Let's add occupants to our digital twins!

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

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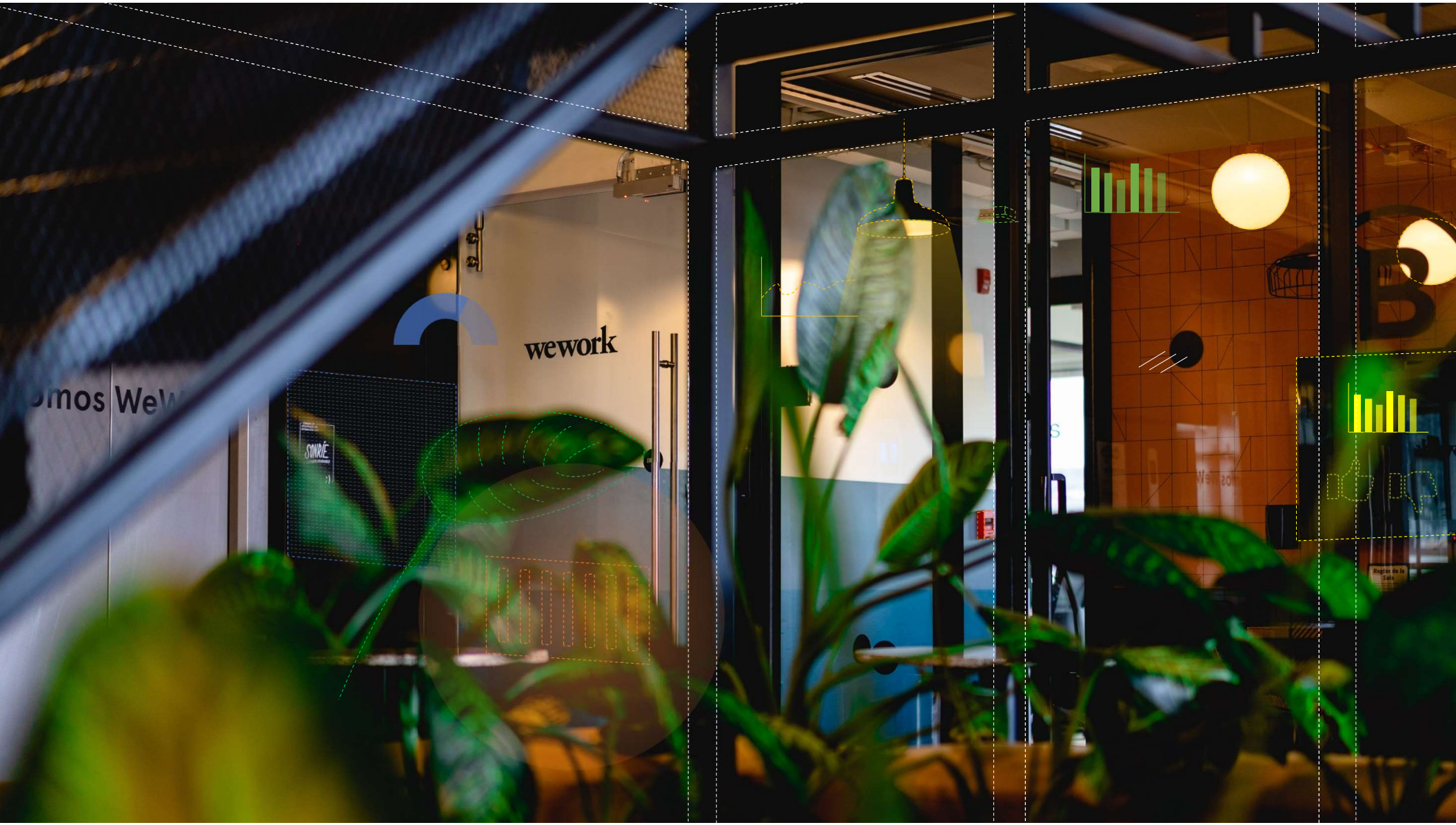
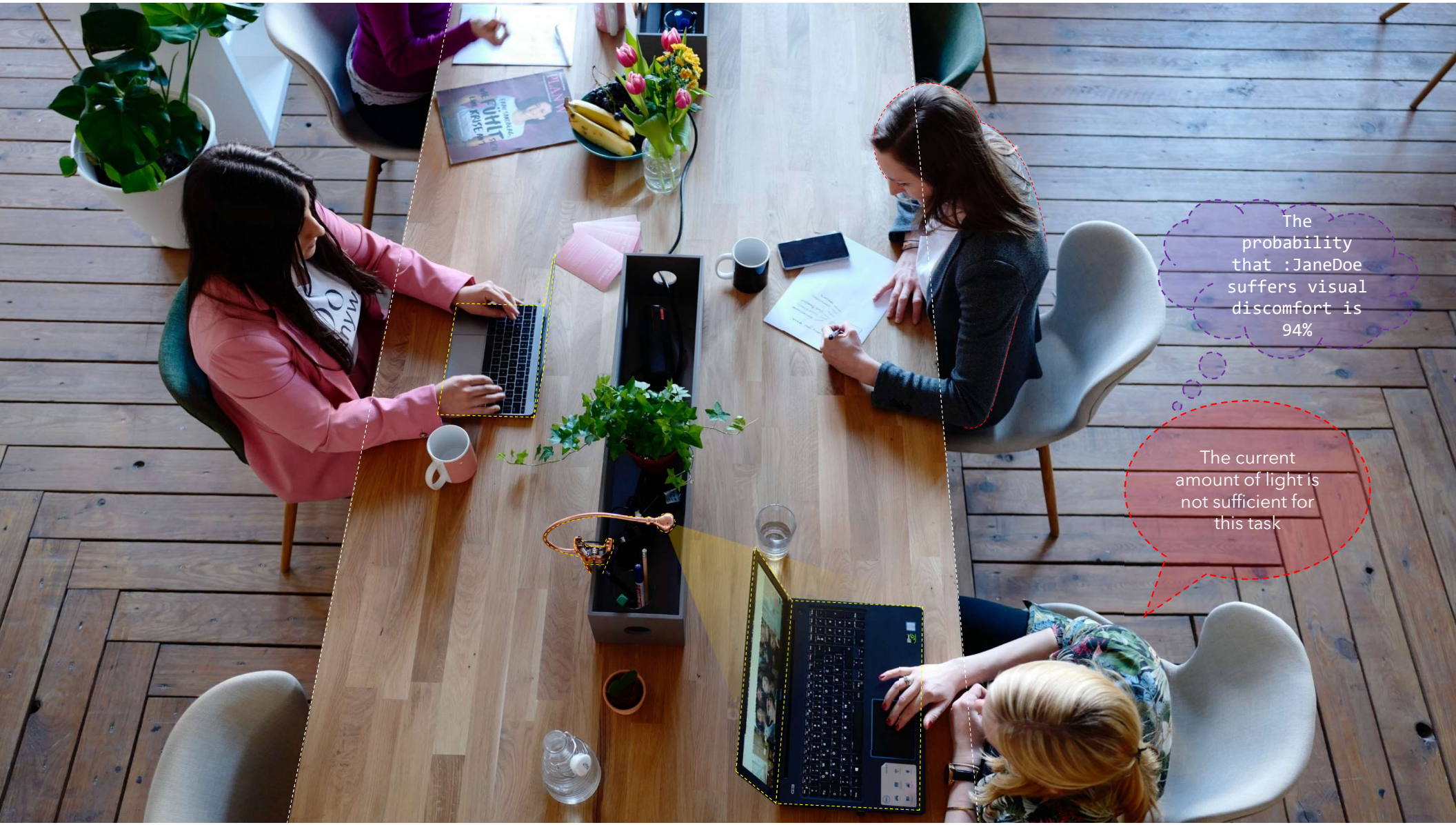
smart TWO kpn


wework

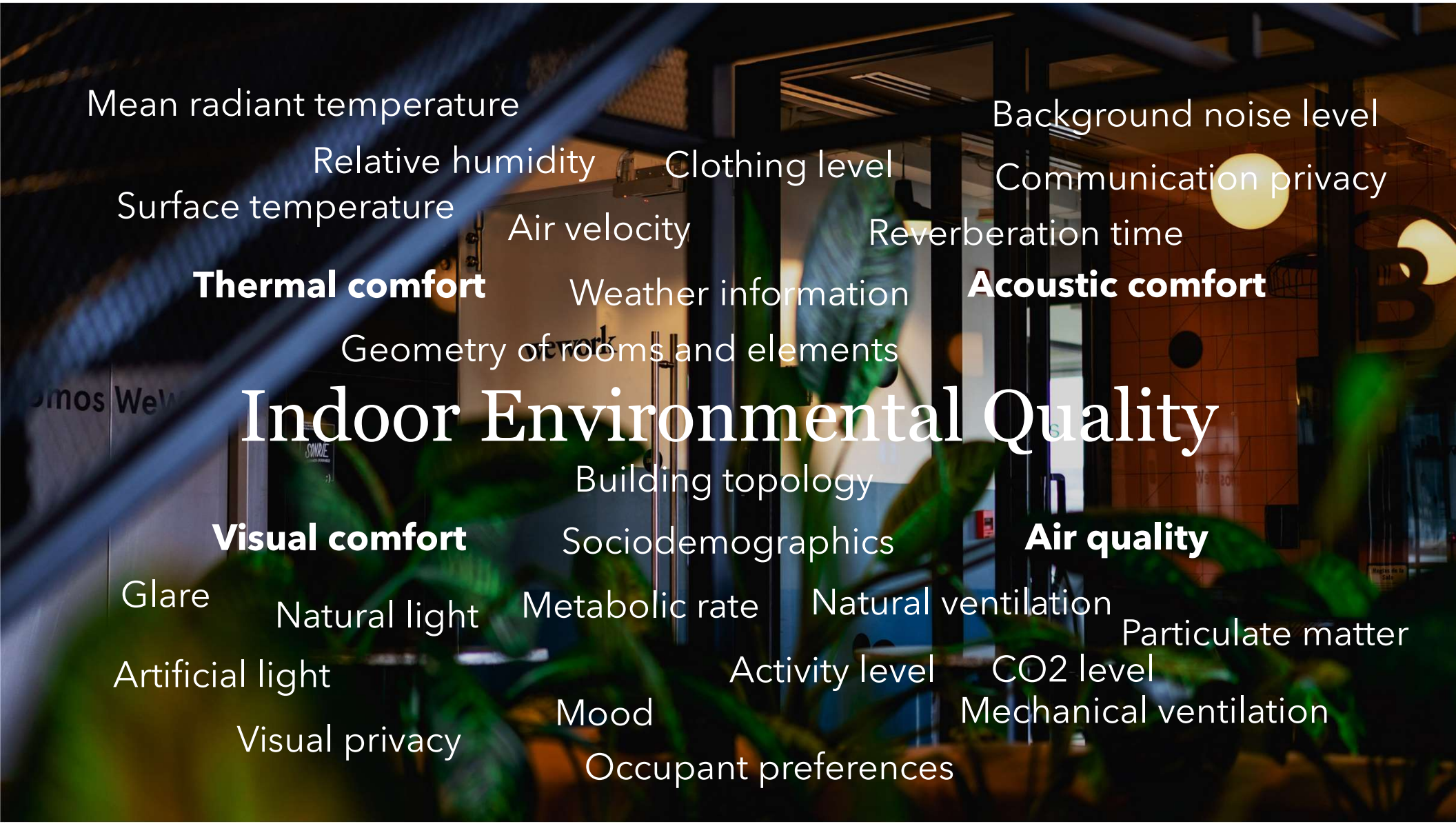

wework


The probability that :JaneDoe suffers visual discomfort is 94%
The current amount of light is not sufficient for this task

While buildings should be designed for their occupants, many buildings fail to satisfy their expectations.

How to monitor building performance?
How to integrate the occupant?
How to create parallel intelligence?

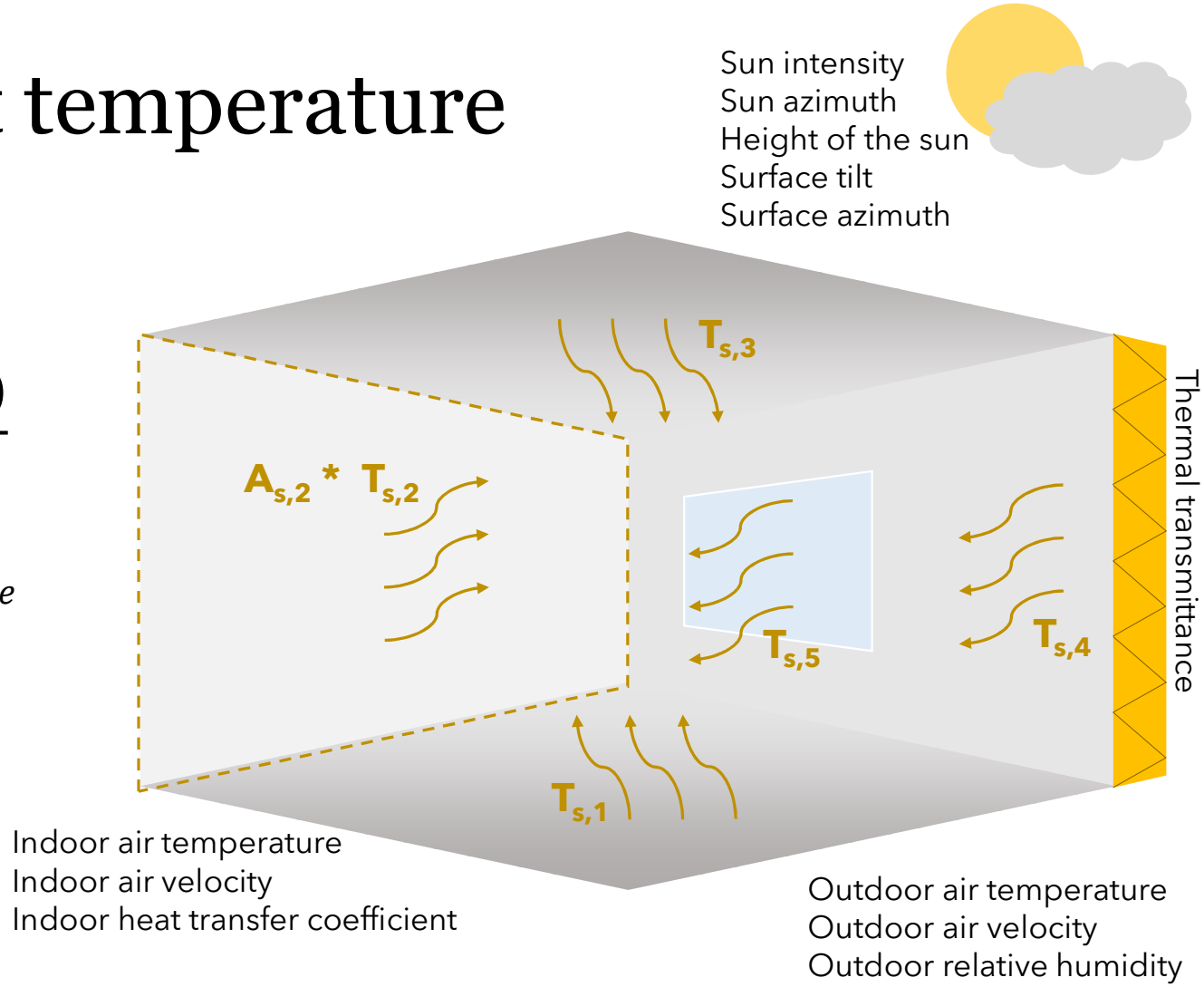
How to monitor building performance?


