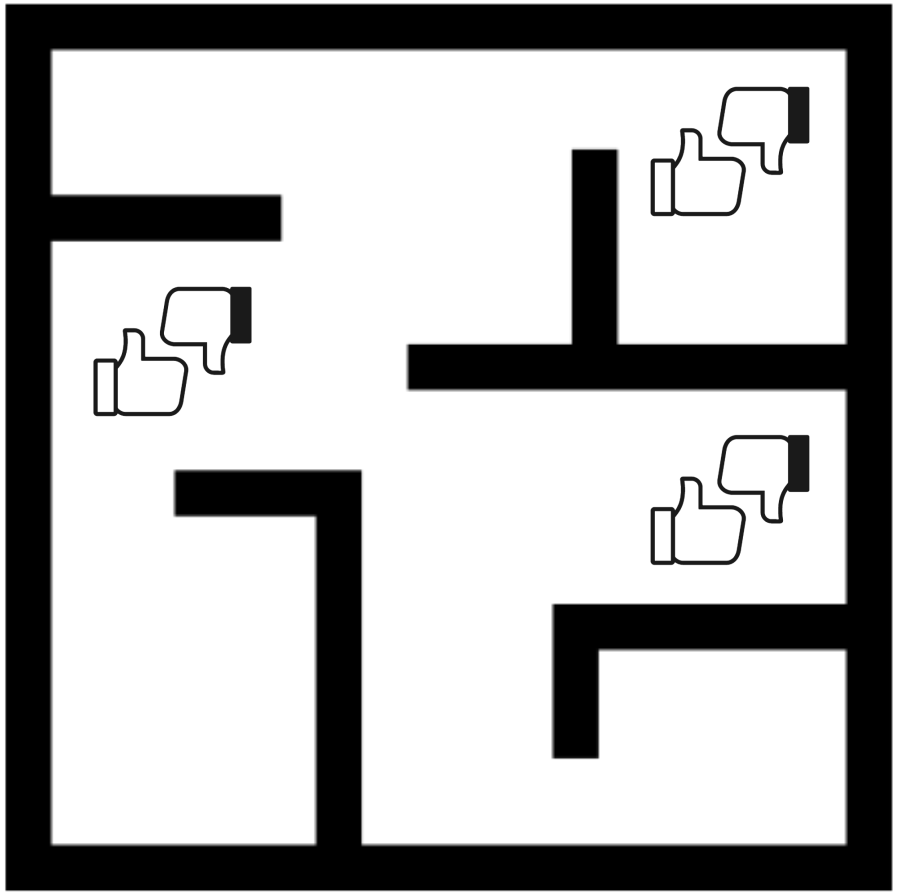
How do we make a *like button* for spaces and cities?

How do we get in-context preference data collection that is specific to objectives related to satisfaction with spaces?

The built environment has increased complexity due to the relevance of **temporal and spatial dimensions**



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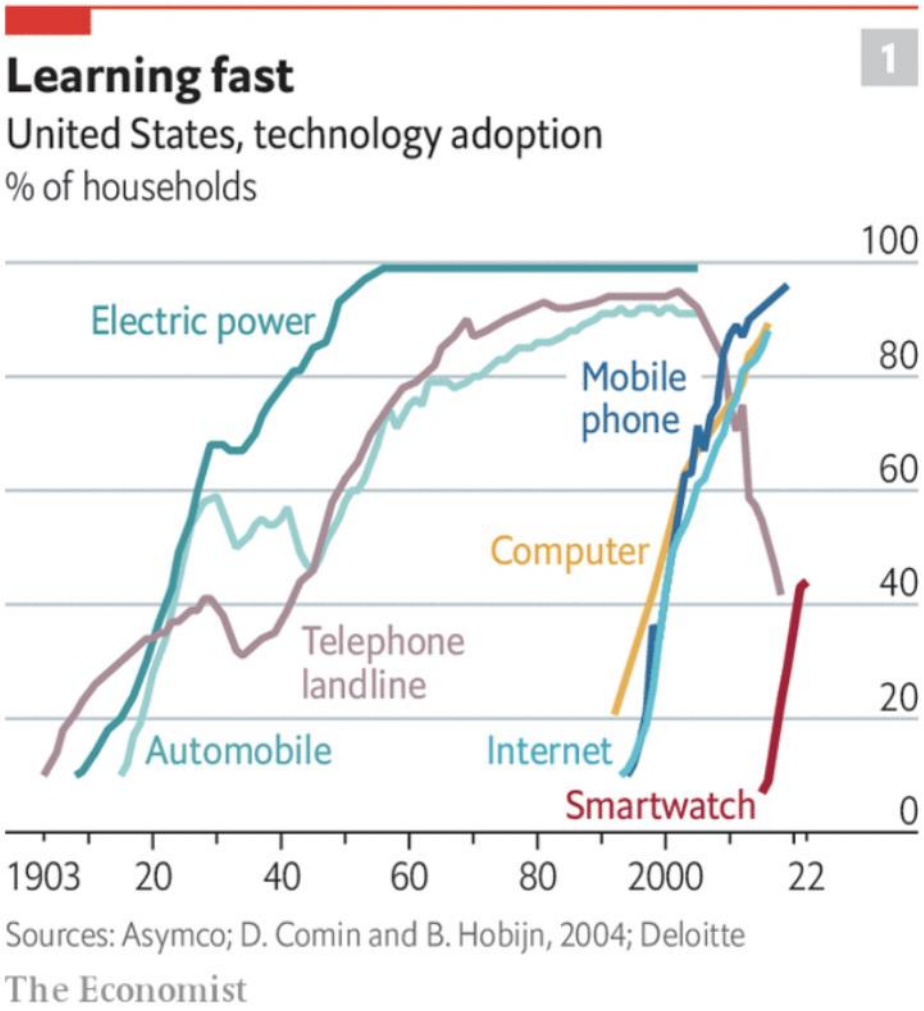
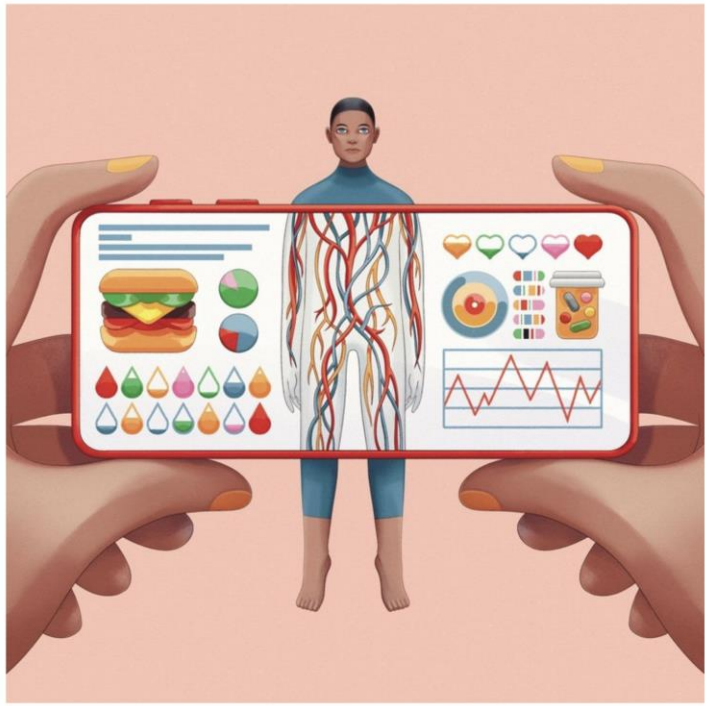
Growth of Quantified Self and Wearable Devices





