Integrating Human Needs and Digital Transformation of Building Automation with Artificial Intelligence

dr. ir. Shalika Walker (Kropman B.V., TU/e)
ir. Karzan Mohammed (TU/e)

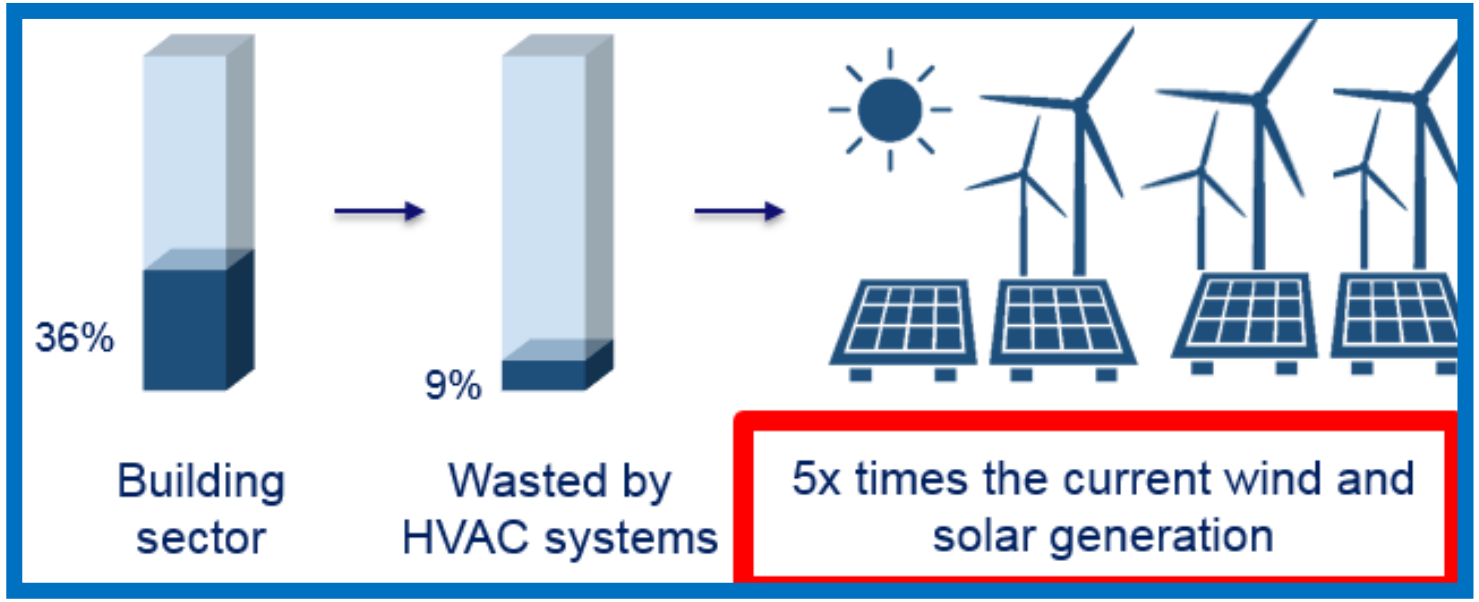
TVVL KENNISPARTNERS

Why transformation is necessary?

- Buildings must become more sustainable (legislation)
- Buildings are becoming increasingly complex → Introduction of new energy systems
- Energy GAP: design < actual energy use
- Existing buildings are the largest group, but also the most difficult
- Occupants are not satisfied
- Current and future lack of skilled personnel

To put that into perspective for NL

That is why we need:
Knowledge, innovation and use of data

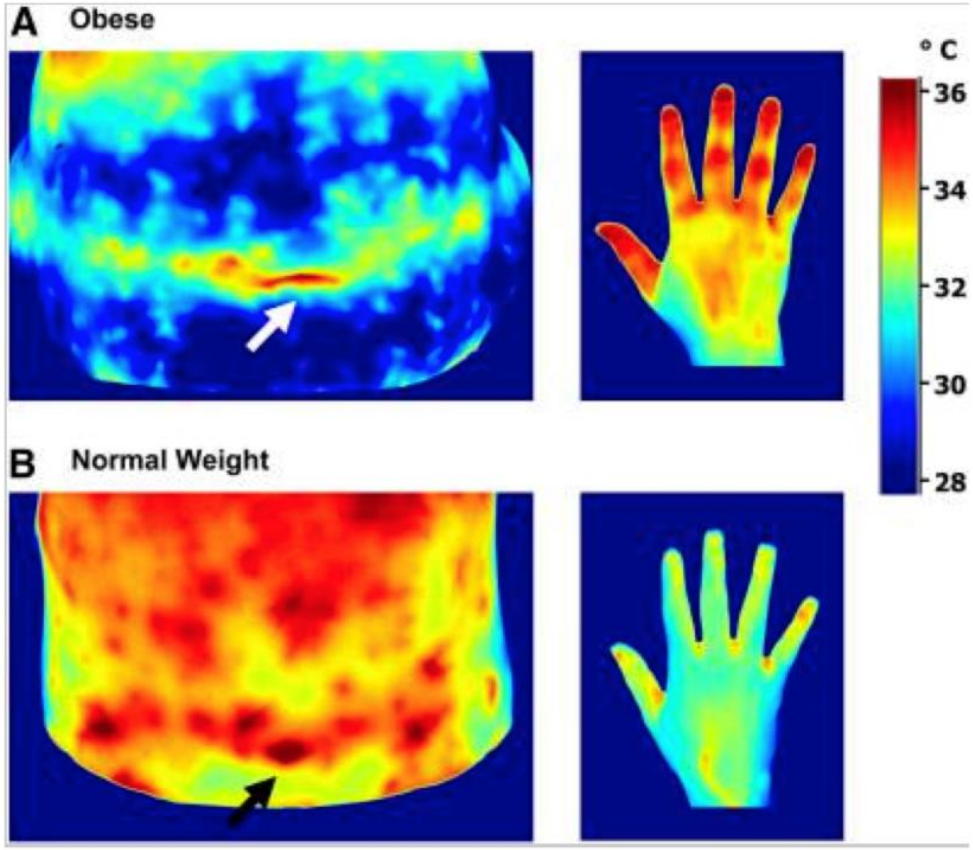


According to statistics from 2021

Human-in-the-loop?