Mean radiant temperature
Relative humidity
Surface temperature
Clothing level
Air velocity
Thermal comfort
Weather information
Geometry of rooms and elements
Background noise level
Communication privacy
Reverberation time
Acoustic comfort
Indoor Environmental Quality
Building topology
Visual comfort
Sociodemographics
Air quality
Glare
Natural light
Metabolic rate
Natural ventilation
Particulate matter
Artificial light
Activity level
CO2 level
Mood
Mechanical ventilation
Visual privacy
Occupant preferences

Mean radiant temperature

$$T_{mr} = \frac{\sum_{i=0}^{n}(T_{s,i} * A_{s,i})}{\sum_{i=0}^{n}(A_{s,i})}$$

$T_{mr} = mean\ radiant\ temperature$
$T_{s,i} = surface\ temperature$
$A_{s,i} = surface\ area$



TOPOLOGY
Rooms
Elements
How they relate to each other

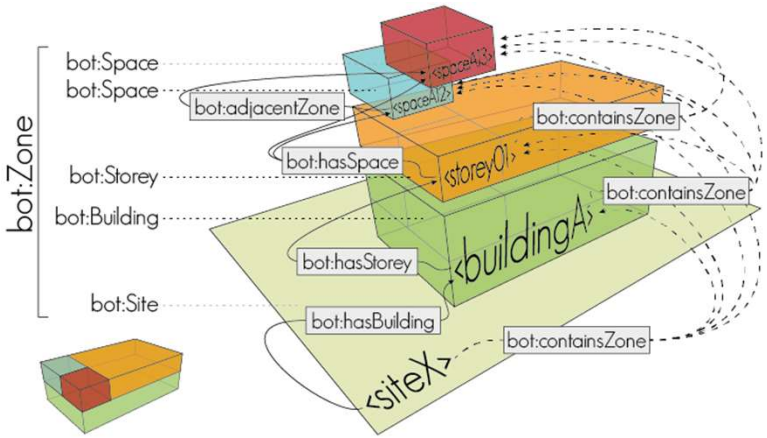
STATIC PROPERTIES
Geometry
Material characteristics

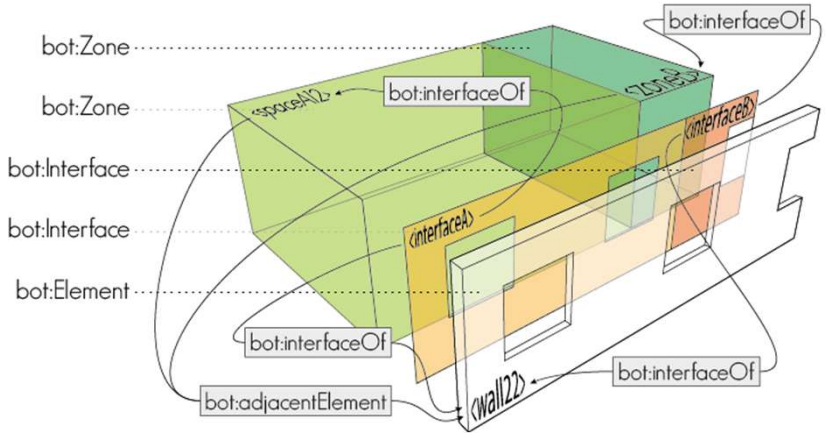
DYNAMIC PROPERTIES
Sensor data
Weather data

Challenge

Integrate the heterogeneous information related to building performance assessments.

Building Topology Ontology (BOT)

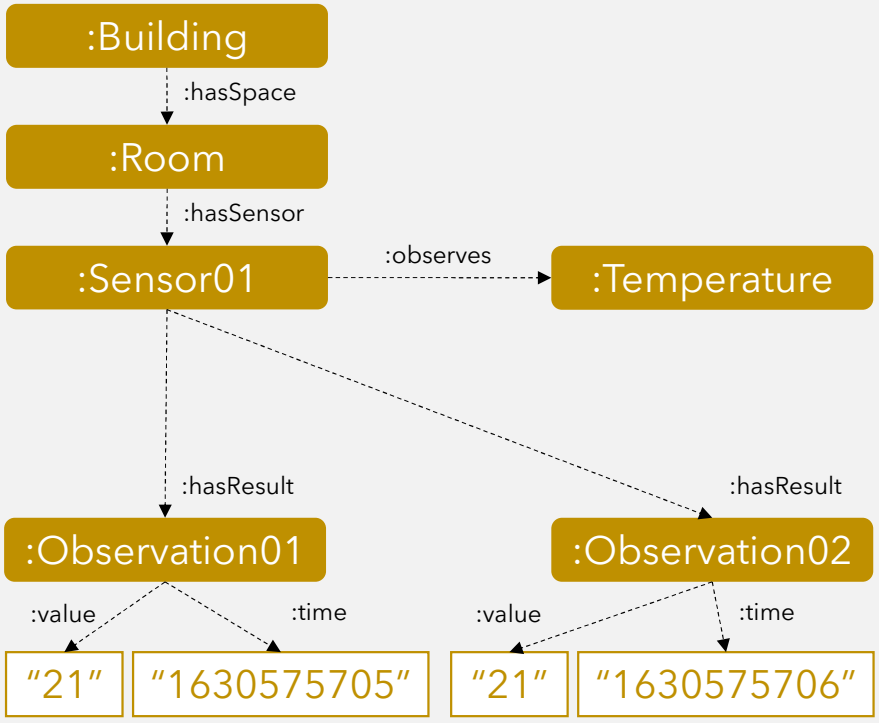




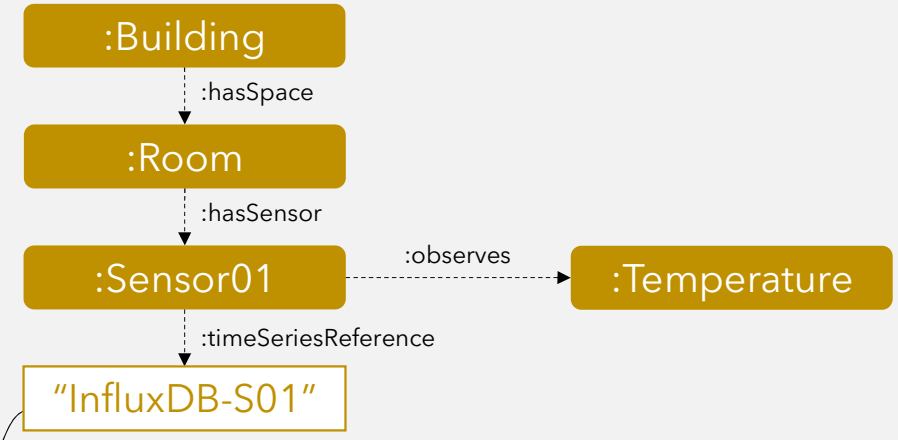
READ MORE
Tang et al. (2019)

Approaches to describe property values

GRAPH DATABASE



GRAPH DATABASE



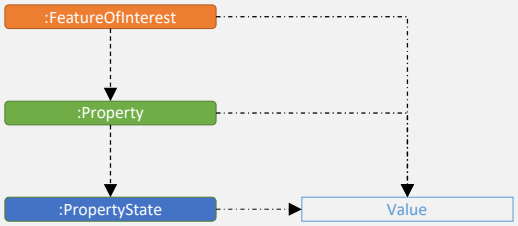
TIME-SERIES DATABASE

```
S01,21,1630575705
S01,21,1630575706
S01,22,1630575709
```

Static and dynamic properties

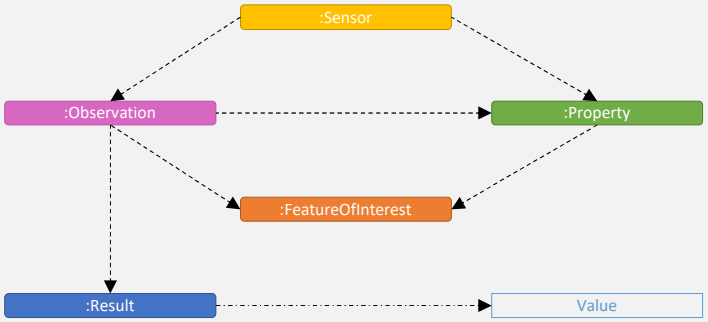
ONTOLOGIES FOR STATIC PROPERTIES

- Ontology for Property Management (**OPM**)
- BIM Design Ontology (**BIMDO**)
- Building Product Ontology (**BPO**)

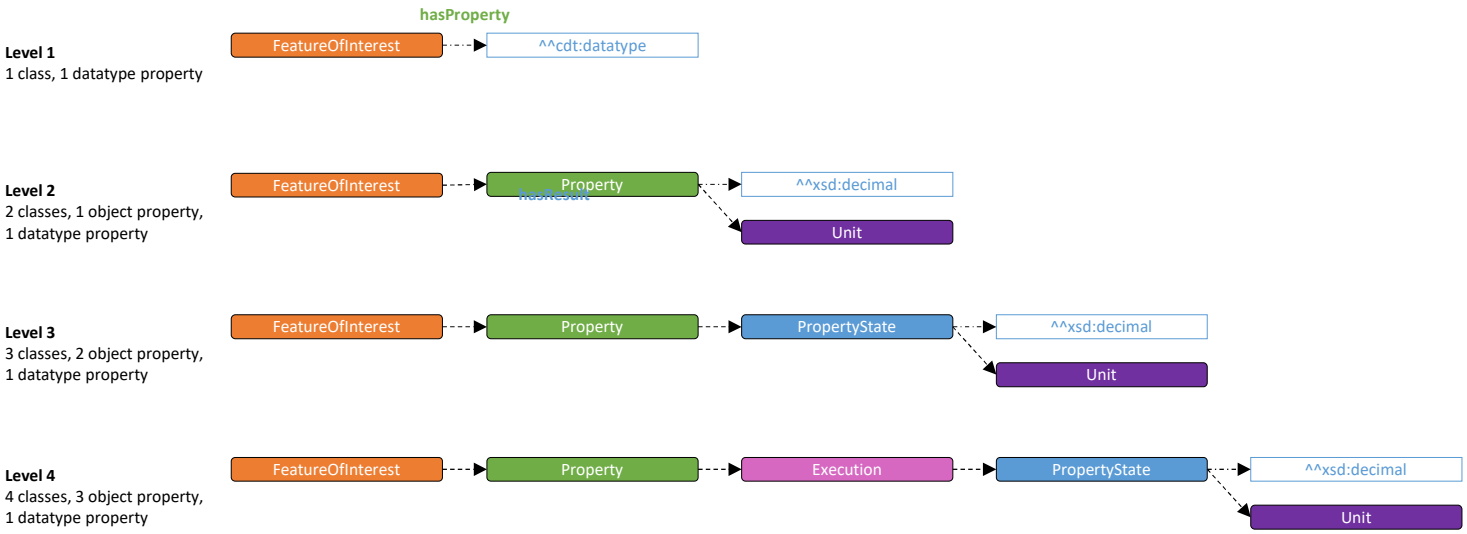


ONTOLOGIES FOR DYNAMIC PROPERTIES

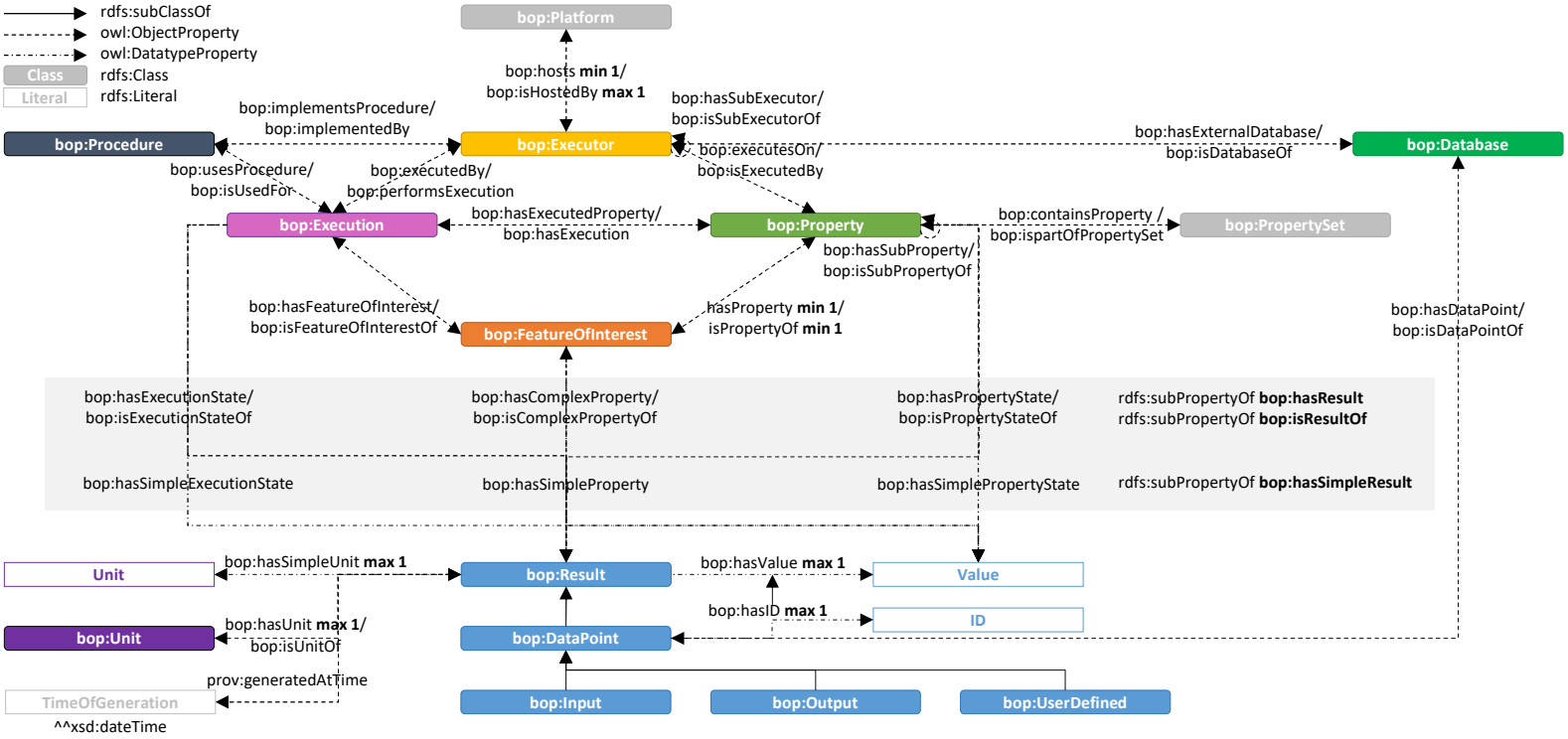
- Semantic Sensor Network Ontology (**SSN**)
- Sensor, Observation, Sample and Actuator (**SOSA**)
- Smart Applications REFerence Ontology (**SAREF**)
- **Brick**