Measuring up

The quantified self

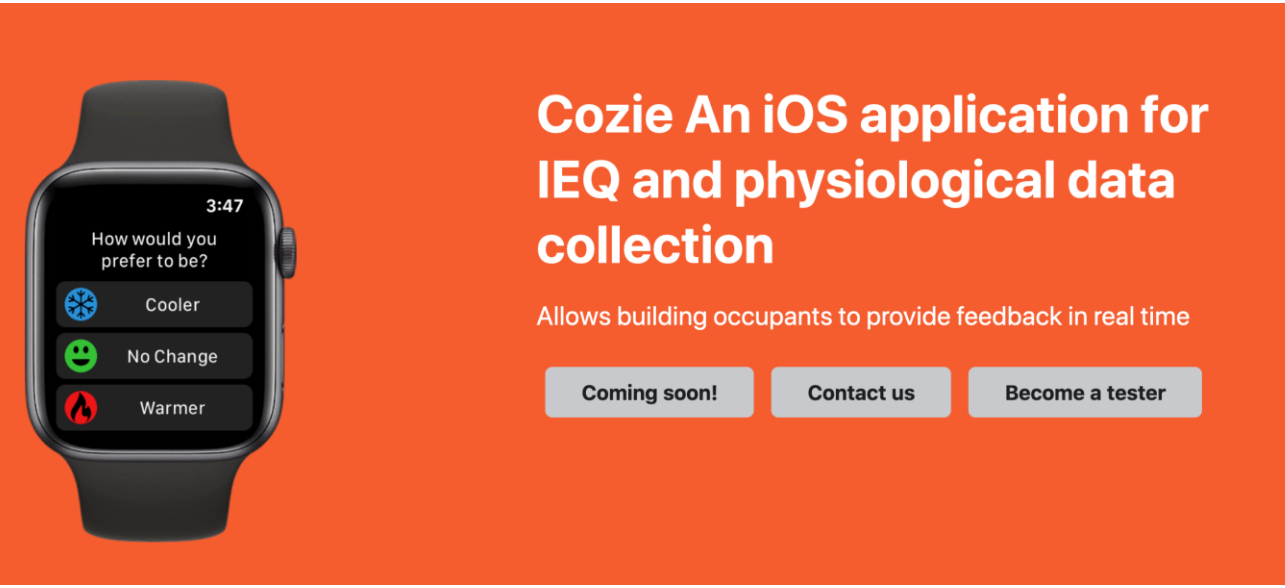
TECHNOLOGY QUARTERLY - MAY 7TH 2022

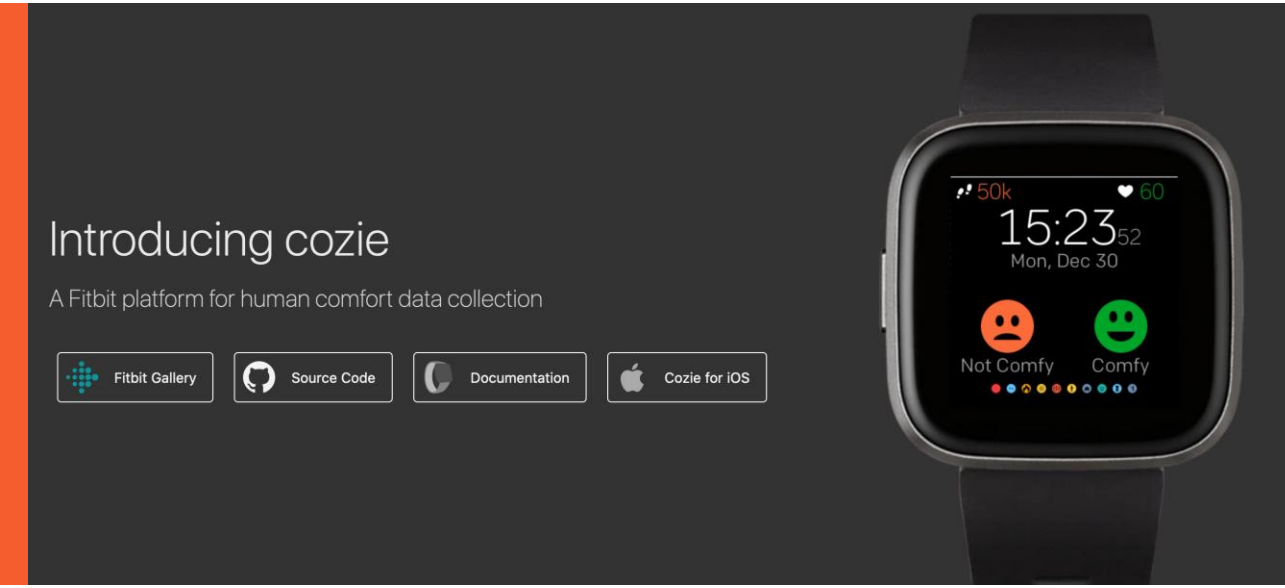
Wearable fitness trackers and smartwatches are connecting health care to daily life, says Slavea Chankova

"In America smartwatches are catching on as fast as did early mobile phones.
In 2021 about one in four Americans was estimated to own a smartwatch or fitness tracker."

https://www.economist.com/technology-quarterly/2022/05/01/wearable-devices-are-connecting-health-care-to-daily-life

Cozie Platform: Collecting Occupant Data at Scale in the Built Environment





https://cozie-apple.app/

https://cozie.app/

- Leverage smart watch and phone occupant interaction quickly and easily to characterize built environments
- ***Open-source***, scalable and available for FitBit and Apple Watch
- **Collaboration with UC Berkeley SinBerBest2/CBE**

https://github.com/cozie-app

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Micro-survey (EMA) Watch-based Question Flows