Moreover, energy wastage because of mismatch with user preferences:

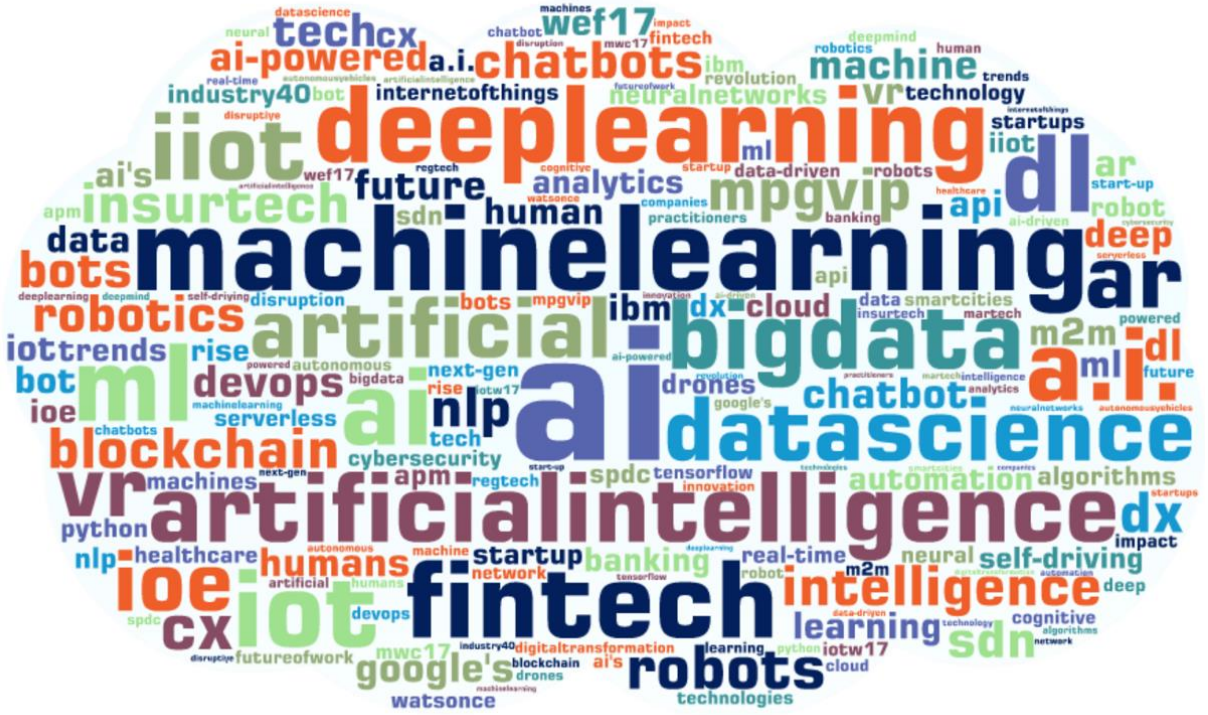
- Large inter-individual differences
- Dissatisfaction & Complaints



Ref: Savastano et al., AJCN 2009

AI and ML for the future?

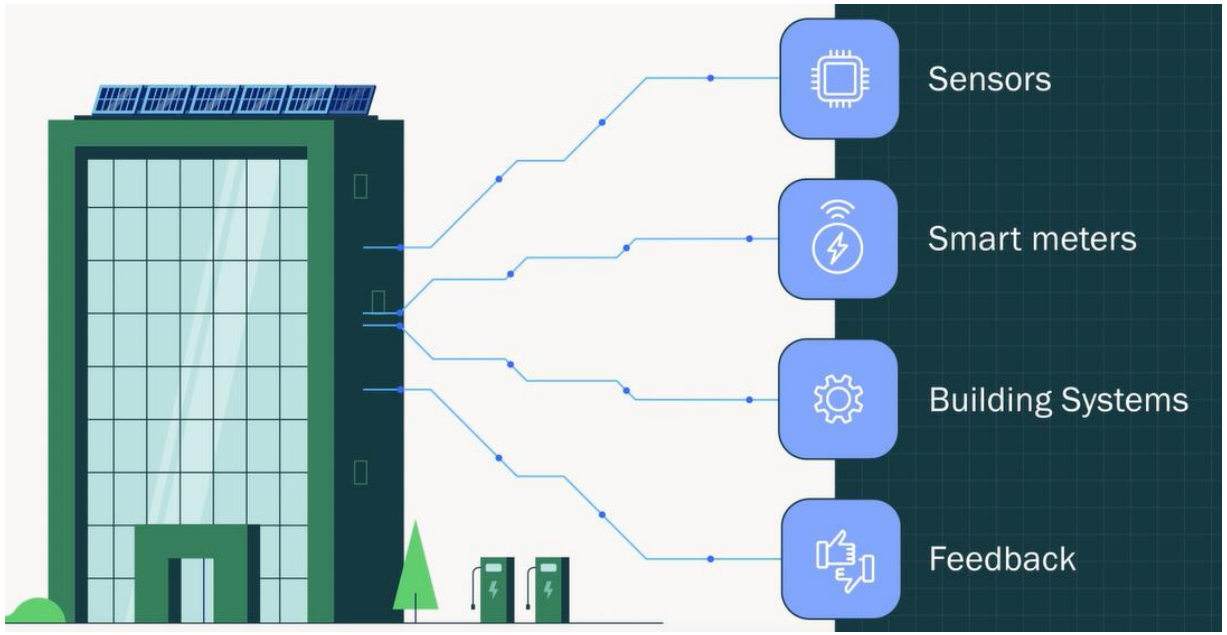
- Can integrating AI and digital transformation address the problems that we have?



Ref: www.vinodsblog.com

Brains4Buildings

- **39 project partners**
- **Empowering utility buildings with brains**



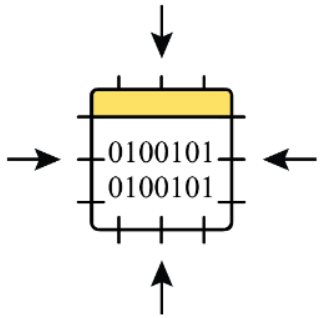
Utilize big data from smart meters, building management systems and the Internet of Things devices

Ref: https://brains4buildings.org/

- Develop methods to reduce energy consumption, increase comfort, respond flexibly to user behavior and local energy supply and demand, and save on installation maintenance costs

Integrating Human Needs and Digital Transformation of Building Automation

Fault detection and diagnosis – Smart maintenance



Data integration - Smart communication

Smart Maintenance

What is smart maintenance in this context?