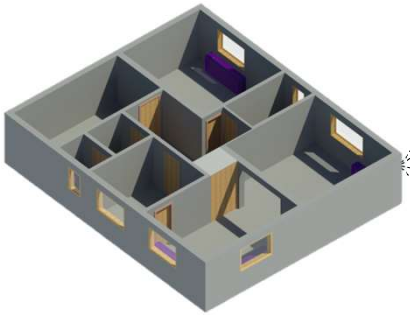


Properties: four levels of detail



Building Performance Ontology (BOP)





TOPOLOGY
Rooms
Elements

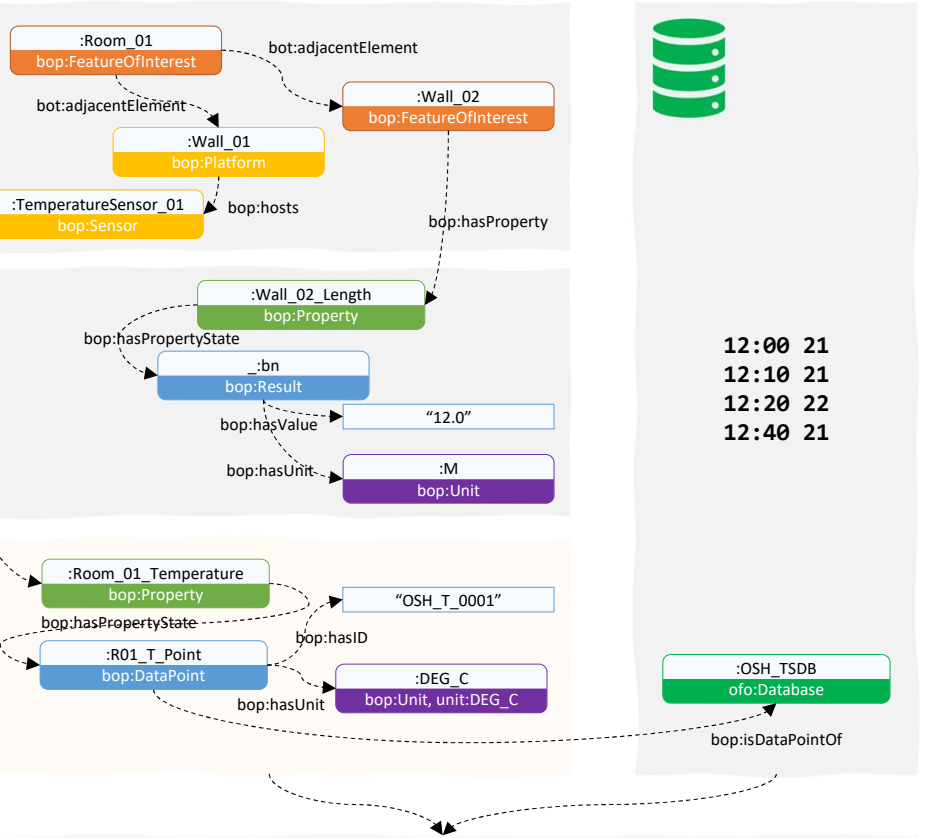
STATIC PROPERTIES
Geometry
Material characteristics

DYNAMIC PROPERTIES
Sensor data
Weather data

RULES AND REGULATION
PMV
PPD

Convert to linked data

Link to external DB



PYTHON
Real-time building performance monitoring

GEOMETRY
GraphDB

```
sparql.setQuery("""PREFIX props: <https://w3id.org/props#>
PREFIX quantitykind: <http://qudt.org/vocab/quantitykind/>
PREFIX bot: <https://w3id.org/bot#>
PREFIX bop: <https://w3id.org/bop#>
PREFIX beo: <http://pi.pauwel.be/voc/buildingelement#>
PREFIX : <https://research.tue.nl/nl/persons/alex-ja-donkers#>

SELECT ?room ?wall ?interface ?interfaceWidthValue

WHERE {
?room bop:hasSimplePropertyState "Bedroom" ;
      bot:adjacentElement ?wall .
?wall a beo:Wall .
?interface bot:interfaceOf ?room, ?wall ;
           bop:hasProperty ?width .
?width a quantitykind:Width ;
       bop:hasPropertyState / bop:hasValue ?interfaceWidthValue
} """)
```

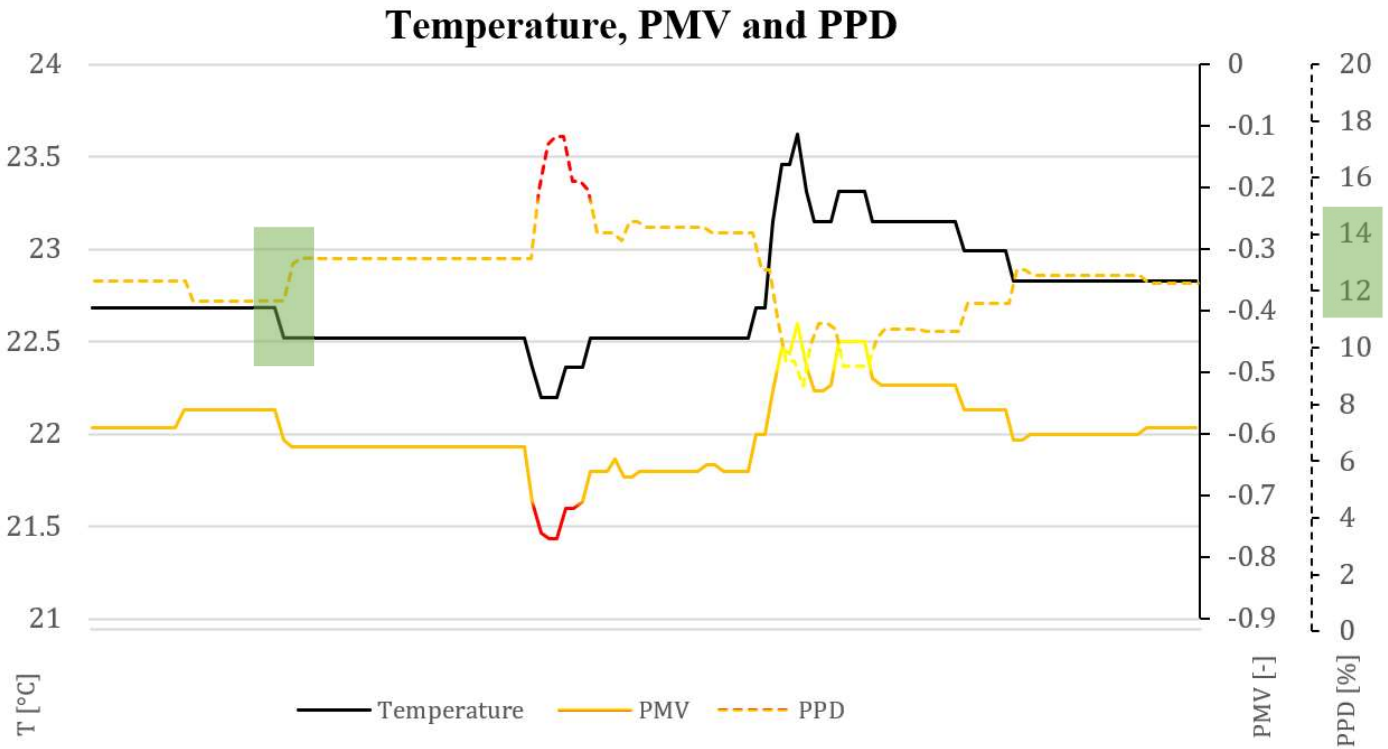
TEMPERATURE
GraphDB

```
graph_url = "http://localhost:7200/repositories/OpenSmartHomeRepos
itory"
sparql = SPARQLWrapper(graph_url)
sparql.setQuery("""PREFIX props: <https://w3id.org/props#>
PREFIX quantitykind: <http://qudt.org/vocab/quantitykind/>
PREFIX bot: <https://w3id.org/bot#>
PREFIX bop: <https://w3id.org/bop#>
PREFIX : <https://research.tue.nl/nl/persons/alex-ja-donkers#>

SELECT ?property ?datapoint ?database

WHERE {
?room bop:hasSimplePropertyState "Bedroom" ;
         bot:containsElement ?sensor .
?sensor bop:observes ?property .
?property a quantitykind:Temperature ;
          bop:hasPropertyState ?datapoint .
?datapoint bop:isDataPointOf ?database .
} """)
```

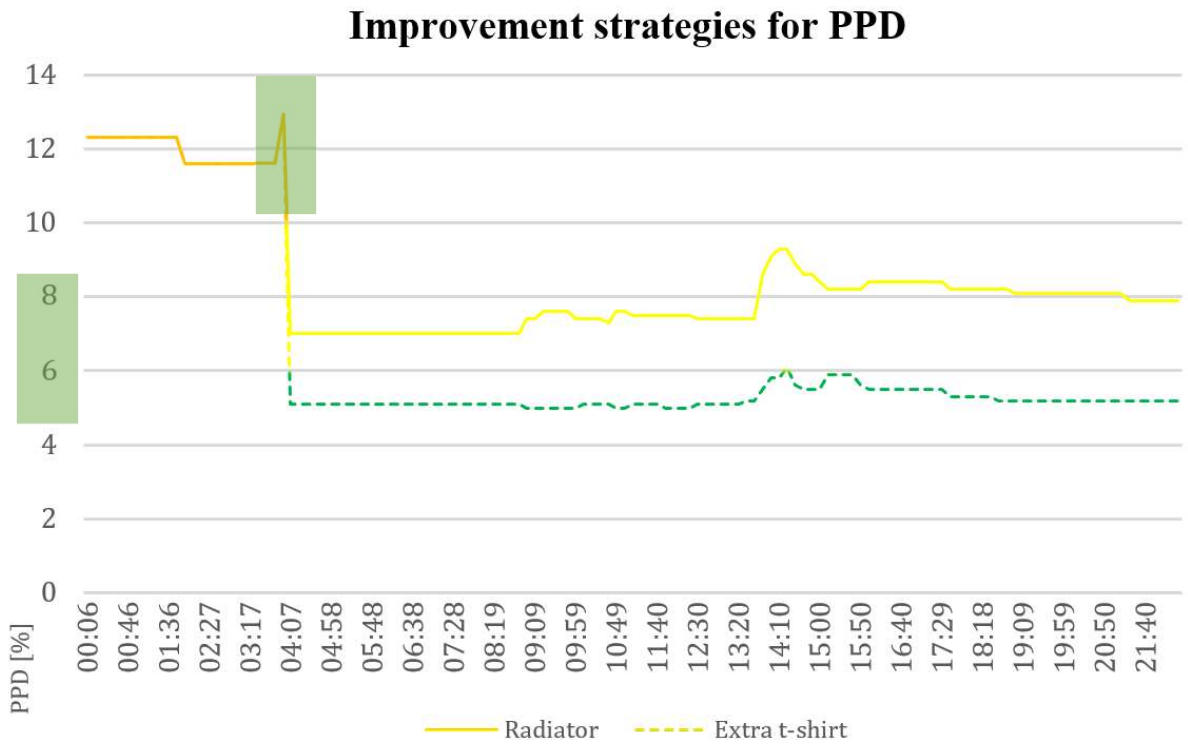
TEMPERATURE
InfluxDB

```
client = InfluxDBClient(host='localhost', port=8086)

client.switch_database(database)

resultset = client.query(

'SELECT ‘ + property + ’ FROM ’ + datapoint + ‘ WHERE time <= ‘ +
str(maxTime) + ‘ AND time > ‘ + str(minTime) + ‘ ORDER BY time
DESC LIMIT 1’)

value = list((resultset.get_points(measurement=datapoint)))

temperature = value[0]['value']
```