Thermal Feedback

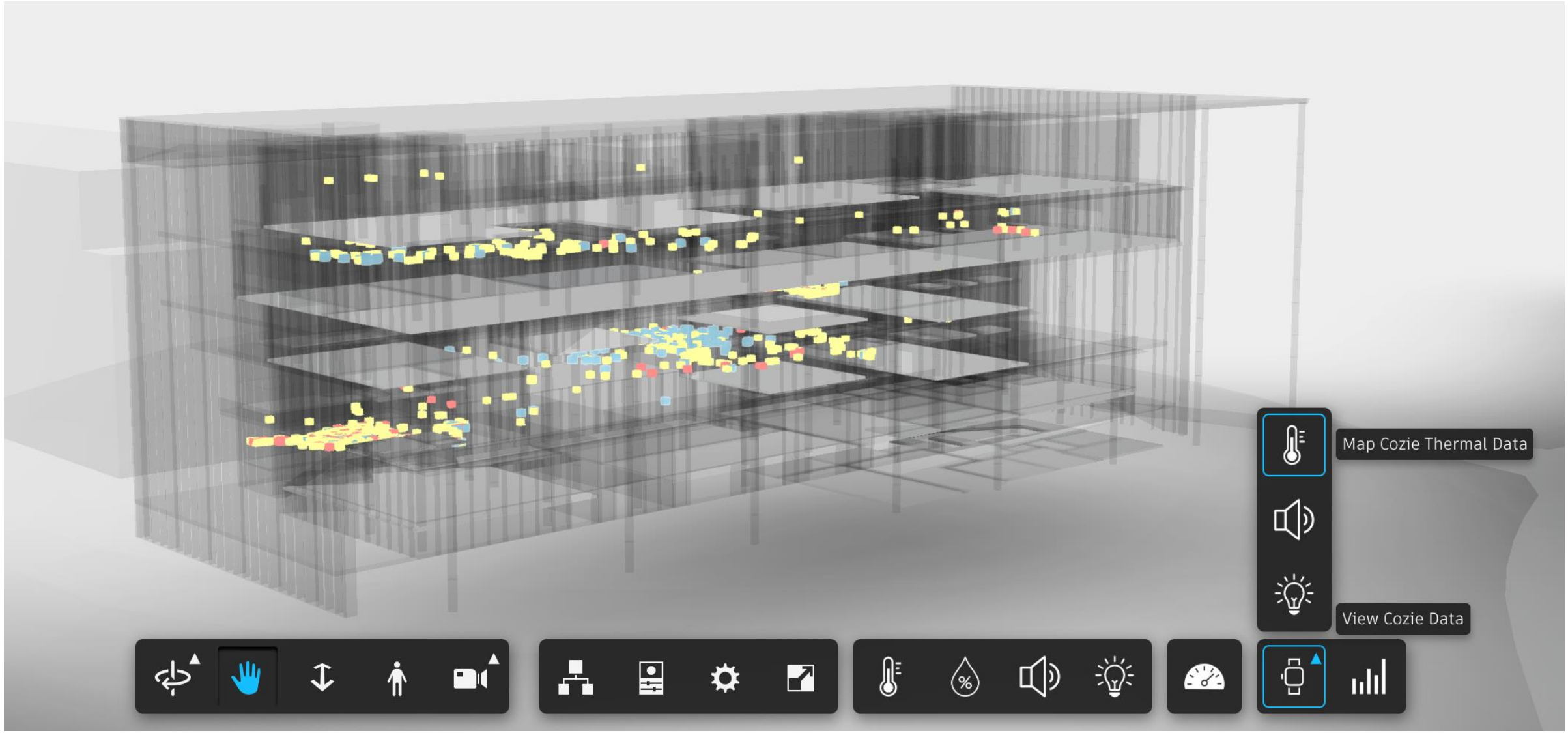
Visual Feedback

Aural Feedback

Jayathissa P, Quintana M, Abdelrahman M, Miller C. Humans-as-a-Sensor for Buildings—Intensive Longitudinal Indoor Comfort Models. Buildings. 2020;10: 174. https://doi.org/10.3390/buildings10100174

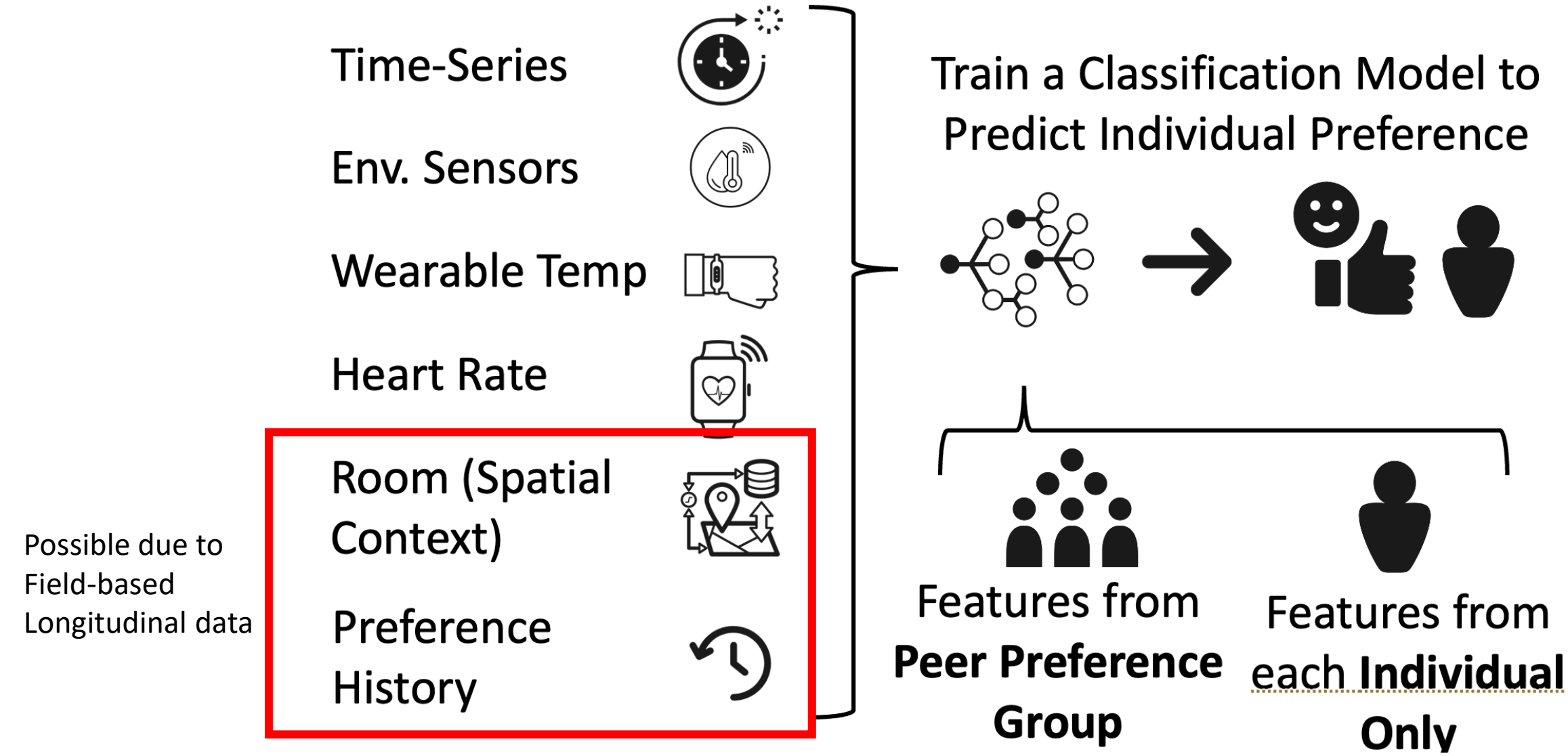
Jayathissa, P., Quintana, M., Sood, T., Nazarian, N., & Miller, C. (2019). Is your clock-face cozie? A smartwatch methodology for the in-situ collection of occupant comfort data. *Journal of Physics. Conference Series*, *1343*(1), 012145. https://doi.org/10.1088/1742-6596/1343/1/012145