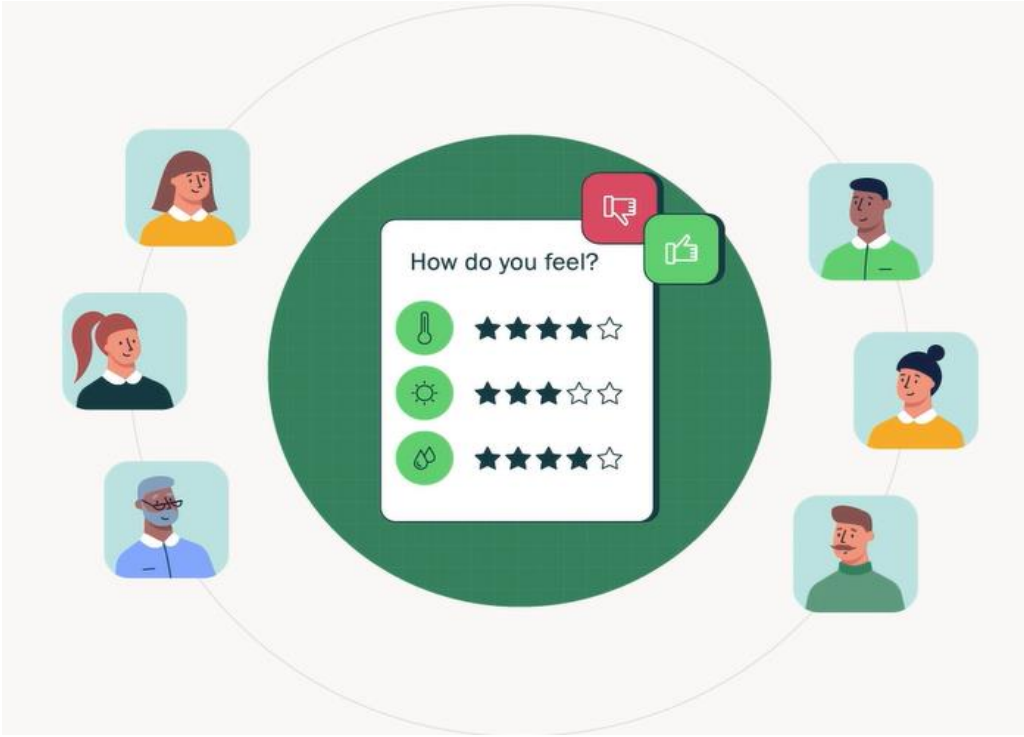
- Automated fault detection and diagnosis systems using machine learning
- Early detection of faults → Reduce energy wastage