Results: PMV and PPD

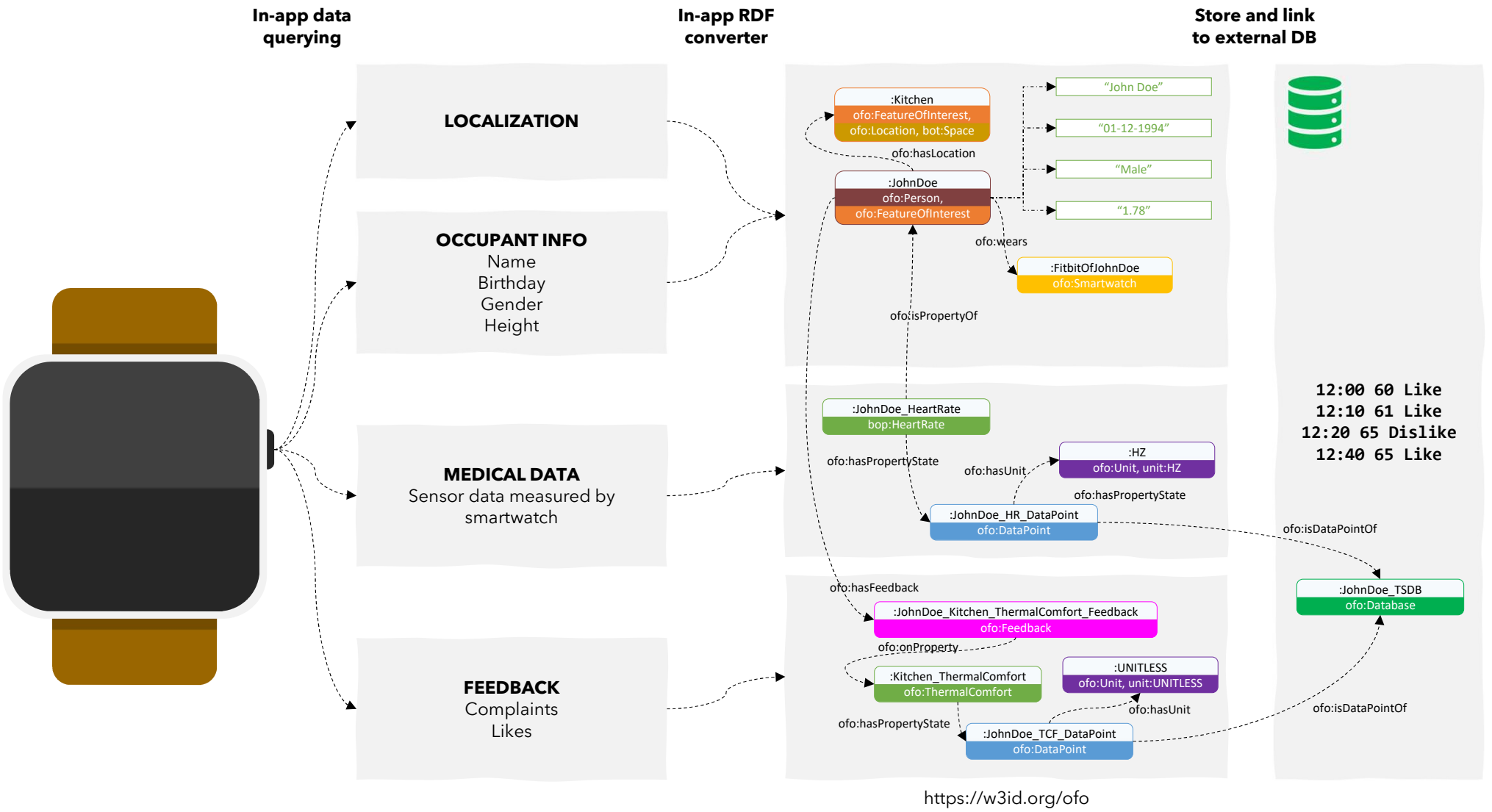


Results: PMV and PPD improvements



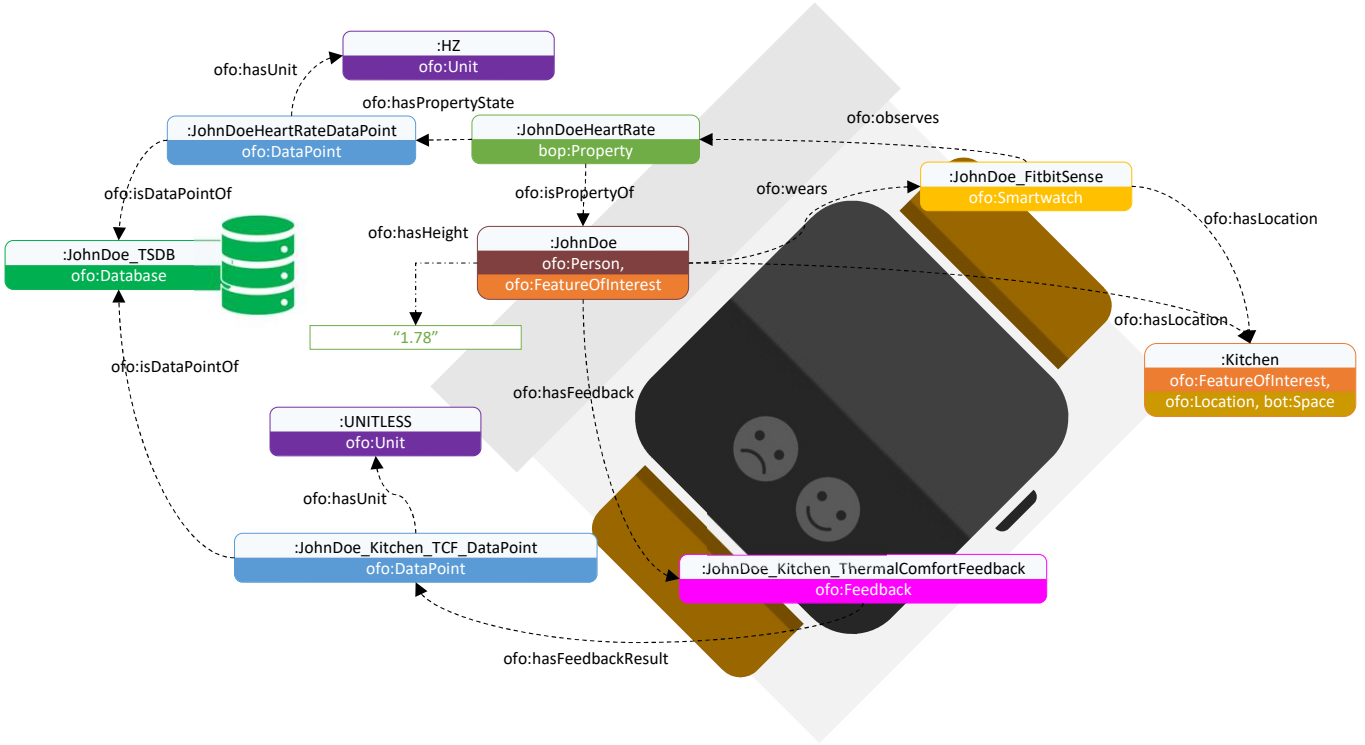
How to integrate the occupant?

Mintal

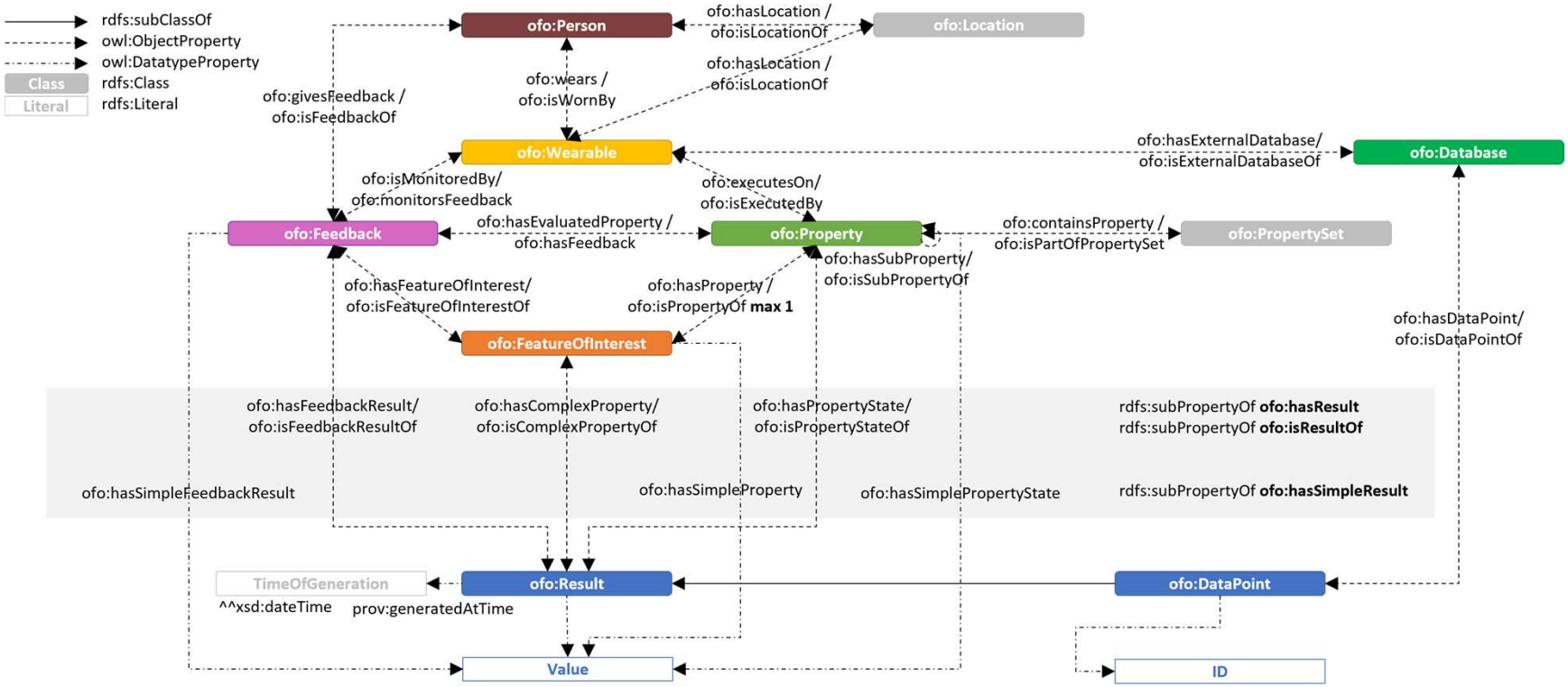


https://w3id.org/ofo

Mintal *resulting data structure*



Occupant Feedback Ontology (OFO)



Querying with OFO

CQ1: What active feedback is given by the occupant?

SPARQL

```
PREFIX ofo: <https://w3id.org/ofo#>
SELECT ?comfortProperty ?feedback ?dataPoint ?database
WHERE {
:JohnDoe ofo:givesFeedback ?feedback .
?feedback ofo:hasEvaluatedProperty ?comfortProperty .
?comfortProperty a ofo:Property .
?feedback ofo:hasResult ?dataPoint .
?dataPoint ofo:isDataPointOf ?database . }
```

InfluxDB

```
USE ?database SELECT ?feedback FROM ?dataPoint ORDER BY time DESC LIMIT 1
```

Querying with OFO

CQ2: What passive feedback is measured by the wearable?

SPARQL

```
PREFIX ofo: <https://w3id.org/ofo#>
PREFIX opt: <https://alexdonkers.github.io/opt#>
SELECT ?personalProperty ?dataPoint ?database
WHERE {
:JohnsFitbit ofo:executesOn ?personalProperty .
?personalProperty a opt:PersonalProperty .
?personalProperty ofo:hasResult ?dataPoint .
?dataPoint ofo:isDataPointOf ?database . }
```

InfluxDB

```
USE ?database SELECT ?personalProperty FROM ?dataPoint ORDER BY time DESC
LIMIT 1
```

Querying with OFO

CQ3: What location or object is the feedback referring to?

SPARQL

```
PREFIX ofo: <https://w3id.org/ofo#>
SELECT ?feedback ?foi
WHERE {
:JohnDoe ofo:givesFeedback ?feedback .
?feedback ofo:hasFeatureOfInterest ?foi . }
```

InfluxDB

```
PREFIX ofo: <https://w3id.org/ofo#>
SELECT ?location ?dataPoint ?database
WHERE {
:JohnDoe ofo:hasLocation ?location .
?location ofo:hasDataPoint ?dataPoint .
?dataPoint ofo:isDataPointOF ?database . }
```

Querying with OFO

CQ5: What feedback was given to a FOI between time t1 and t2?

SPARQL

```
SELECT ?feedback ?result ?resultTime
WHERE {
?feedback ofo:hasResult ?result .
?result prov:generatedAtTimev ?resultTime .
BIND(xsd:dateTime(NOW()) AS ?now) .
FILTER (YEAR(xsd:dateTime(?resultTime)) >
(YEAR(?now) - 3)) }
```

InfluxDB

```
USE ?database
SELECT ?feedback FROM ?dataPoint WHERE time > ?t1 and time <= ?t2
```

Querying with OFO

CQ6: What feedback is given to the properties related to a specific IEQ parameter?

SPARQL

```
SELECT ?database ?feedback ?dataPoint .
WHERE {
:ThermalComfortPropertySet ofo:containsProperty ?property .
?property ofo:hasFeedback / ofo:isFeedbackOf :JohnDoe .
?feedback ofo:hasResult ?dataPoint . }
```

SPARQL

```
SELECT ?database ?feedback ?dataPoint
WHERE {
:ThermalComfortPropertySet
ofo:containsProperty ?property .
?property ofo:hasFeedback ?feedback .
?feedback ofo:isFeedbackOf ?person .
```

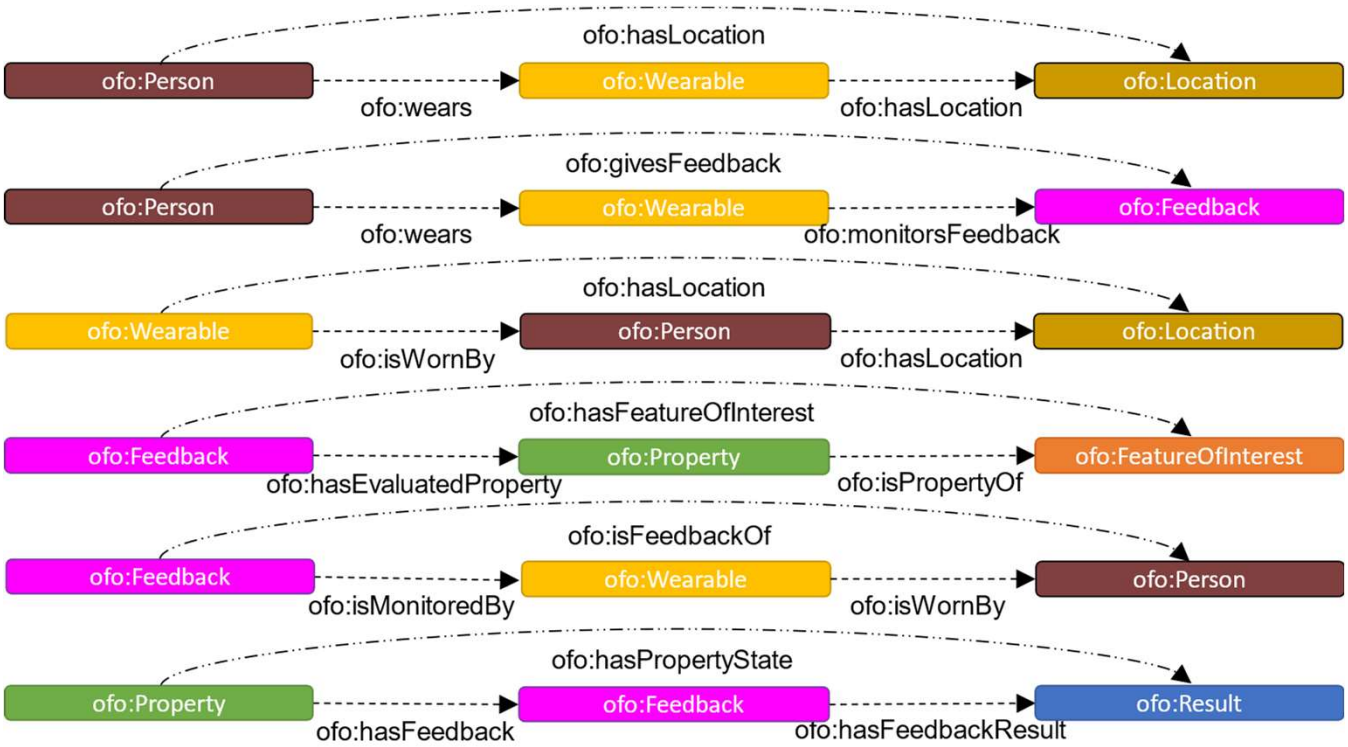
Querying with OFO

CQ7: What passive feedback is measured by the wearable during the active feedback of the occupant?