Scalable Field-based Data Collection



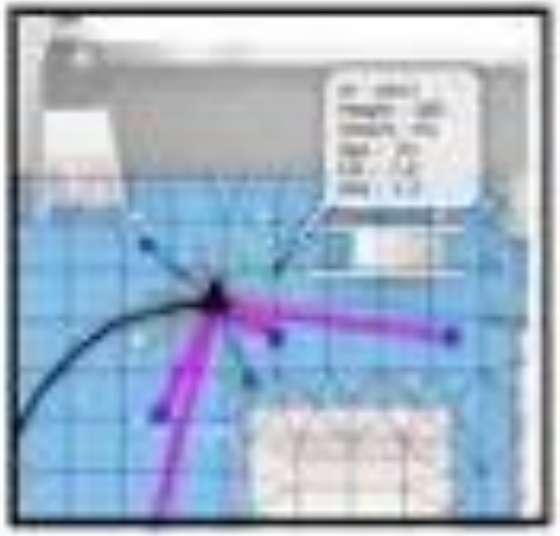
Jayathissa P, Quintana M, Abdelrahman M, Miller C. Humans-as-a-Sensor for Buildings—Intensive Longitudinal Indoor Comfort Models. Buildings. 2020;10: 174. https://doi.org/10.3390/buildings10100174

Building New Types of ML-driven Comfort Preference Prediction Models



Possible due to Field-based Longitudinal data

Jayathissa P, Quintana M, Abdelrahman M, Miller C. Humans-as-a-Sensor for Buildings—Intensive Longitudinal Indoor Comfort Models. Buildings. 2020;10: 174. https://doi.org/10.3390/buildings10100174



SDE4 - Level 3

Thinking Beyond Thermal Comfort

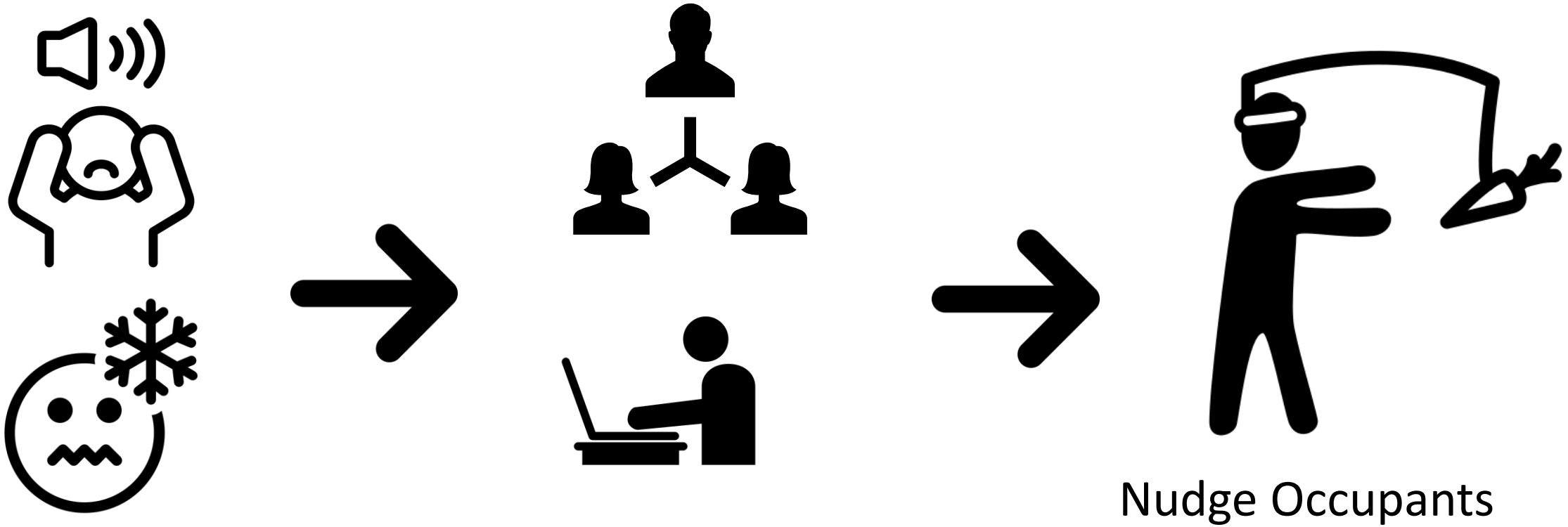
Building's Impact on Movement

Noise, Distraction and Privacy

Infection Risk Perception

Miller, C., Christensen, R., Leong, J. K., Abdelrahman, M. M., Tartarini, F., Quintana, M., Mueller, A. M., & Frei, M. (2022). *Smartwatch-based ecological momentary assessments for occupant wellness and privacy in buildings*. *Accepted at the Indoor Air 2022 Conference*