Important aspects

Low-cost sensor performance

Ref: https://doi.org/10.1016/j.envint.2022.107372

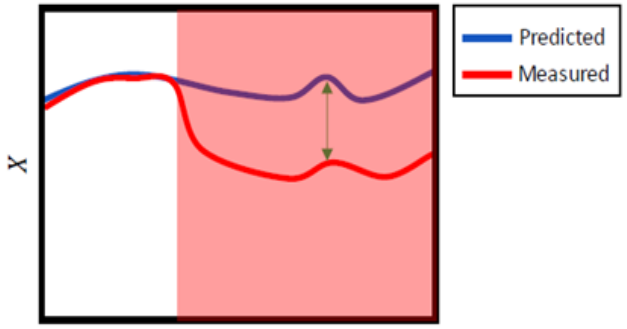
Feedback from users



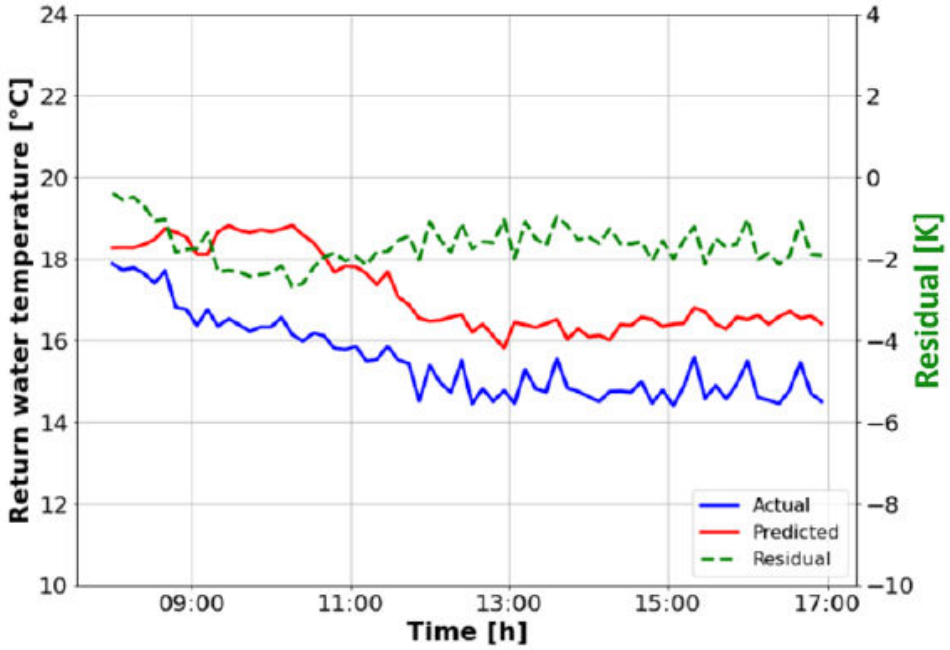
Ref: https://brains4buildings.org/

Machine learning

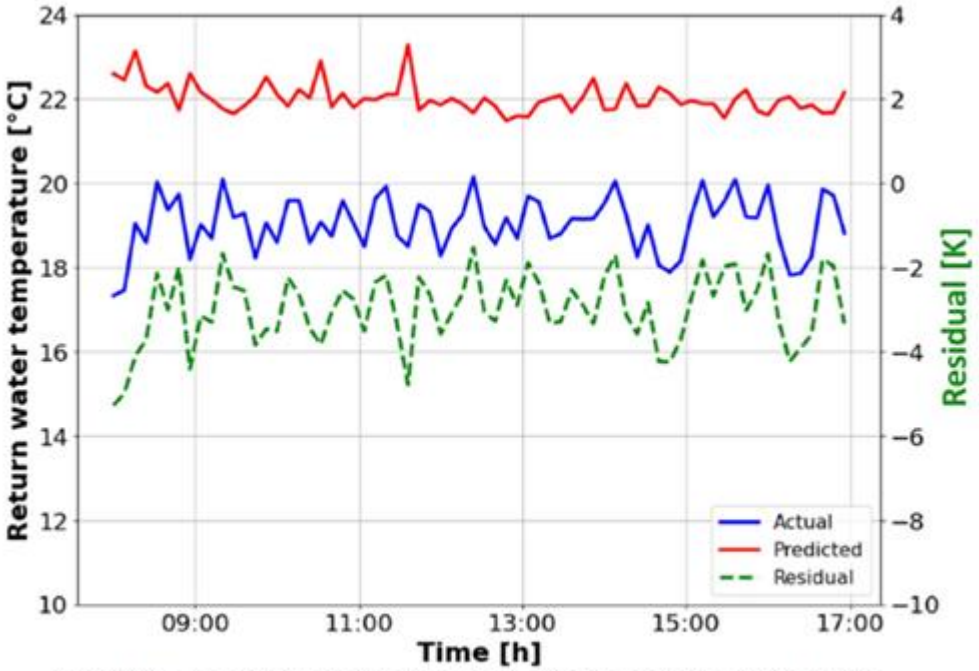
Fault Detection - Example



Variable prediction



Fault-free prediction (9 hours) using ML model

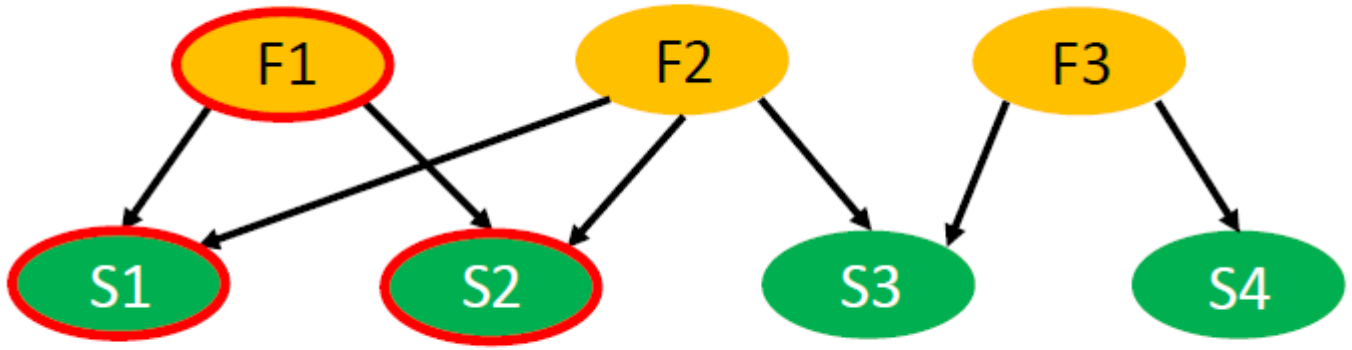


Fault–free prediction of return water temperature during 50% stuck valve fault

Ref: In Proceedings Clima 2022 (pp. 1-8)

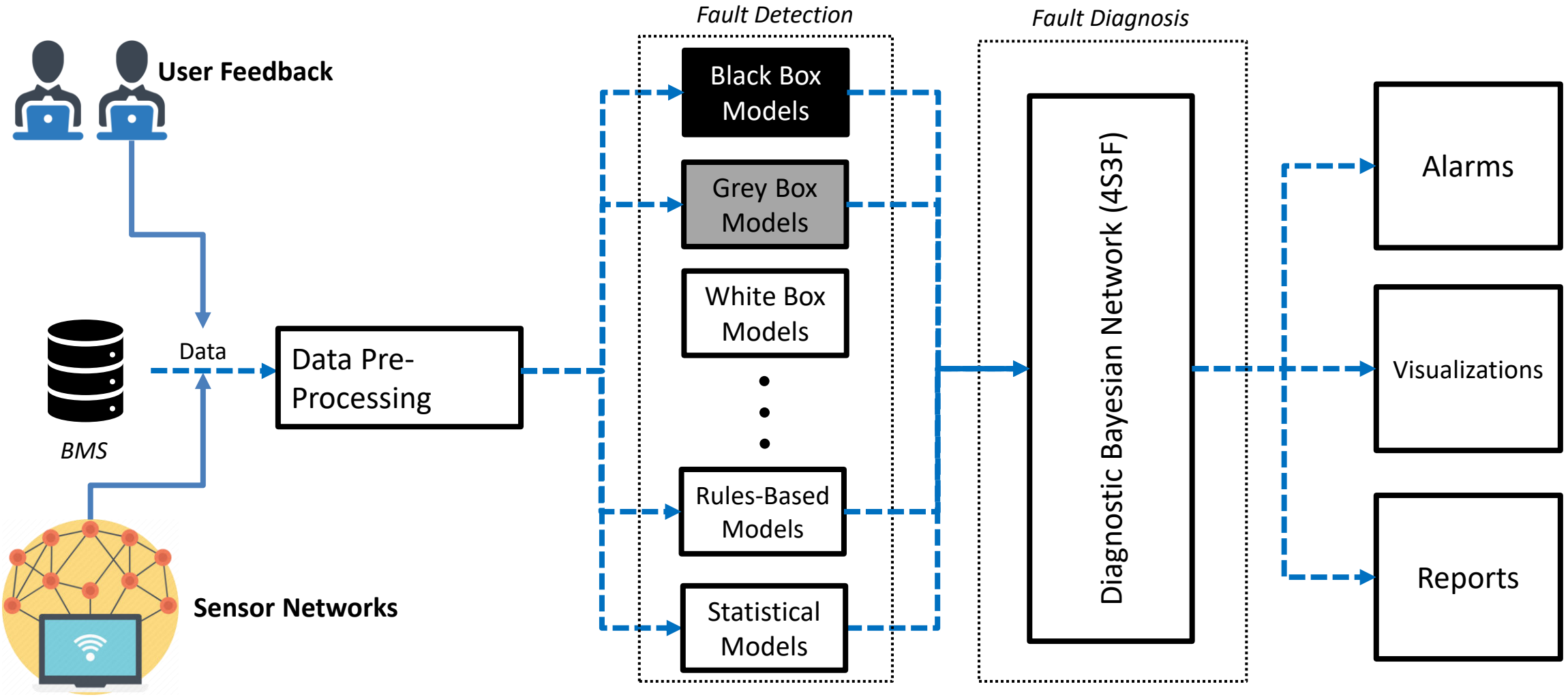
Fault Diagnose

- **Bayesian Network – Using P&ID**
- **For different types of sensor networks – Sensor rich to sensor poor**



Diagnostic Bayesian Network (4S3F)