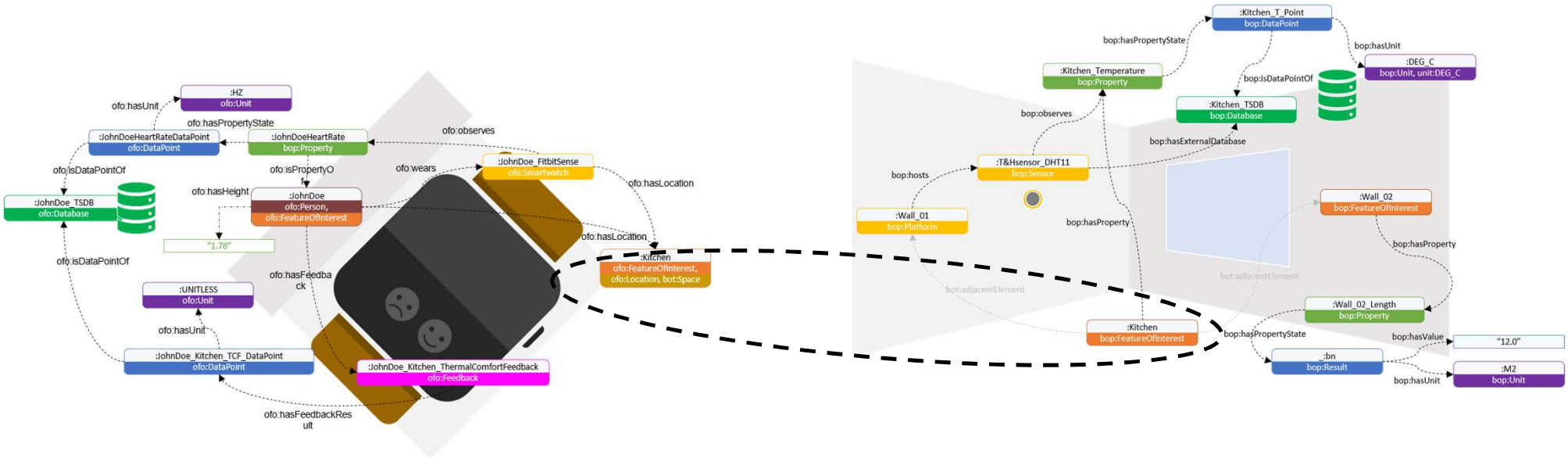
SPARQL

```
PREFIX ofo: <https://w3id.org/ofo#>
SELECT ?property ?dataPoint ?database
WHERE {
:ThermalComfortPropertySet ofo:containsProperty ?property .
{ ?property ofo:isPropertyOf :JohnDoe . }
UNION
{ ?property ofo:hasFeedback / ofo:isFeedbackOf :JohnDoe . }
?property ofo:hasResult ?dataPoint . }
```

Property chains



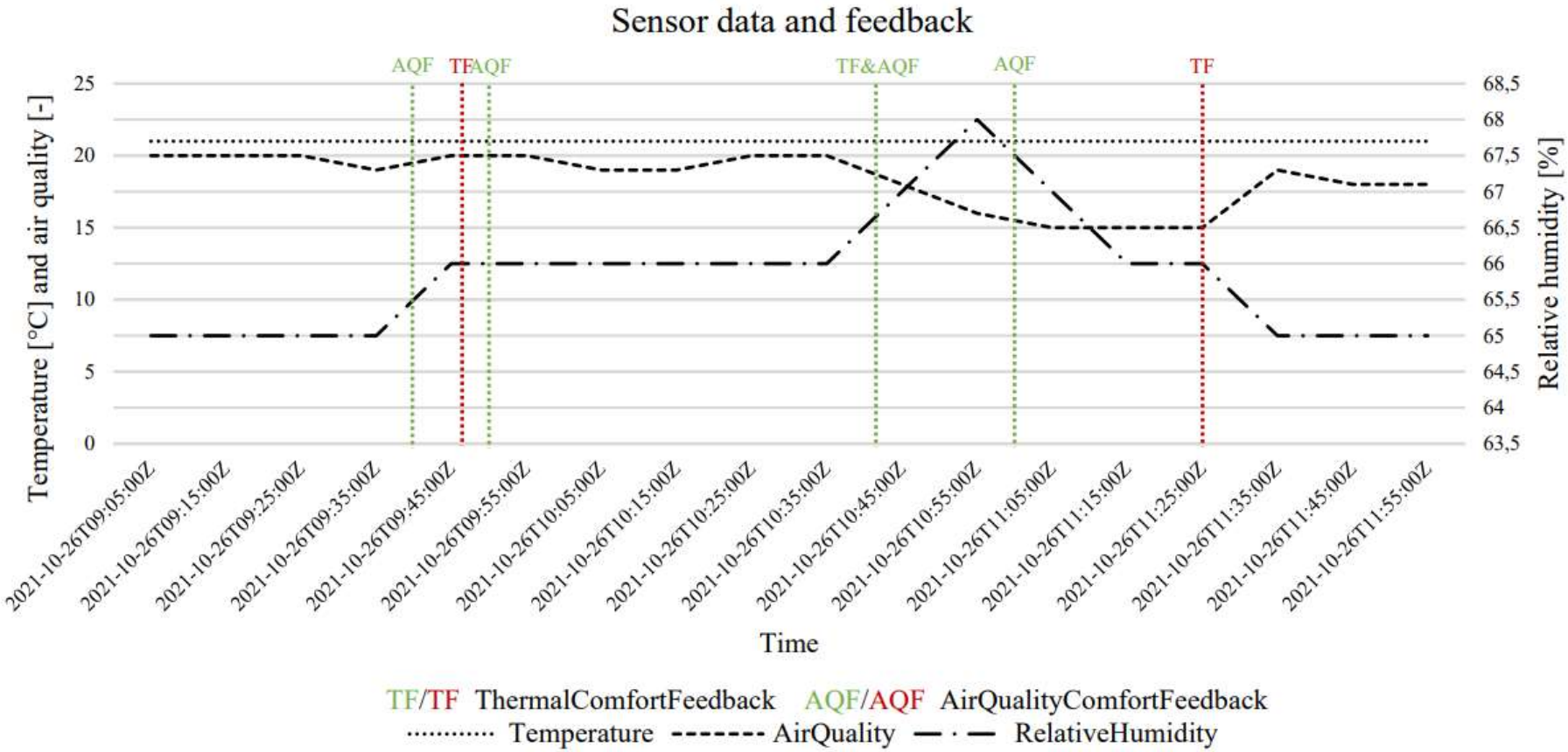
Integrating feedback and LBD



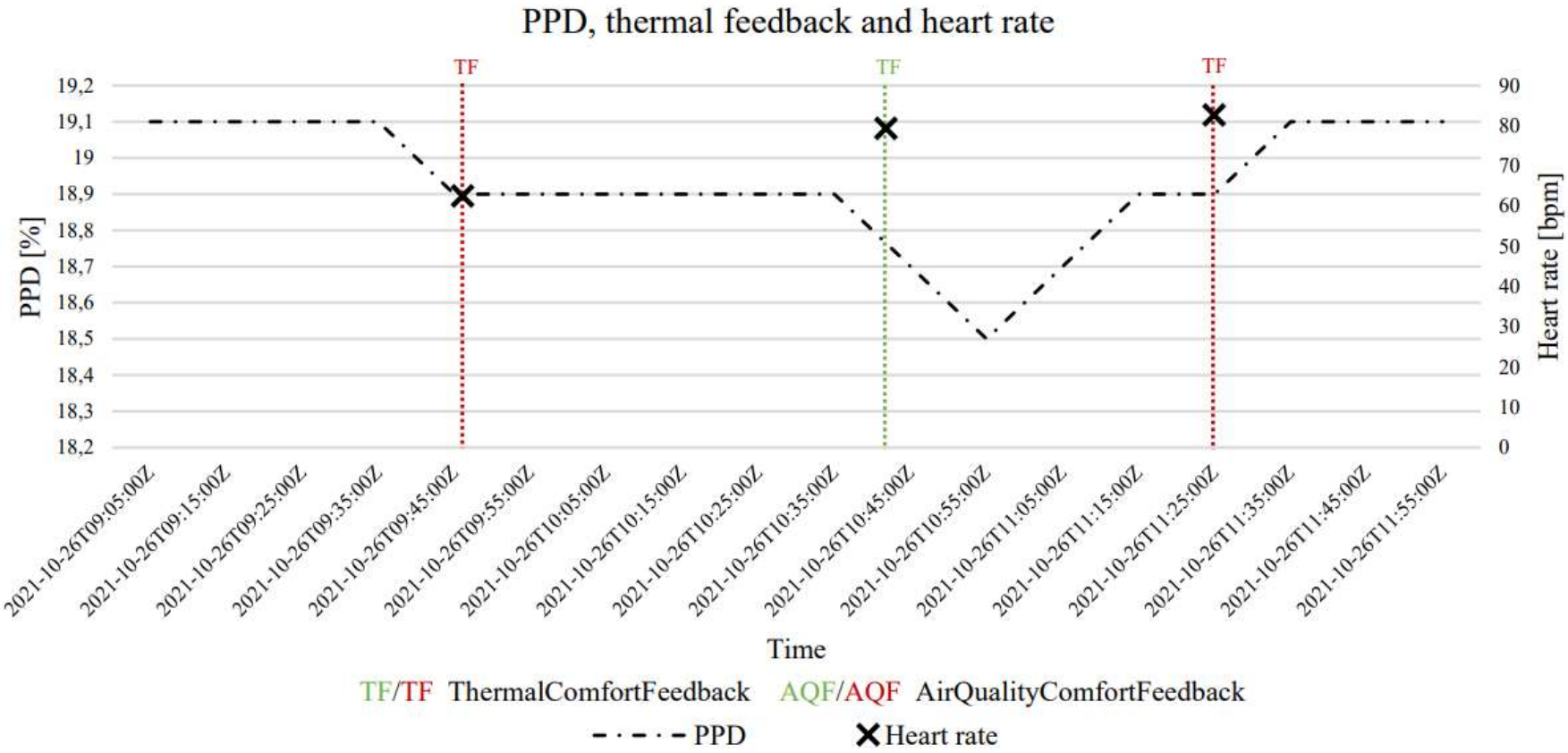
Perceived building performance

Measured building performance

What can it do?

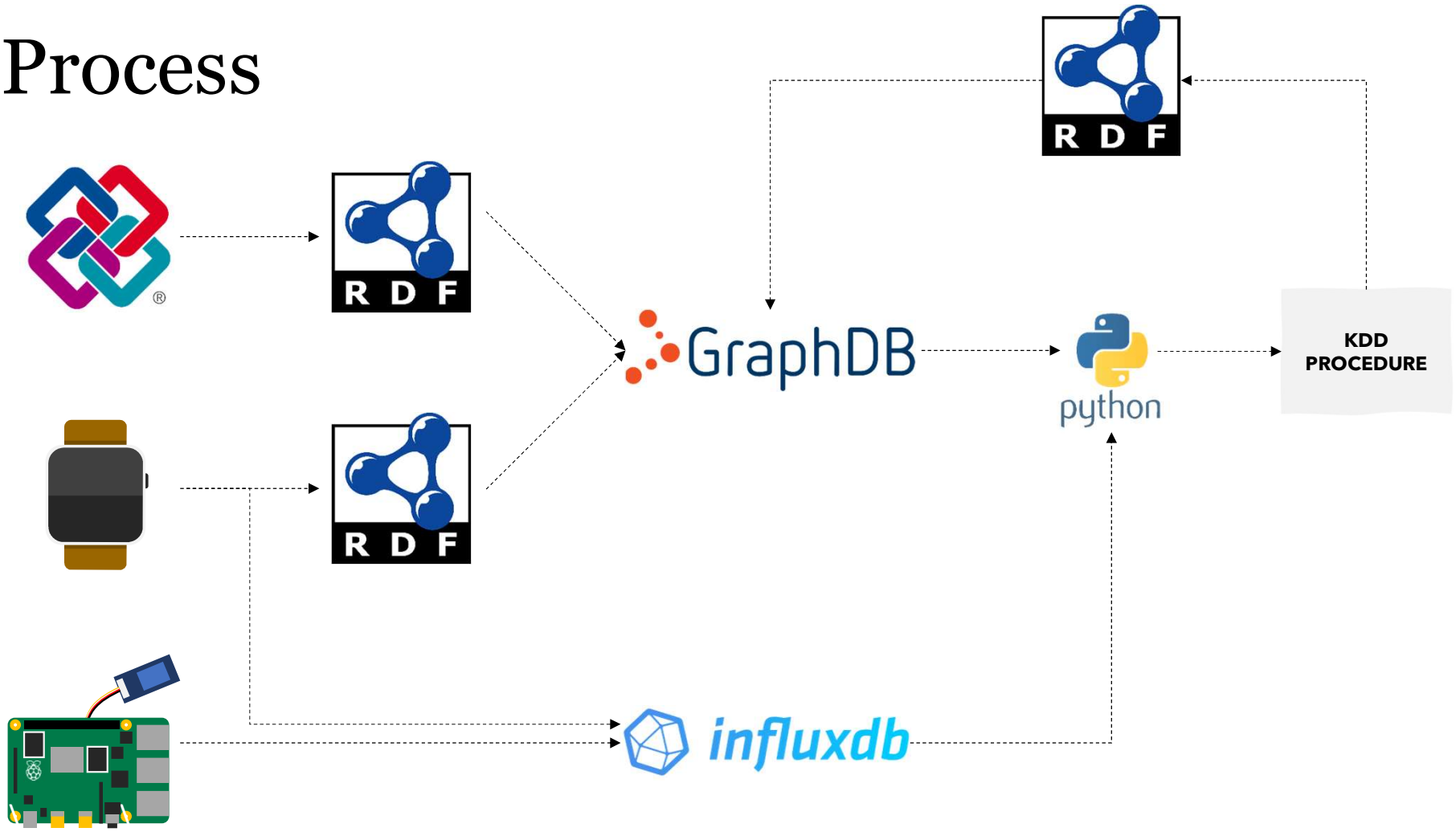


What can it do?