New Deployment on Noise Distraction and Thermal Comfort across Singapore



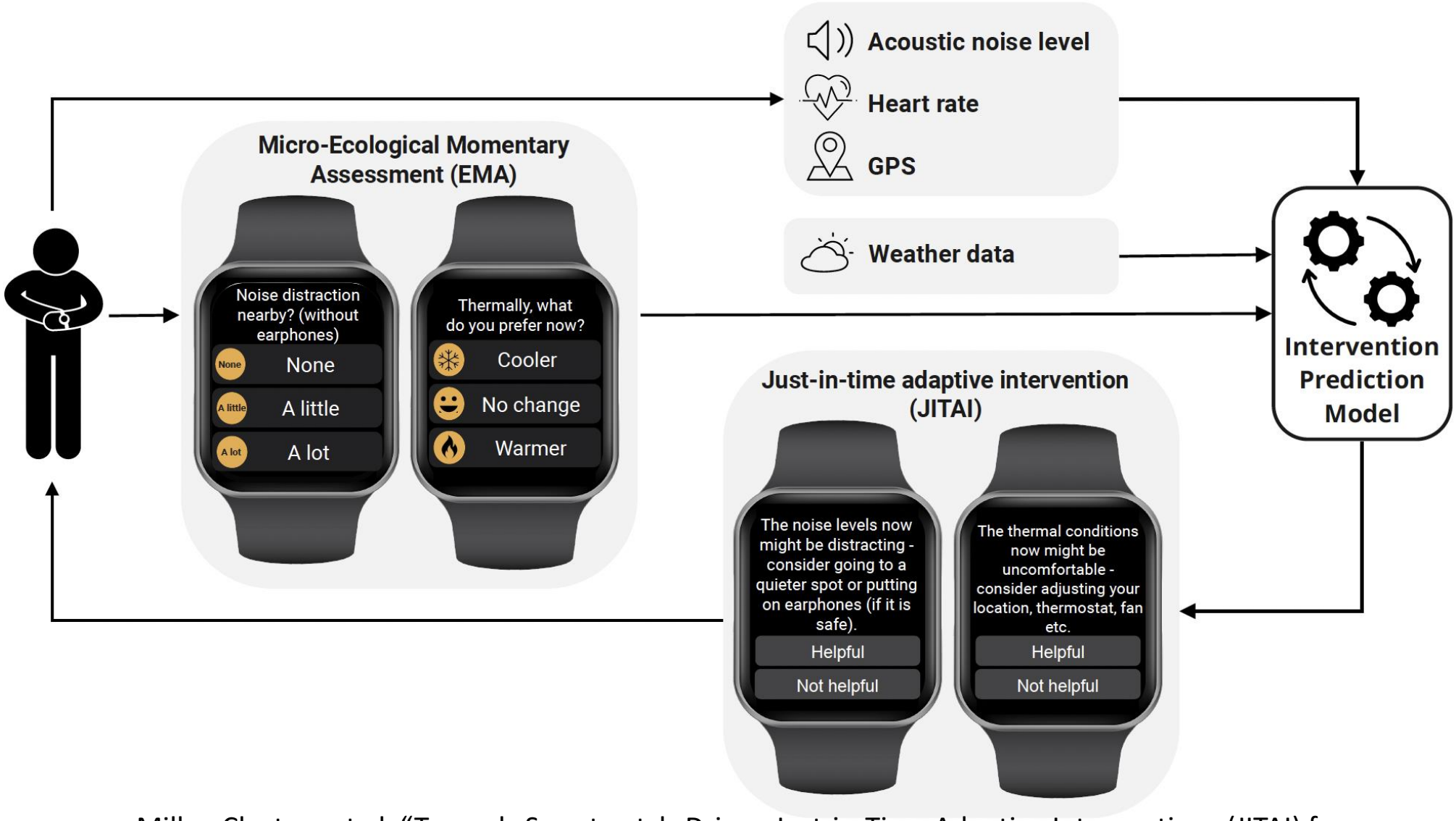
Detect and Learn Occupants' Preferences

Understand Context

Nudge Occupants to Improve their Situation (Just-in-Time Adaptive Interventions or JITAI)

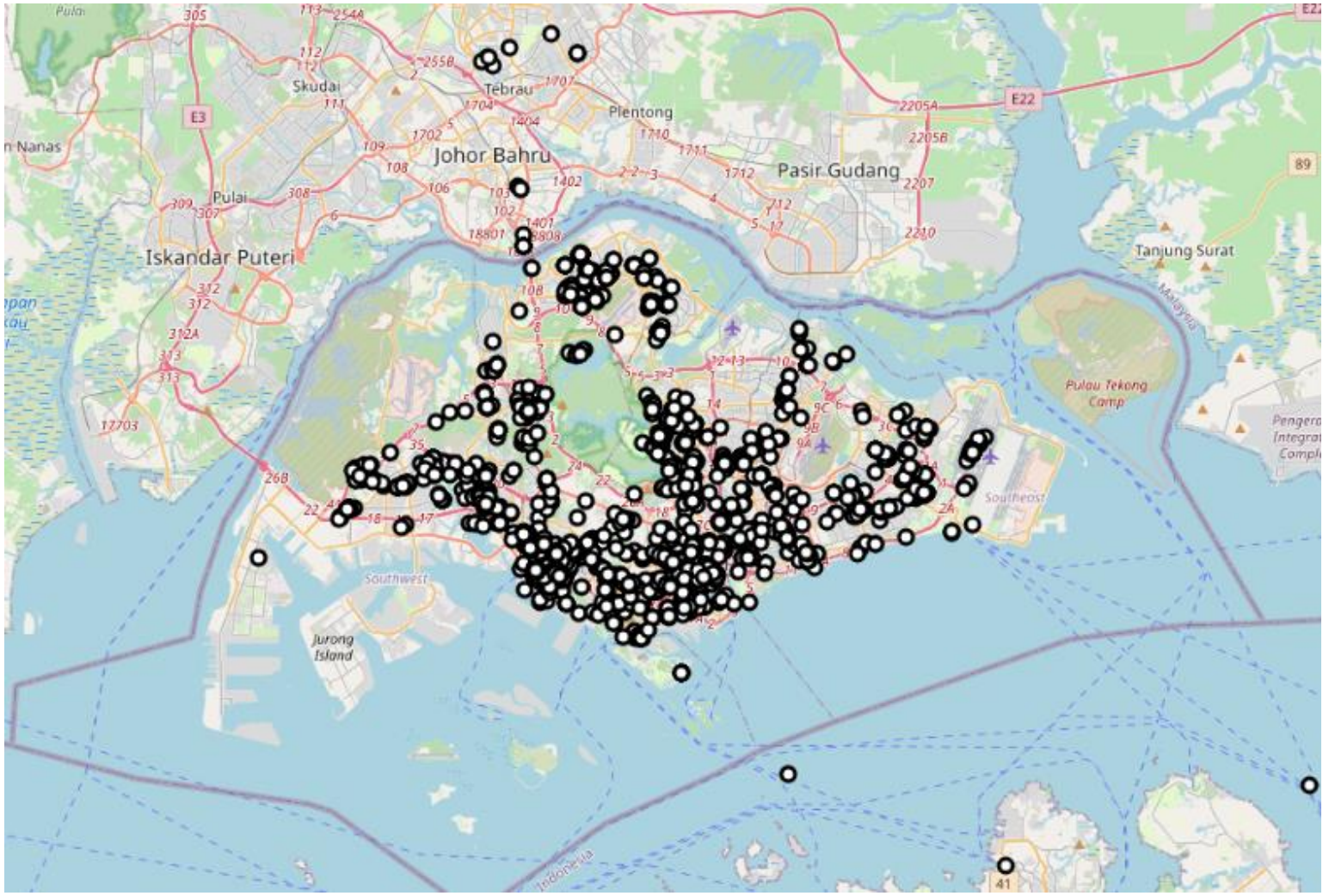
Miller, Clayton, et al. "Towards Smartwatch-Driven Just-in-Time Adaptive Interventions (JITAI) for Building Occupants." *The 9th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation*, November 9-10 2022, https://doi.org/10.1145/3563357.3566135.