Overview: Fault Detection & Diagnosis Method



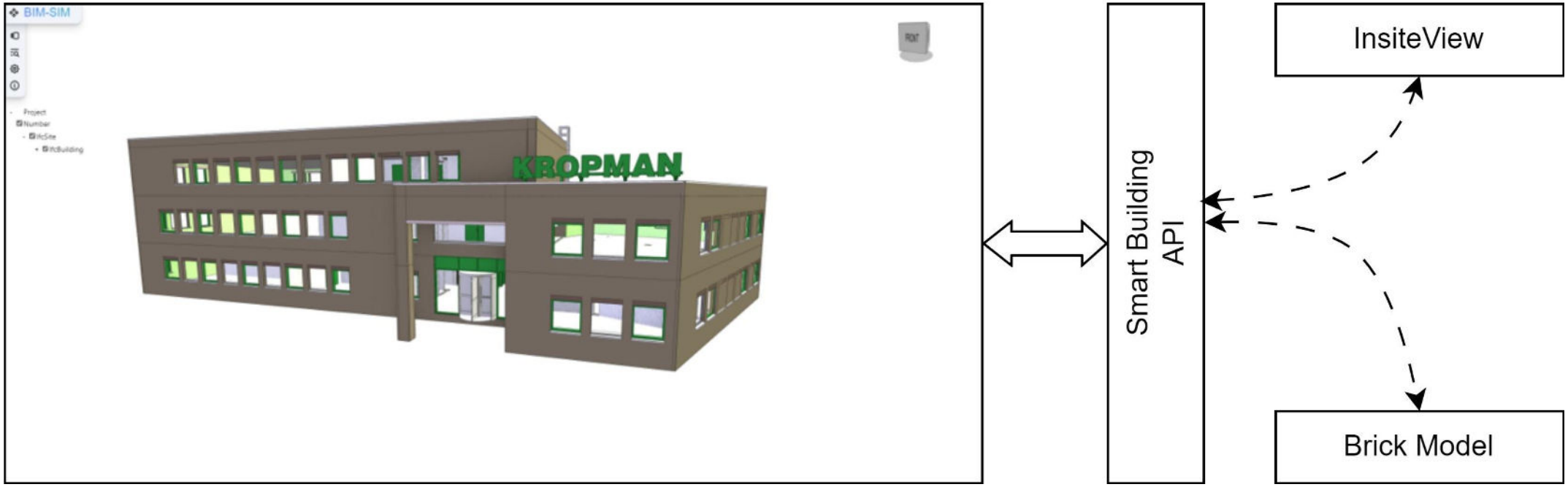
Ref: Adapted based on Thamban (2022): TVVL Presentation

Data Integration

Ref: https://doi.org/10.34641/clima.2022.228

- Standardized ways to connect data sources
- Digital-twin concept (InsiteView + Brick + BIM Integration)
- Vision → Use of Virtual Reality / Augmented Reality

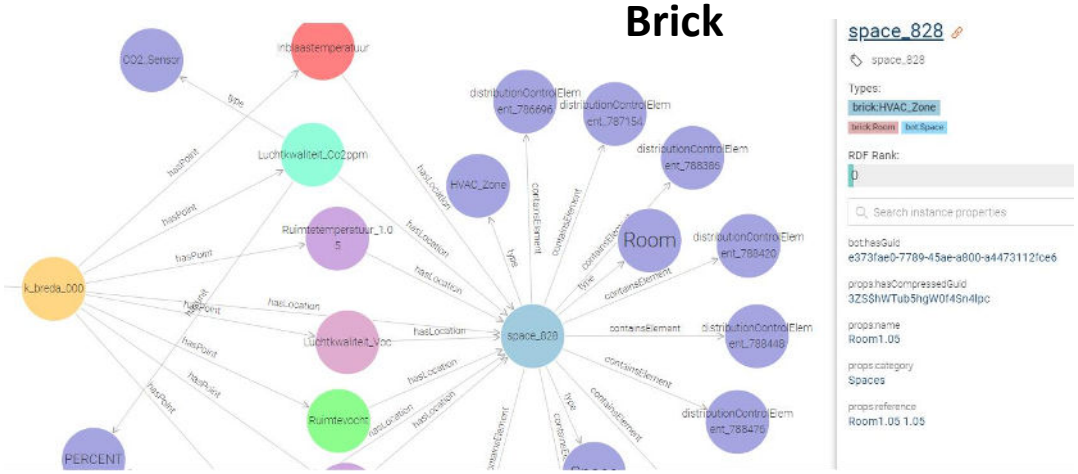
Digital Twin



Digital-Twin Implementation

Building Information Model (BIM)

Brick



Insite-view

GET	`/insite-view`	Returns a list of allocated insiteView rpc calls for a user
GET	`/insite-view/realtimedata/ref`	Returns real-time data of a data point by point ref
GET	`/insite-view/historicaldata/ref`	Returns historical data of a data point by point ref
POST	`/insite-view/realtimedata/guid`	Returns real-time data of a data point by point Ifc Guid

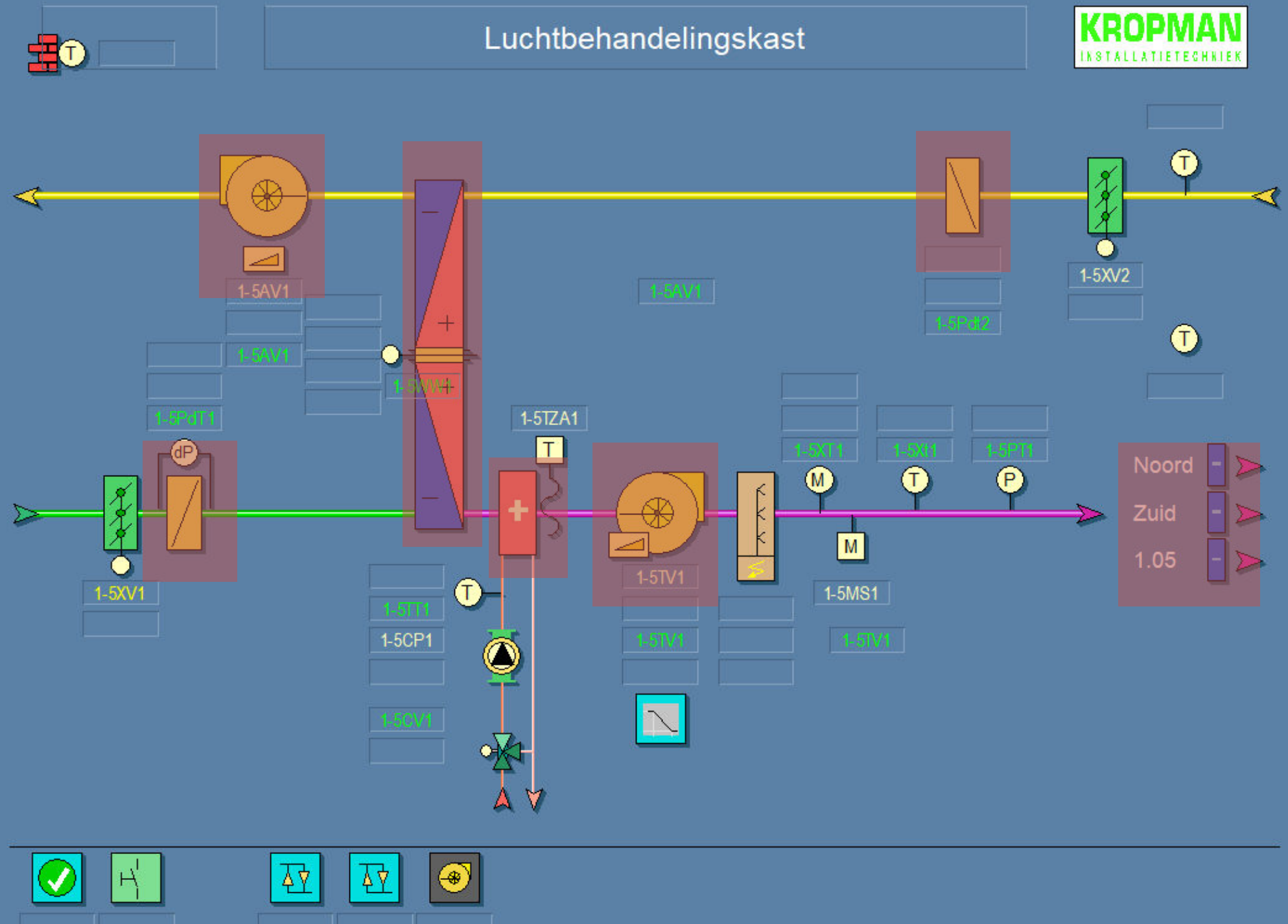
Theory in Practice
Implementation at Living Lab