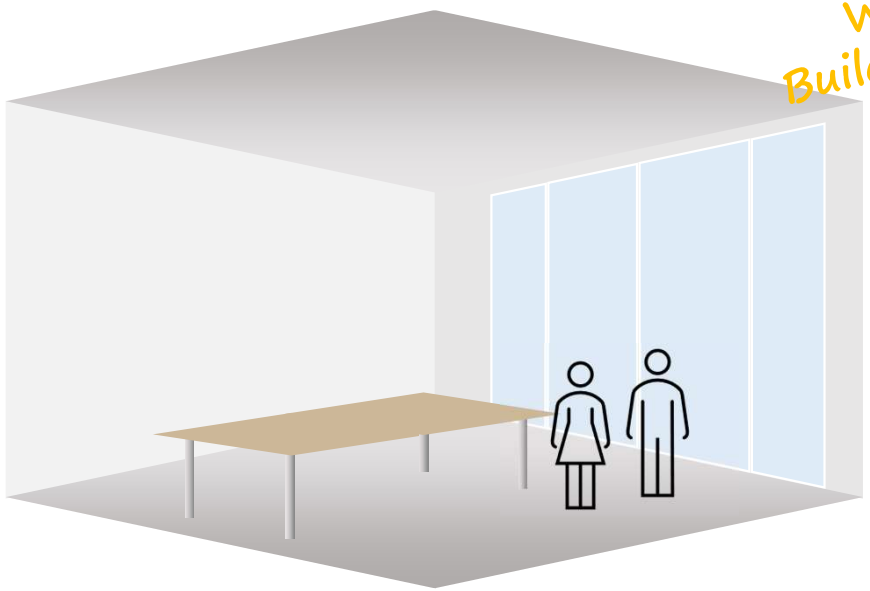
How to create parallel intelligence?

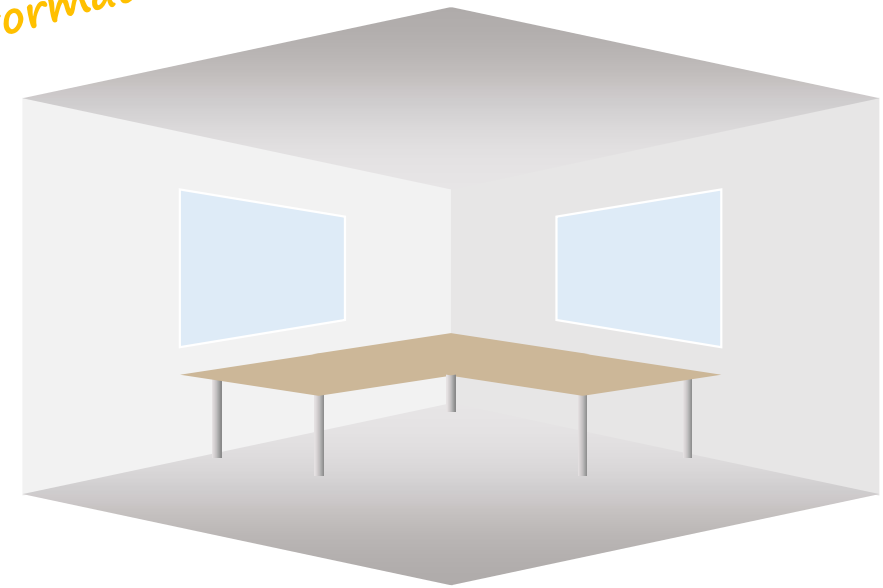
Process



Case study 1

3 weeks
2 occupants
Feedback
Sensor data
Weather data
Building information



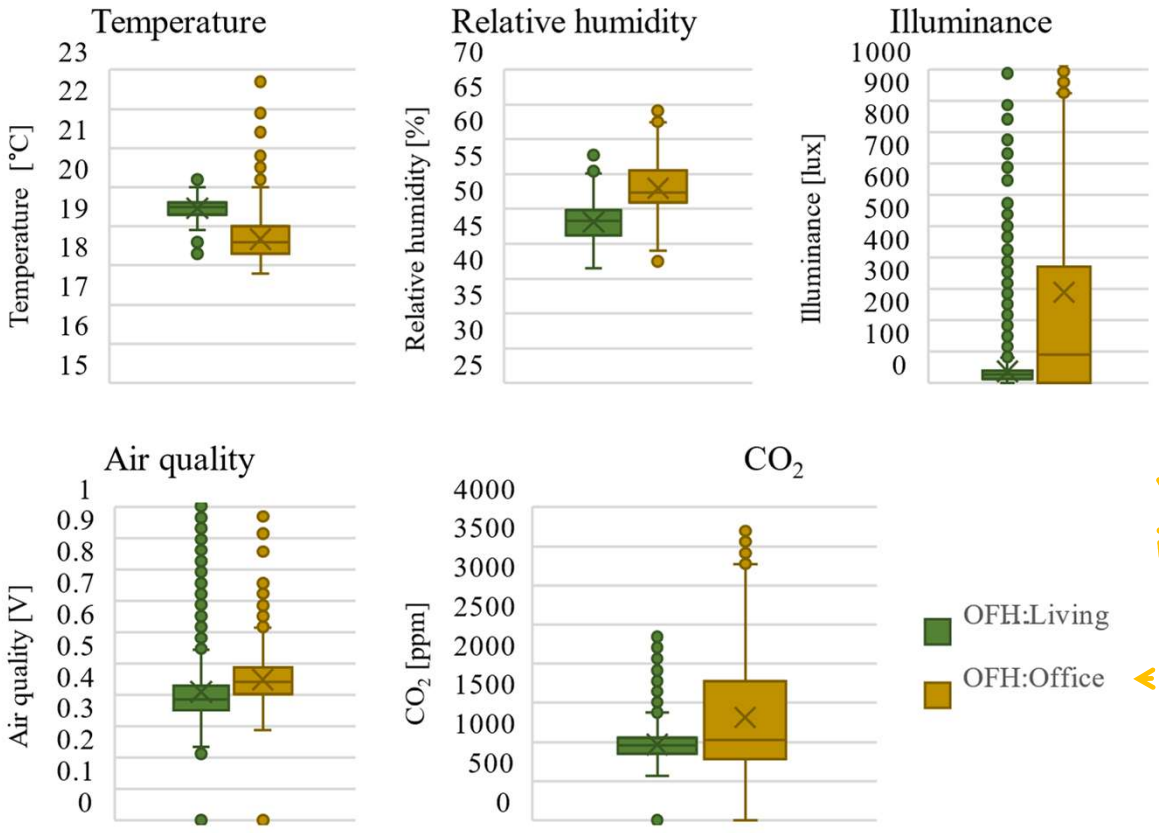


Living room

Office space

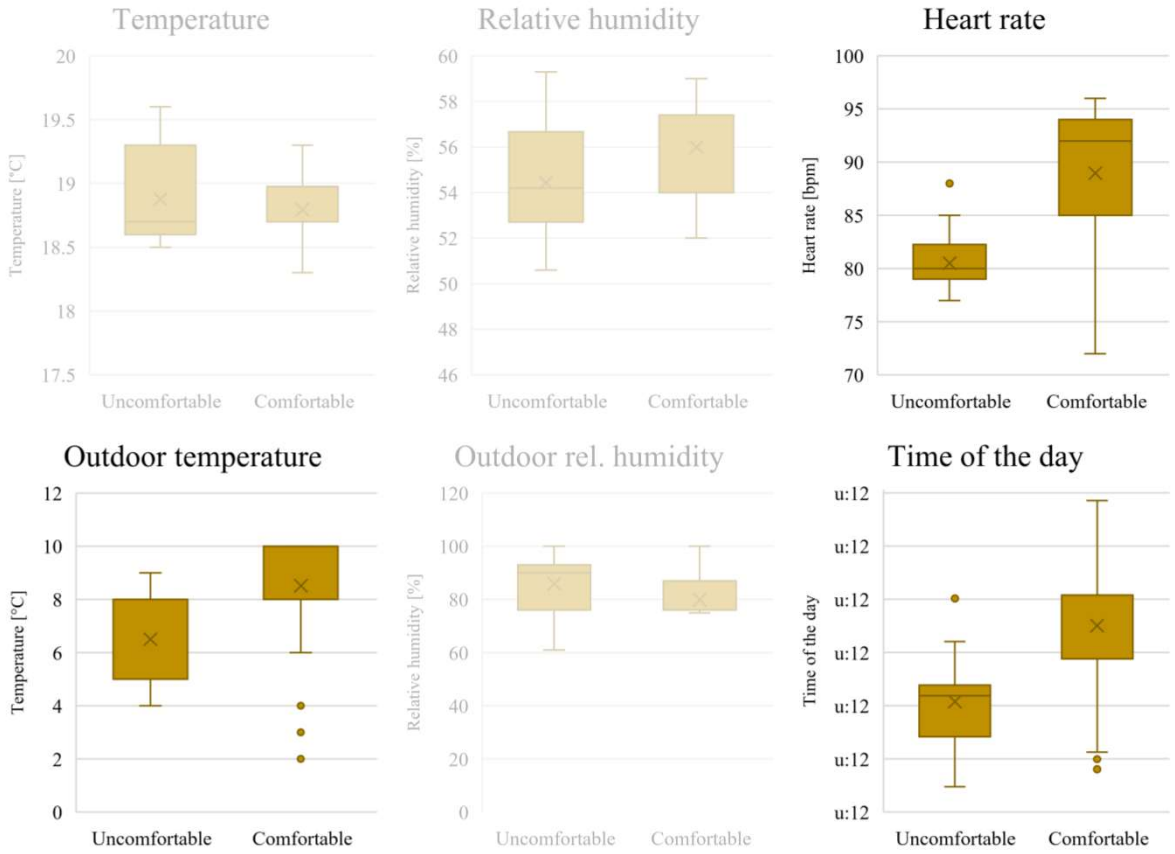
time;		ch-001;	ch-002; …;	ch-020;	weather;	outdoor te
23-1-2022	17:45:00	48.85;	1.15;	2.422;	Overcast;	4;

Case study 1: Comparing IEQ performance

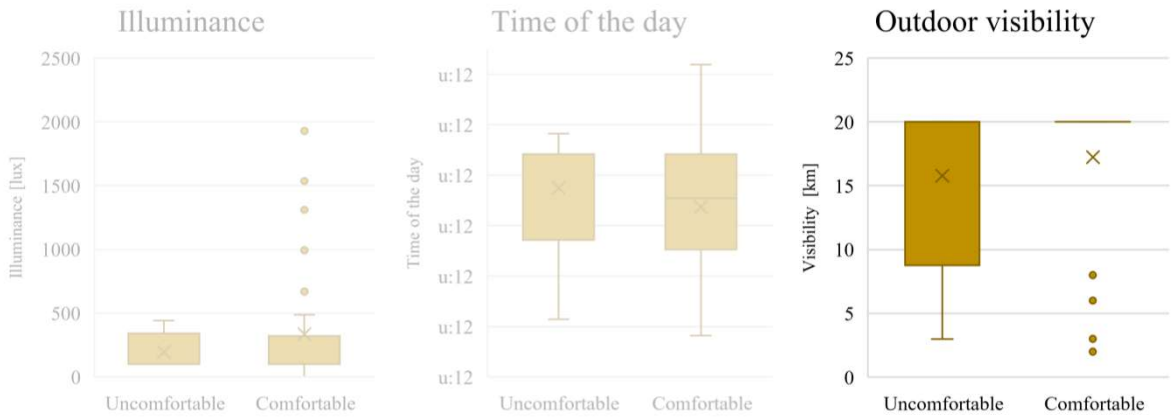


We can compare individual building parameters as well

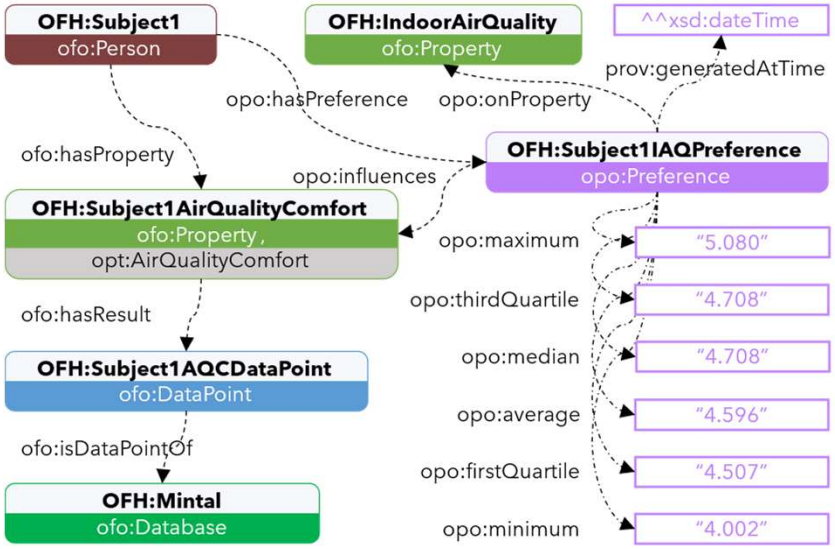
Case study 1: Individual thermal comfort