Just-in-time Adaptive Intervention (JITAI) Messages for Buildings



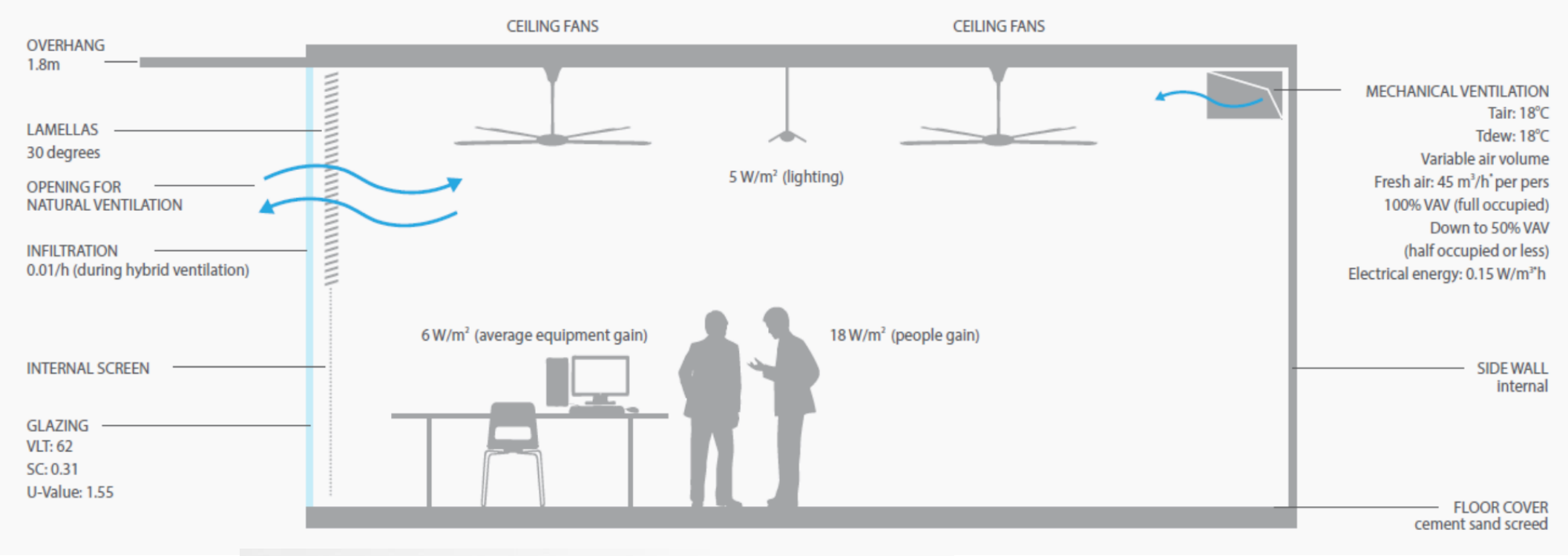
Miller, Clayton, et al. "Towards Smartwatch-Driven Just-in-Time Adaptive Interventions (JITAI) for Building Occupants." *The 9th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation*, November 9-10 2022, https://doi.org/10.1145/3563357.3566135.

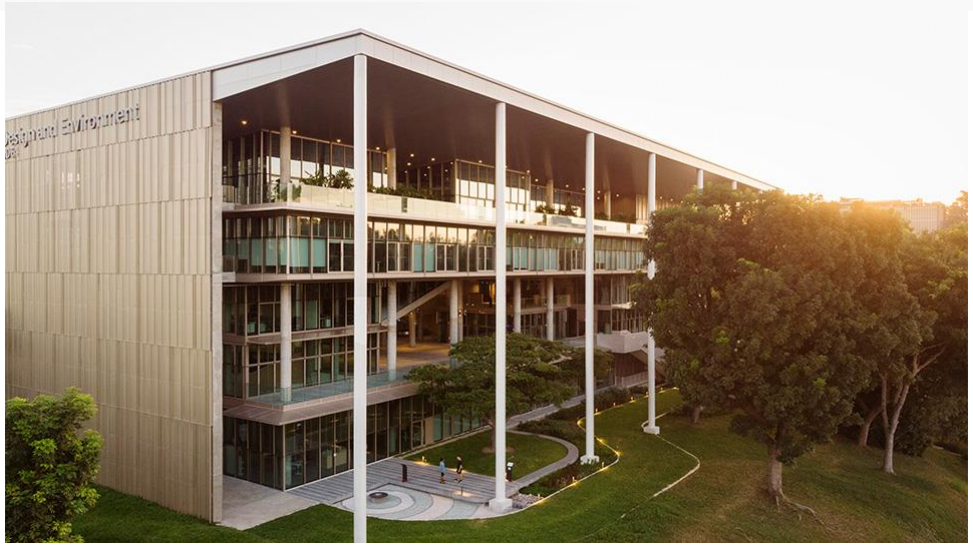
Scalability of Data Collection across Singapore



Miller, Clayton, et al. “Towards Smartwatch-Driven Just-in-Time Adaptive Interventions (JITAI) for Building Occupants.” *The 9th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation*, November 9-10 2022, https://doi.org/10.1145/3563357.3566135.