Overview

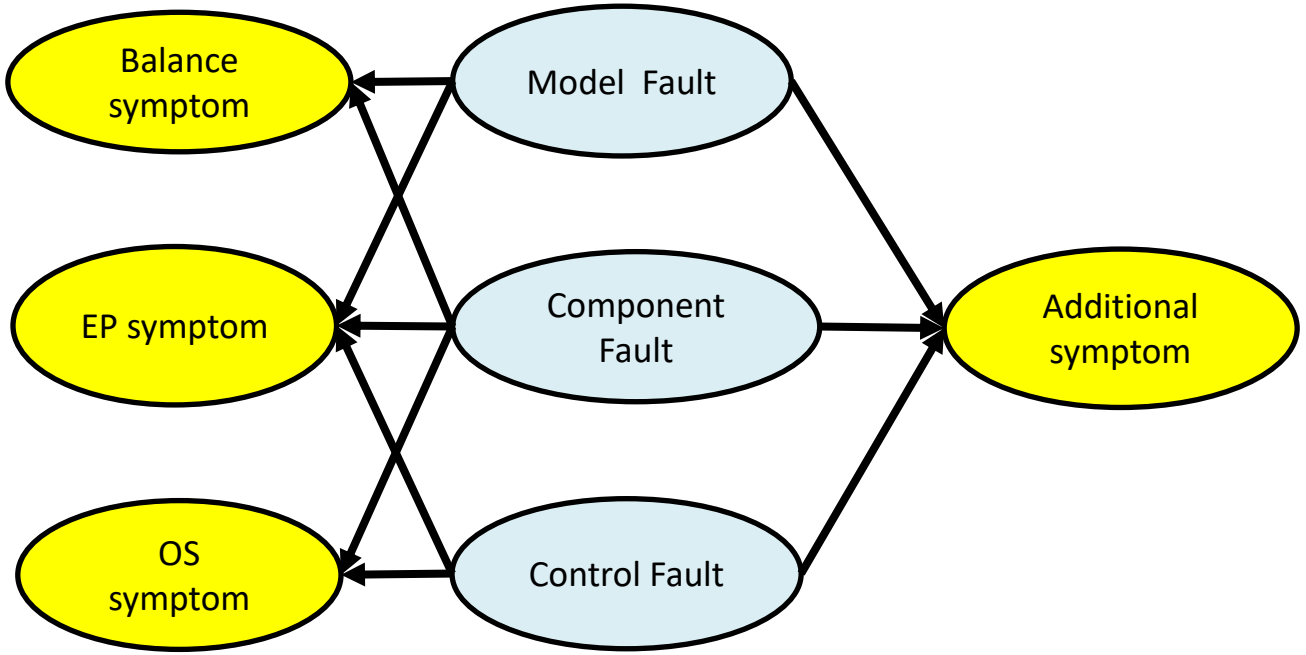
- **Objective:**
  - **Introduce Faults in HVAC System**
  - **Test the theories in practice**

- **Data Acquisition:**
  - **Objective data from sensors**
  - **Subjective data through occupant feedback**