Case study 1: Individual visual comfort

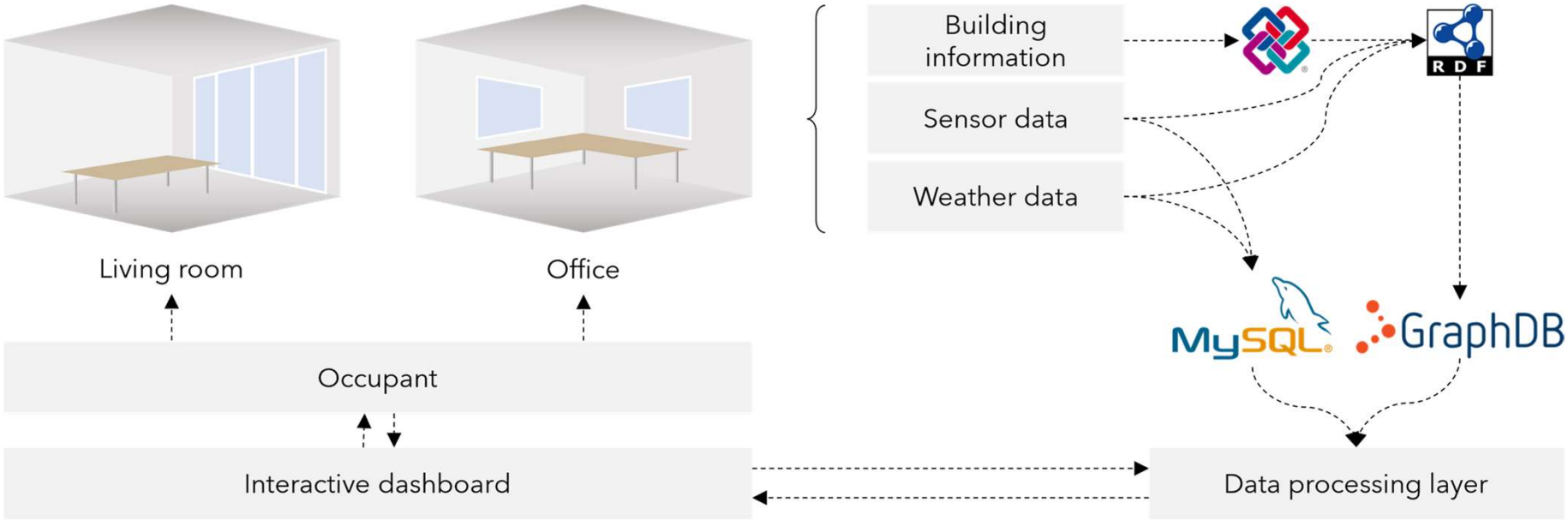


Case study 1: Knowledge integration




```
PREFIX OFH: <https://github.com/AlexDonkers/OpenFamilyHome#>
PREFIX opo: <https://alexdonkers.github.io/opo#>
PREFIX prov: <http://www.w3.org/ns/prov#>
SELECT ?firstQuartile ?thirdQuartile
WHERE { OFH:Subject1 opo:hasPreference ?preference .
?preference opo:onProperty OFH:IndoorAirQuality .
?preference prov:generatedAtTime ?time .
?preference opo:firstQuartile ?firstQuartile .
?preference opo:thirdQuartile ?thirdQuartile . }
ORDER BY DESC(?time) LIMIT 1
```

Case study 2

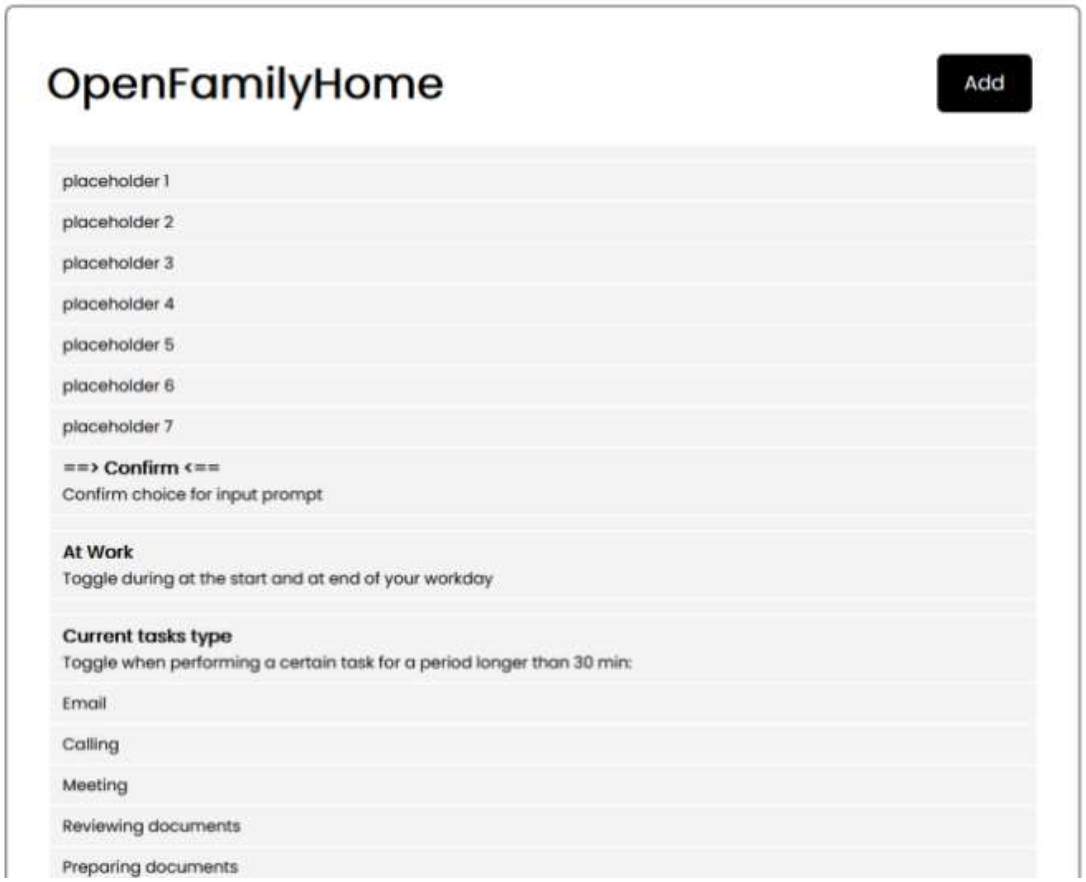

Building information
Sensor data
Weather data
RDF
Living room
Office
MySQL
GraphDB
Occupant
Interactive dashboard
Data processing layer

Case study 2: The interactive dashboard

TIPS
pop up when the measured value of a parameter exceeds predefined threshold values.

DIRECT FEEDBACK
can be given at any time to comment on the current state of a parameter (negative, neutral, or positive tag)

MICROSURVEYS
the dashboard actively asks the occupant to give feedback on random parameters to reduce bias



Case study 2: Equation

$$P_{p,o,i,d} = P_{p,o,i,d-1} + G_{p,o}\left(\frac{\Sigma_{t=0}^{n} M_{p,t} + F_{p,o,i,t} * c_{cat}}{n} - P_{p,o,i,d-1}\right) + H_{o,d} - H_{o,d-1}$$