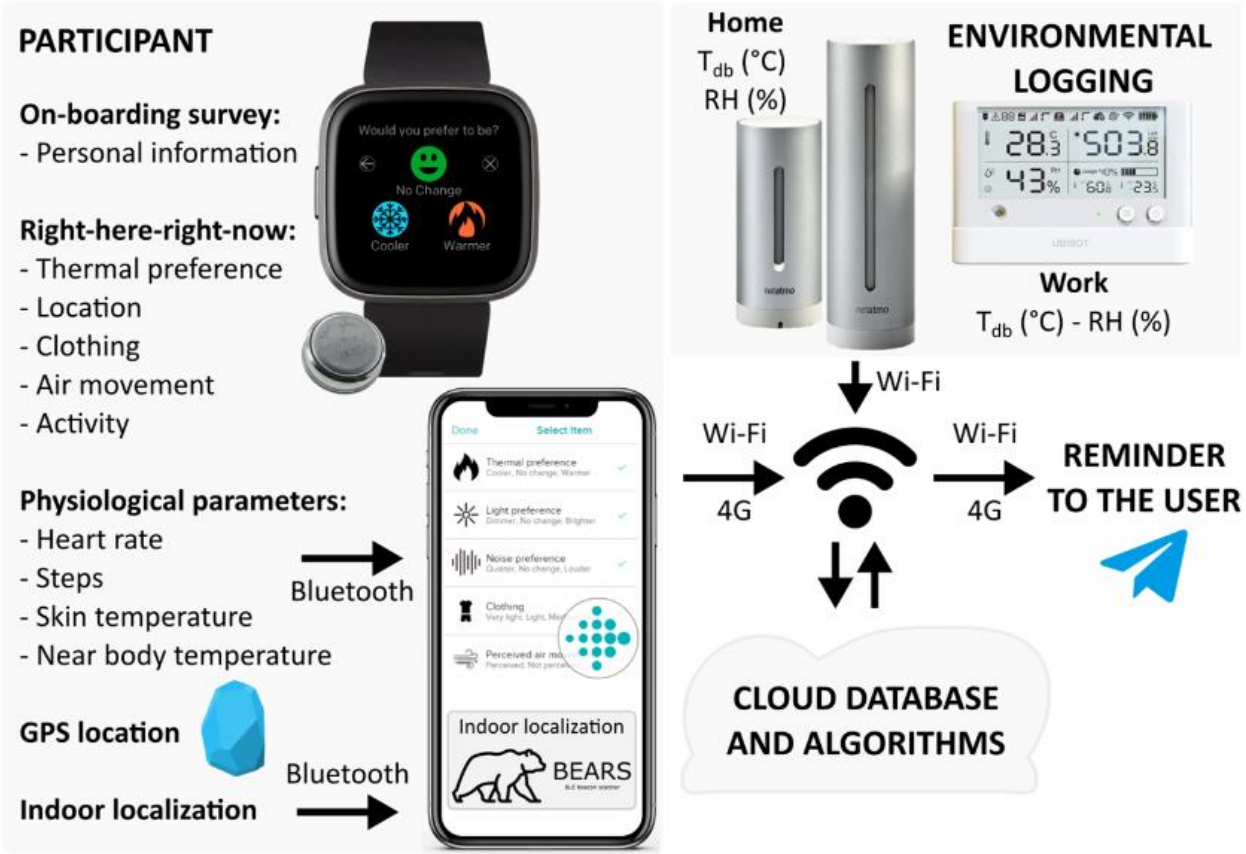
NUS Mixed Mode Ventilation – Using Fans in Commercial Buildings





Collab. with Dr. Adrian Chong (PI) at NUS

SinBerBEST2 Laboratory – NUS-Berkeley - Indoor Thermal Comfort ML



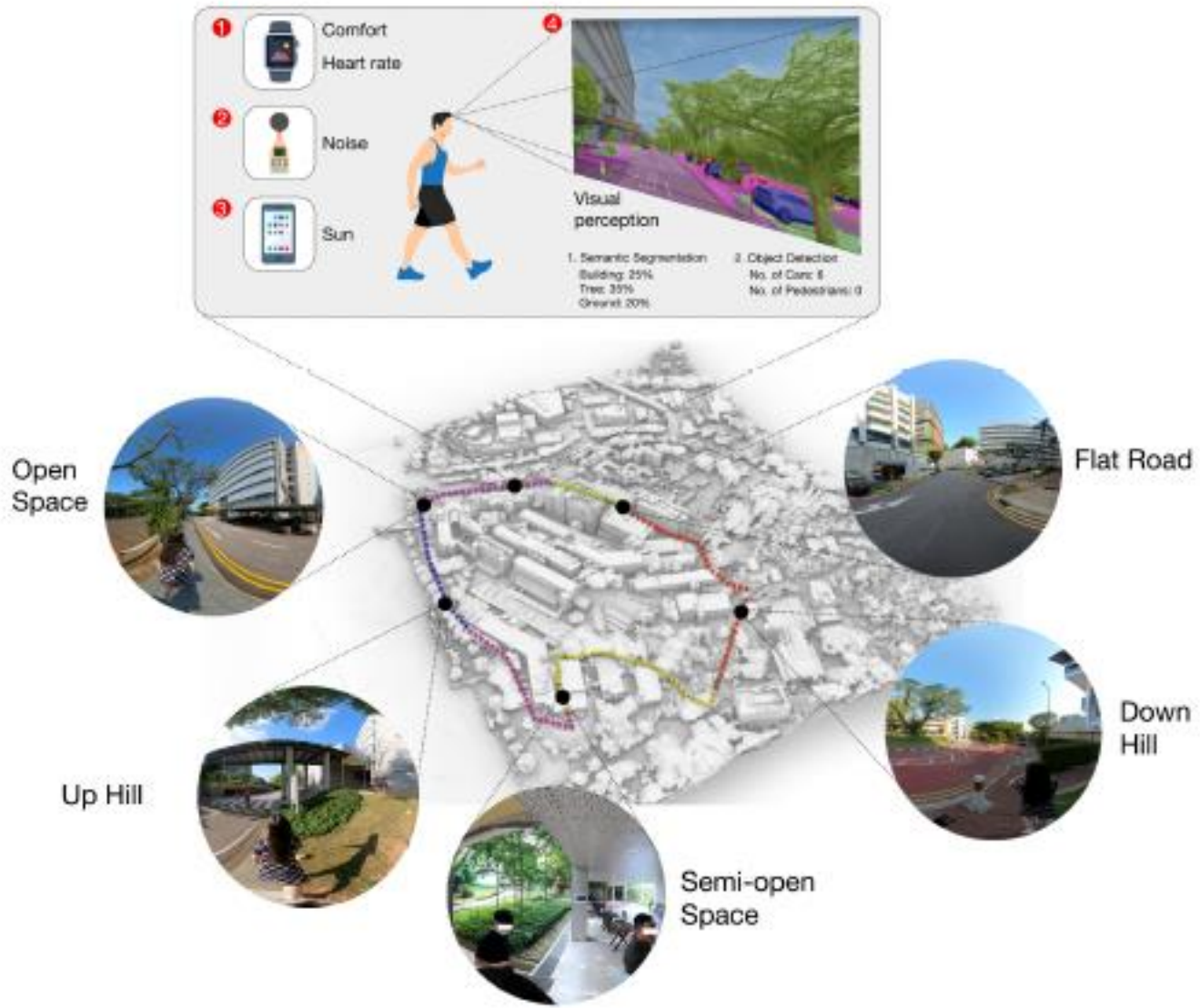
(a) **Cold start**: **Top** The occupant is directly assigned to the cohort with the matching value (b) **Warm start**: Data points collected from the new participant are evaluated on each ex- of the onboarding survey used for cohort creation. **Bottom** The clustering algorithm used isting *Cohort model*. The participant is then assigned to the cohort on which it had the for cohort creation is used on the participant's onboarding survey responses to predict the best-averaged performance based on F1-micro score. corresponding cohort.