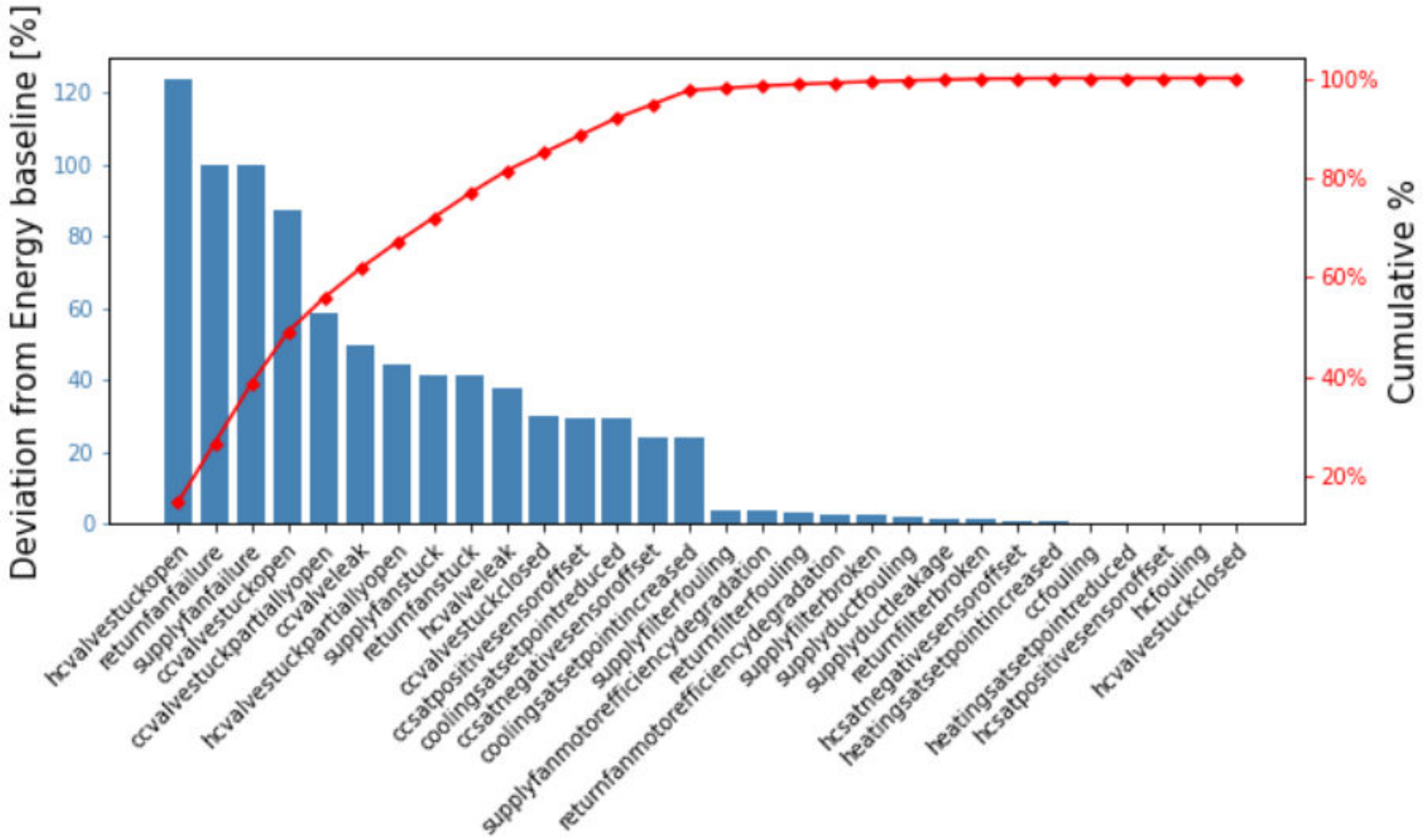
Kropman Breda – Living Lab


Luchtbehandelingskast
KROPMAN
INSTALLATIETECHNIEK
T
1-5AV1
1-5AV1
1-5AV1
1-5PdT1
1-5WW1
1-5TZA1
1-5PdT2
1-5XV2
1-5XV1
dP
1-5TT1
1-5CP1
1-5CV1
1-5TV1
1-5TV1
1-5TV1
1-5XT1
1-5Xt1
1-5PT1
1-5MS1
M
M
P
Noord
Zuid
1.05

Fault and Symptom Classification



Taal et al. (2021)


Deviation from Energy baseline [%]
Cumulative %
0
20
40
60
80
100
120
20%
40%
60%
80%
100%
hcvalvestuckopen
returnfanfailure
supplyfanfailure
ccvalvestuckopen
ccvalvestuckpartiallyopen
hcvalvestuckpartiallyopen
ccvalveleak
supplyfanstuck
returnfanstuck
hcvalveleak
ccvalvestuckclosed
ccsatpositivesensoroffset
coolingsatsetpointreduced
ccsatnegativesensoroffset
coolingsatsetpointincreased
supplyfilterfouling
supplyfanmotorefficiencydegradation
returnfanmotorefficiencydegradation
returnfilterfouling
supplyfilterbroken
supplyductfouling
supplyductleakage
returnfilterbroken
hcsatnegativesensoroffset
heatingsatsetpointincreased
ccfouling
heatingsatsetpointreduced
hcsatpositivesensoroffset
hcfouling
hcvalvestuckclosed

Faults

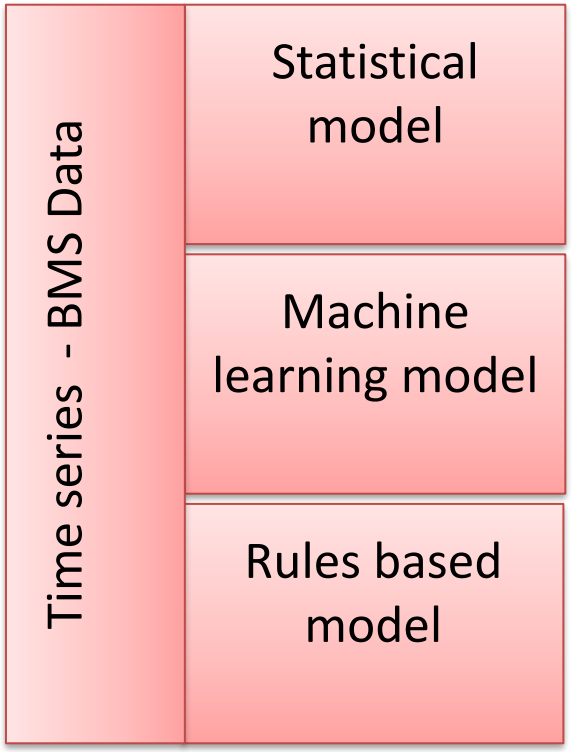
Progress: Tested faults

Faults focusing on:

i. **Heating coil valve**
ii. **Fan**
iii. **Heat recovery wheel**
iv. **Sensor bias**
v. **Control settings**

S. No.	Category	Heating Season Faults
1	Component (Valve Actuator)	Heating Coil Valve Stuck (Negative Stuck- Close to zero)
2		Heating Coil Valve Stuck (Positive Stuck)
3	Component (Heat Recovery Wheel)	HRW Failure (0%)
4		HRW Stuck (40%)
5	Component (Fan)	Fan Stuck
6	Sensor Bias	Supply Air Temperature Sensor Bias
7		Indoor Air Temperature Sensor Bias
8		Supply Water Temperature Bias
9		Supply Air Pressure Sensor Bias
10	Control	Supply Air Pressure Set Point Fault
11		Unstable Heating Coil Valve Control
12		Incorrect SAT Set Point - Lower
13		Incorrect SAT Set Point - Higher