Preferred value

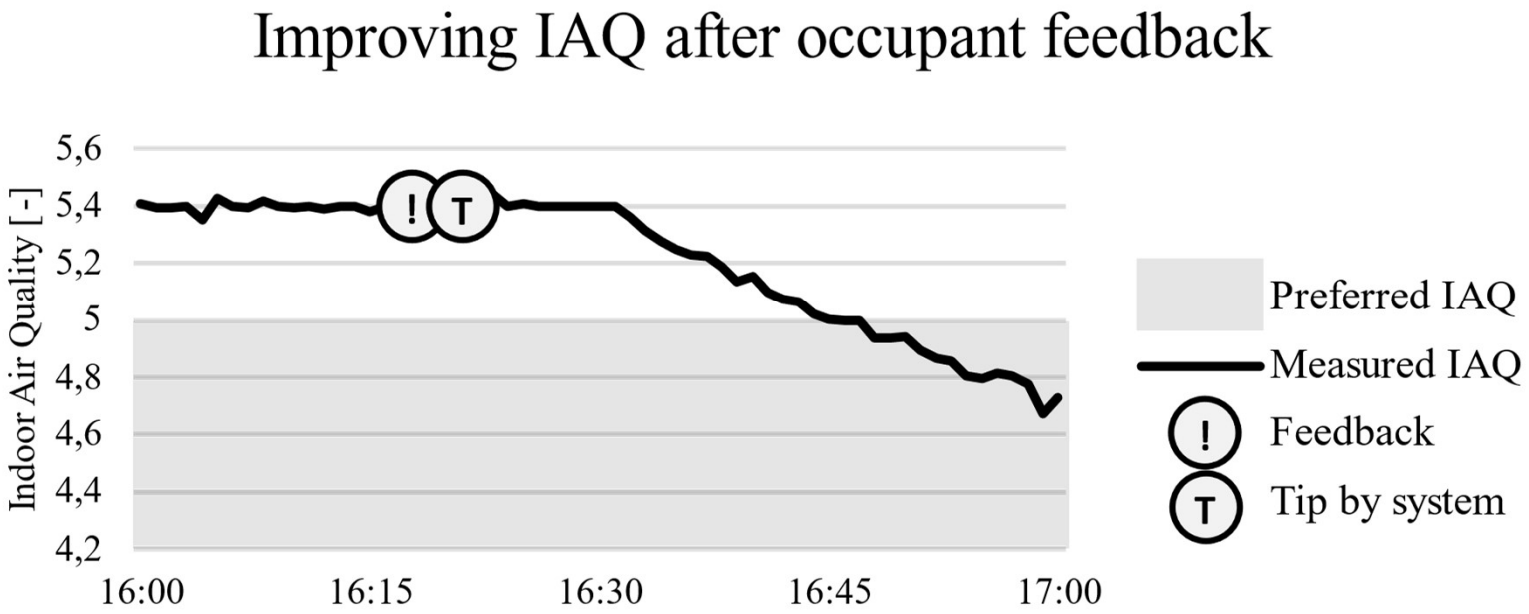
Old preferred value

Measured value

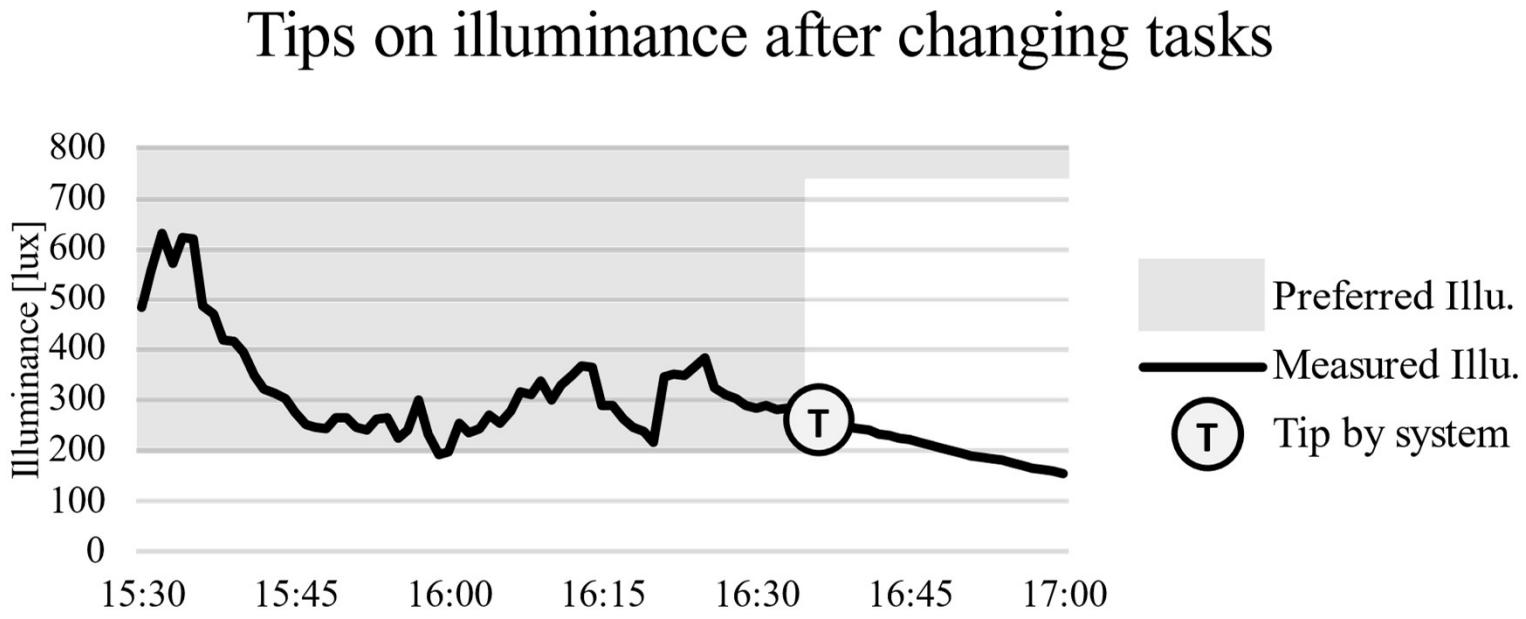
Feedback on value

Health correction

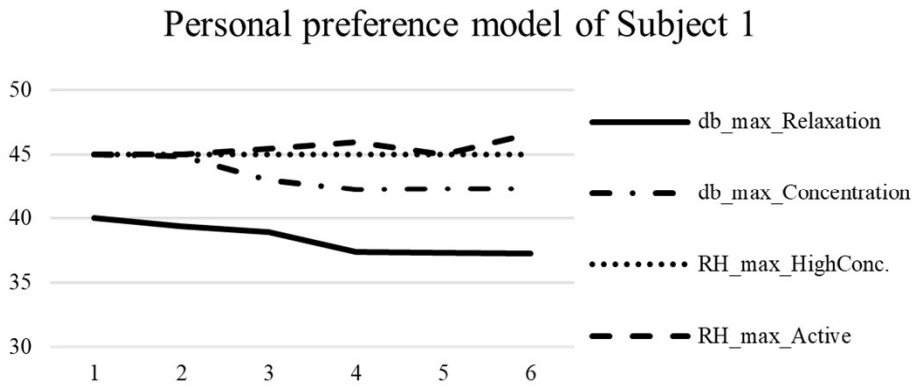
Case study 2: Results

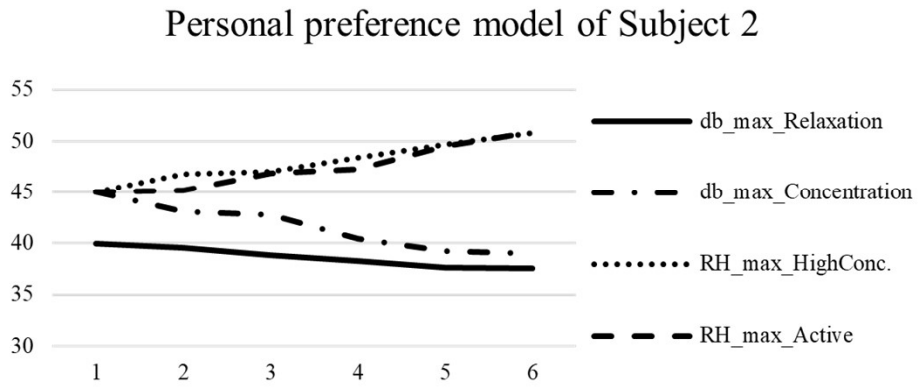


Case study 2: Results

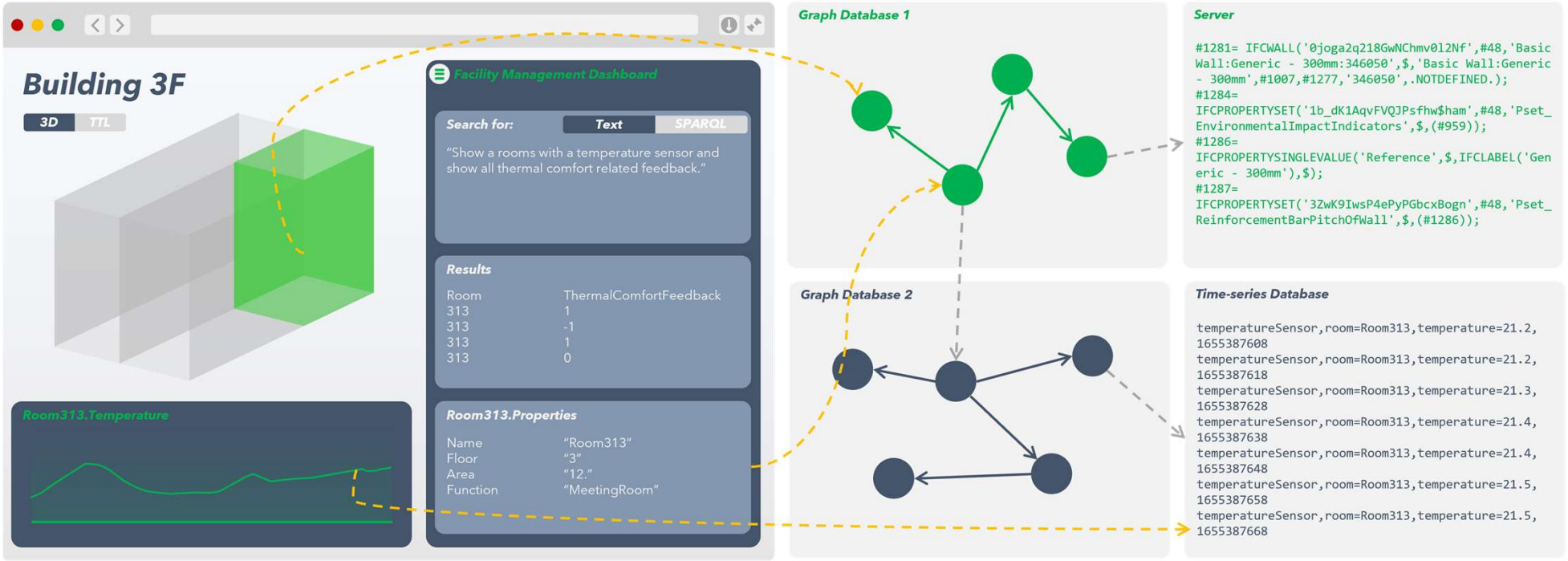


Case study 2: Personal preference models





Current work


Building 3F
3D
TTL
Facility Management Dashboard
Search for:
Text
SPARQL
"Show a rooms with a temperature sensor and show all thermal comfort related feedback."
Results
Room ThermalComfortFeedback
313 1
313 -1
313 1
313 0
Room313.Temperature
Room313.Properties
Name "Room313"
Floor "3"
Area "12."
Function "MeetingRoom"
Graph Database 1
Graph Database 2
Server
#1281= IFCWALL('0joga2q218GwNChmv0l2Nf',#48,'Basic Wall:Generic - 300mm:346050',$,'Basic Wall:Generic - 300mm',#1007,#1277,'346050',.NOTDEFINED.);
#1284= IFCPROPERTYSET('1b_dK1AqvFVQJPsfhw$ham',#48,'Pset_EnvironmentalImpactIndicators',$,(#959));
#1286= IFCPROPERTYSINGLEVALUE('Reference',$,IFCLABEL('Generic - 300mm'),$);
#1287= IFCPROPERTYSET('3ZwK9IwsP4ePyPGbcxBogn',#48,'Pset_ReinforcementBarPitchOfWall',$,(#1286));
Time-series Database
temperatureSensor,room=Room313,temperature=21.2, 1655387608
temperatureSensor,room=Room313,temperature=21.2, 1655387618
temperatureSensor,room=Room313,temperature=21.3, 1655387628
temperatureSensor,room=Room313,temperature=21.4, 1655387638
temperatureSensor,room=Room313,temperature=21.4, 1655387648
temperatureSensor,room=Room313,temperature=21.5, 1655387658
temperatureSensor,room=Room313,temperature=21.5, 1655387668

LBD viz

OPEN FLAT

Options –

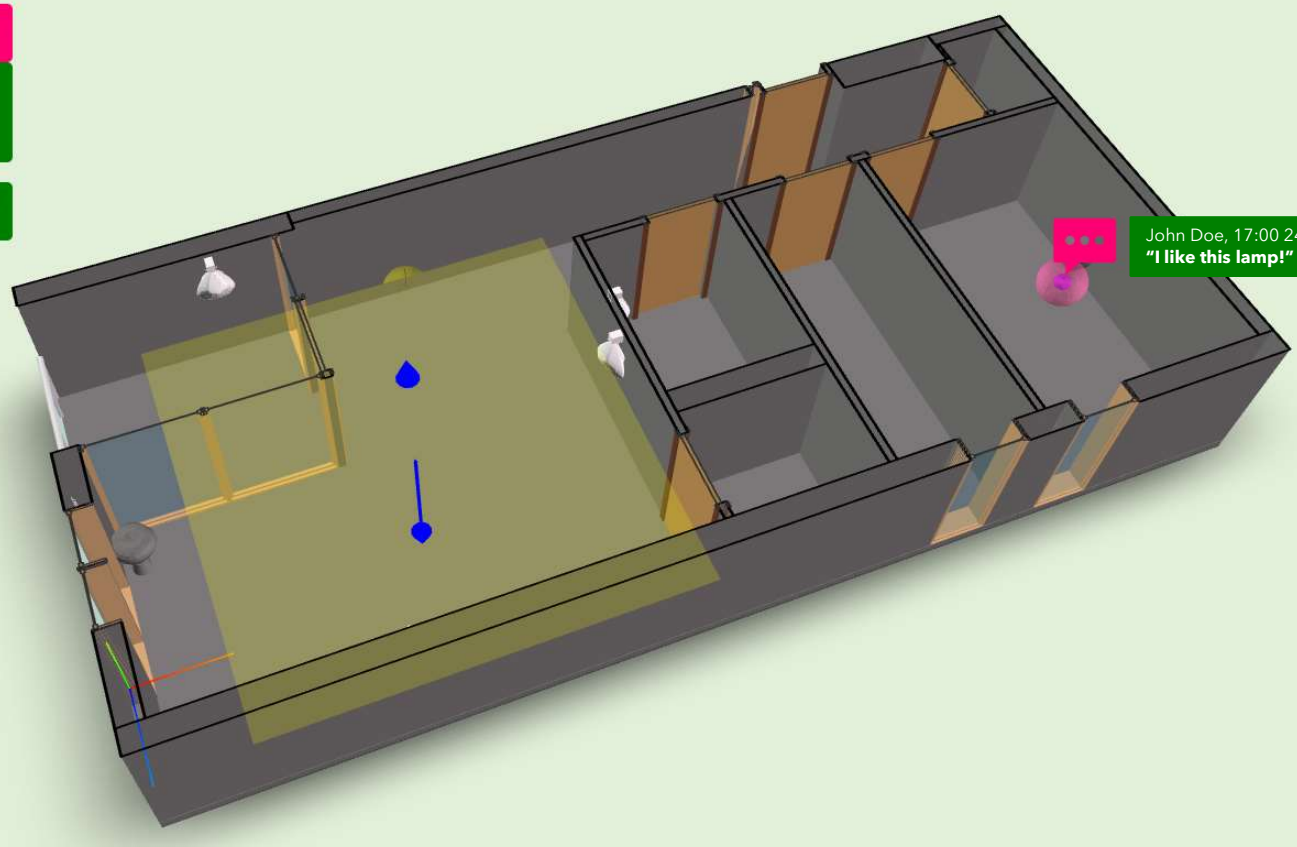
Load IFC | Crop model | Measure

Queries –

Find | SPARQL | Graph locator

Find all feedback

Results +

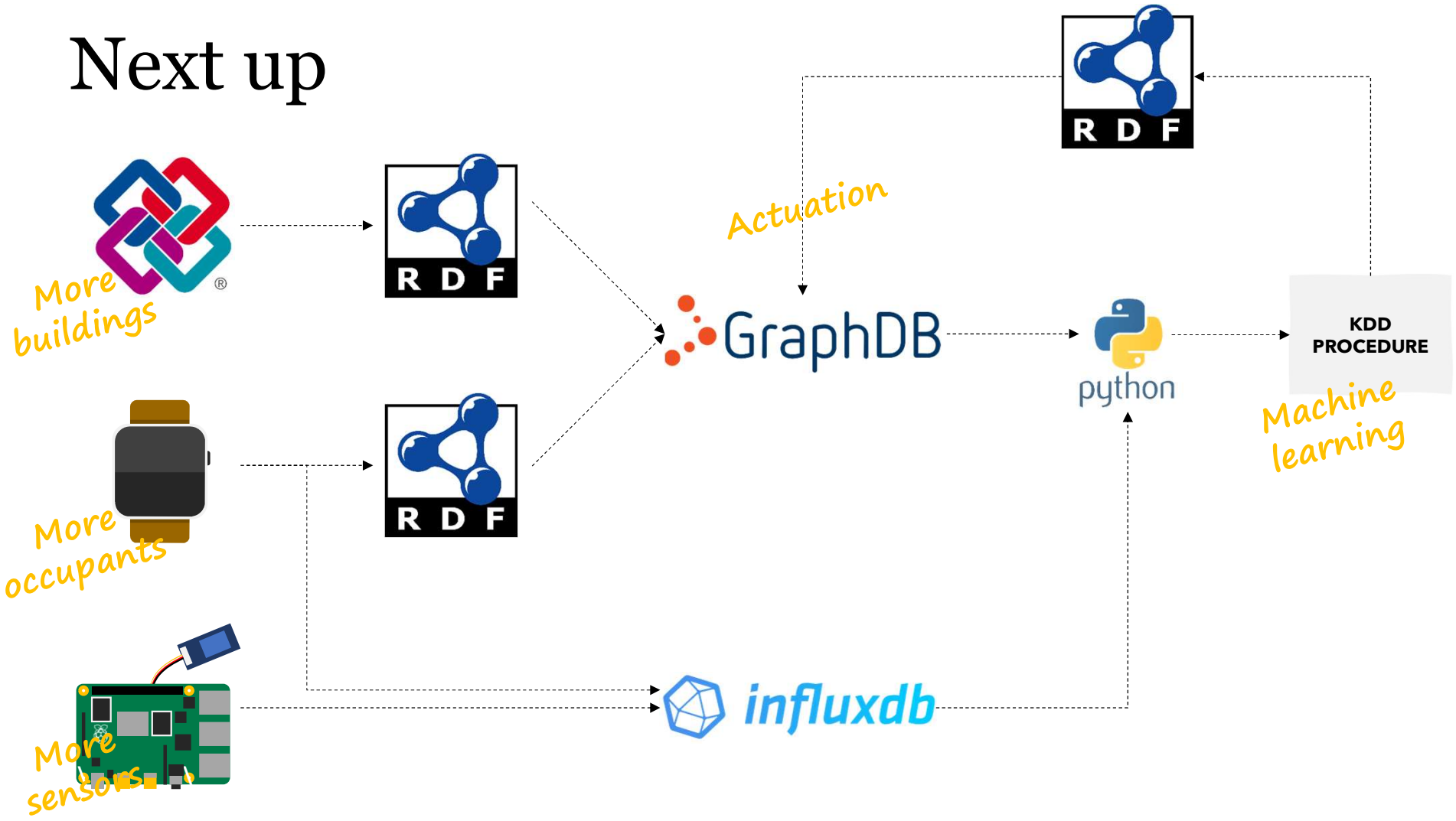


John Doe, 17:00 24-06-2022
"I like this lamp!"

BY ALEX DONKERS

TU/e kpn

Next up


More buildings
More occupants
More sensors
RDF
RDF
RDF
Actuation
GraphDB
python
KDD PROCEDURE
Machine learning
influxdb

Resources!

Ontologies
BOP: https://w3id.org/bop
OFO: https://w3id.org/ofo

Open data
Open smart home: https://github.com/AlexDonkers/ofo/tree/main/docs/OpenSmartHome
Open flat: https://github.com/AlexDonkers/ofo/tree/main/docs/OpenFlat
Open family home: on github soon

Papers
Real-Time Building Performance Monitoring using Semantic Digital Twins: http://ceur-ws.org/Vol-3081/05paper.pdf
Knowledge Discovery Approach to Understand Occupant Experience in Cross-Domain Semantic Digital Twins: https://linkedbuildingdata.net/ldac2022/files/papers/paper07.pdf
Linked Data for Smart Homes: Comparing RDF and Labeled Property Graphs: http://ceur-ws.org/Vol-2636/02paper.pdf
Creating Occupant-Centered Digital Twins Using the Occupant Feedback Ontology Implemented in a Smartwatch App [under review]: http://www.semantic-web-journal.net/system/files/swj3158.pdf
Parallel Intelligence in Semantic Digital Twins: An Interactive Decision-Support System for Indoor Comfort: email for pre-print
Automated safety checking in subway construction via semantic web technology and building information modeling [accepted]: Automation in Construction, soon online

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smart TWO
kpn