Collab. with Prof. Stefano Schiavon (PI) from UCB

Tartarini, Federico, et al. "Personal Comfort Models Based on a 6-Month Experiment Using Environmental Parameters and Data from Wearables." *Indoor Air*, vol. 32, no. 11, Nov. 2022, p. e13160, https://doi.org/10.1111/ina.13160.

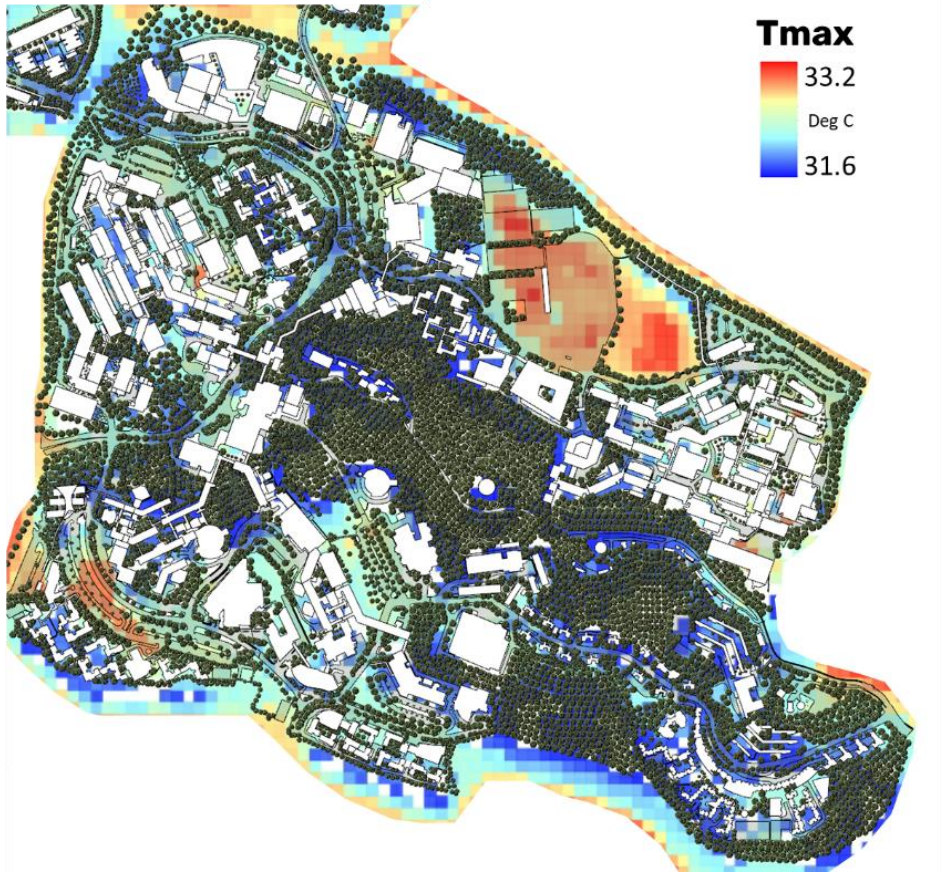
Quintana, Matias, et al. "Cohort Comfort Models — Using Occupant's Similarity to Predict Personal Thermal Preference with Less Data." *Building and Environment*, vol. 227, Jan. 2023, p. 109685, https://doi.org/10.1016/j.buildenv.2022.109685.

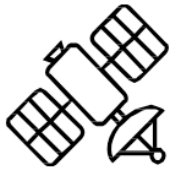
NUS Digital Twin Project – Participatory Urban-Building-Human DT



Collab. with Dr. Filip Biljecki (PI) at NUS

NUS BEAM Project – Reducing Urban Heat Islands on Campus





Satellite imaging

- Surface temperature
- Vegetation
- Large scale coverage

Ground-based sensing

- Air Temperature
- Humidity
- Wind
- Rain
- Solar Radiation
- Pollution
- Ground based coverage

Infrared (IR) cameras

- Urban surface temperature
- Heat emitted by buildings
- Cooling effect of vegetation
- Bird's eye view coverage

Meteorological towers

- High resolution of ambient temperature and other weather parameters
- Building scale
- Façade heat exchange

Unmanned Aerial Vehicle

- Capture the spatial complexities of urban land surfaces (sub-meter resolution)
- Air and surface temperature

Collab. with Prof. Wong Nyuk Hien (PI) at NUS

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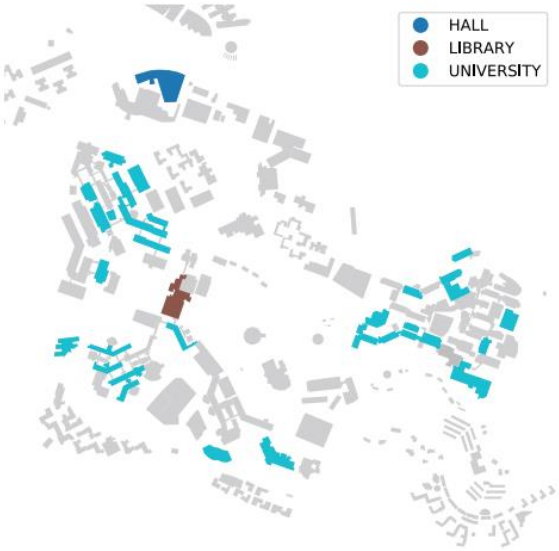
Future Resilient Systems Laboratory - NUS-ETH Zurich – Flex-based Working



Collab. with Prof. Rudi Stouffs (PI) from NUS

Mosteiro-Romero, Martín, et al. “Elastic Buildings: Calibrated District-Scale Simulation of Occupant-Flexible Campus Operation for Hybrid Work Optimization.” *arXiv [physics.soc-Ph]*, Aug. 2022, https://arxiv.org/abs/2210.06124. arXiv.

The Vision: Community-driven Scaled-up Data Collection and Sharing!

The dream is to collect **millions of data points** from *hundreds of thousands of people worldwide* to determine what makes people tick when it comes to satisfaction in buildings

Quintana, M., Abdelrahman, M., Frei, M., Tartarini, F., & Miller, C. (2021). Longitudinal personal thermal comfort preference data in the wild. *Proceedings of the 19th ACM Conference on Embedded Networked Sensor Systems*, 556–559. https://doi.org/10.1145/3485730.3493693

Acknowledgements

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