Input



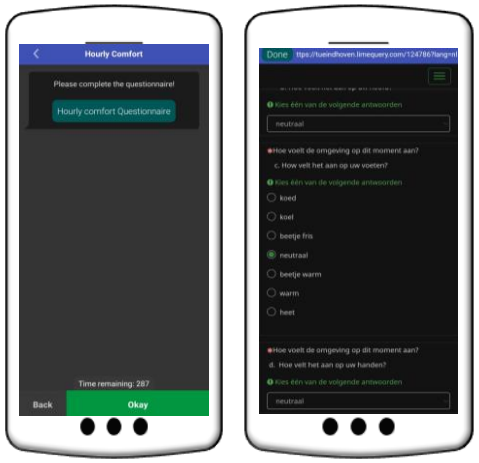
+

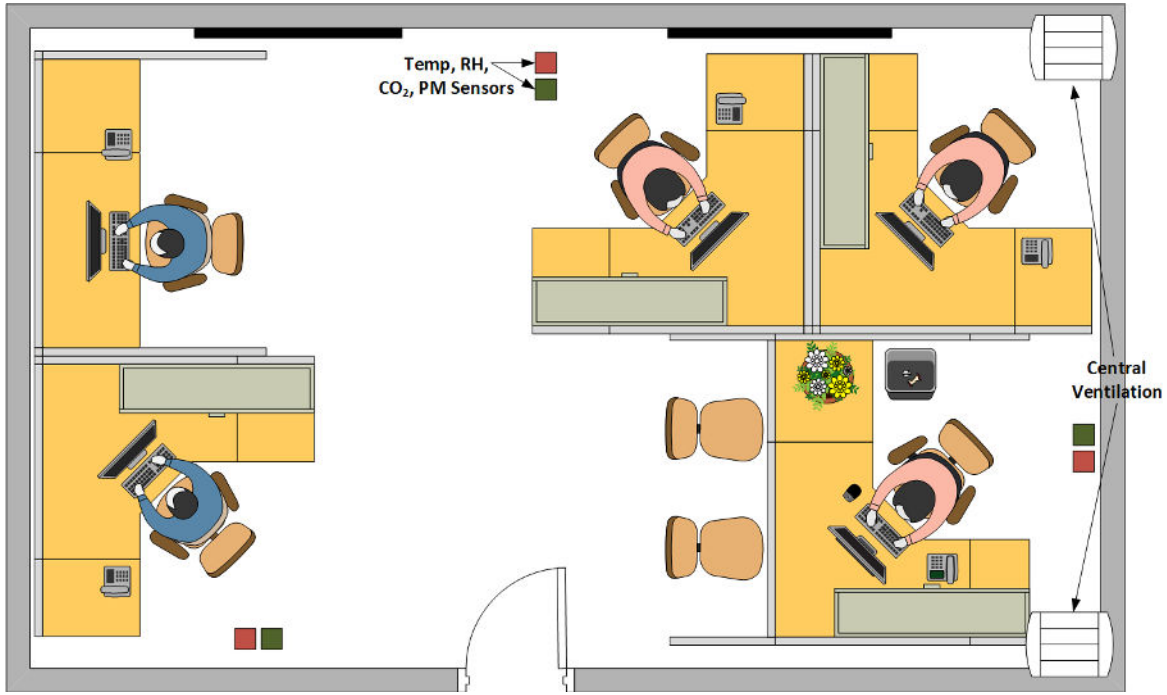
Occupant Feedback

Considering occupant feedback at different levels.

Subjective Data (Occupant Feedback)

- Metricwire is used to collect occupant feedback data
- Three times per day
- Collecting non-faulty data
- Approximately 15 participants





Additional Low-cost Monitors & Virtual Sensors

Data for:

- HVAC systems retrieved from InsiteReport portal of Kropman

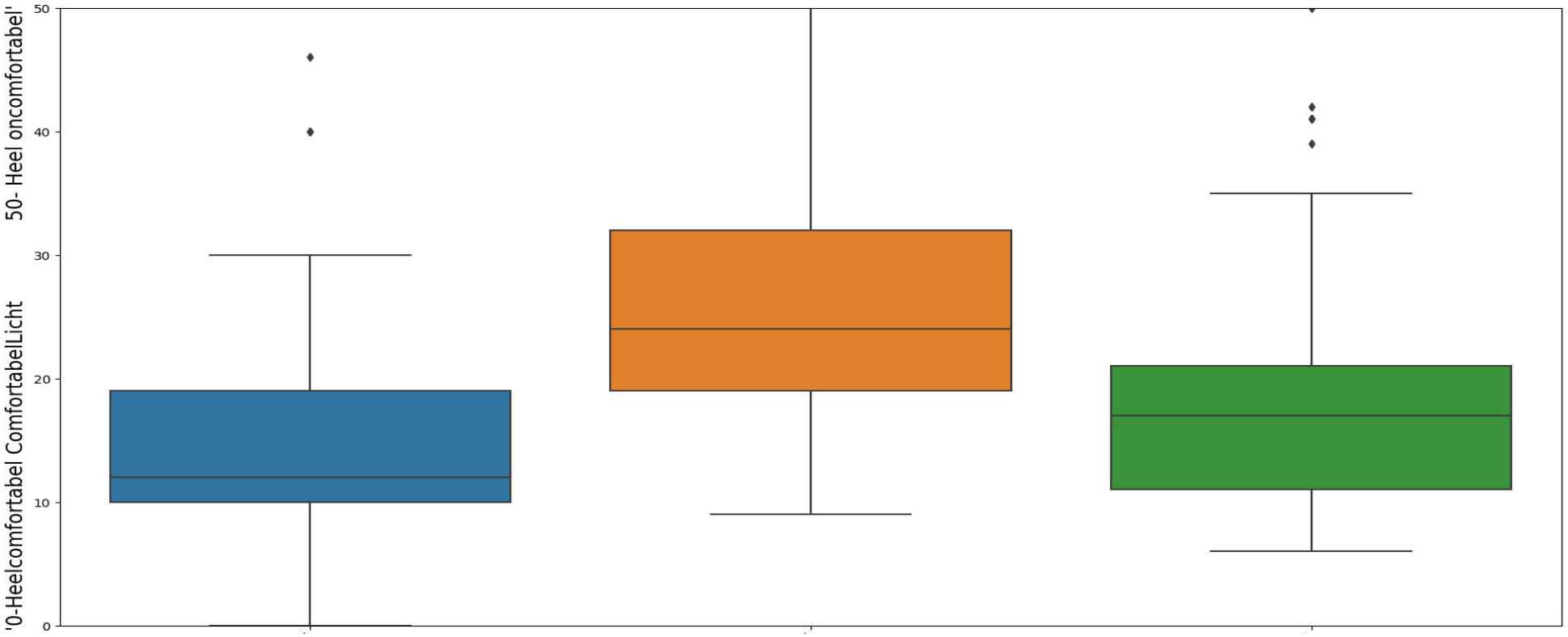
- IAQ sensors data retrieved from Airteq portal

Additional LCMs around HRW & coils

Mass flow rate meters, virtual mass & energy meters to be developed & validated

Airteq LCMs to measure IAQ

Thermal Comfort



Fan Stuck

Heating Coil Valve Stuck-Negative Stuck

Average Fault Free

Expected Output and Applications

- AFDD -Detect and diagnose faults of HVAC
- Generic
- Provide better comfort and reduce energy consumptions
- Re-commissioning and maintenance

Application:

- Commercial buildings (must have BMS)
- AHU (With the minimum number of sensors)
- Integrated to Building Energy Management system

Bedankt voor je aandacht.

Zijn er nog vragen?