

# Fault experiments to generate data from living laboratory

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# KROPMAN



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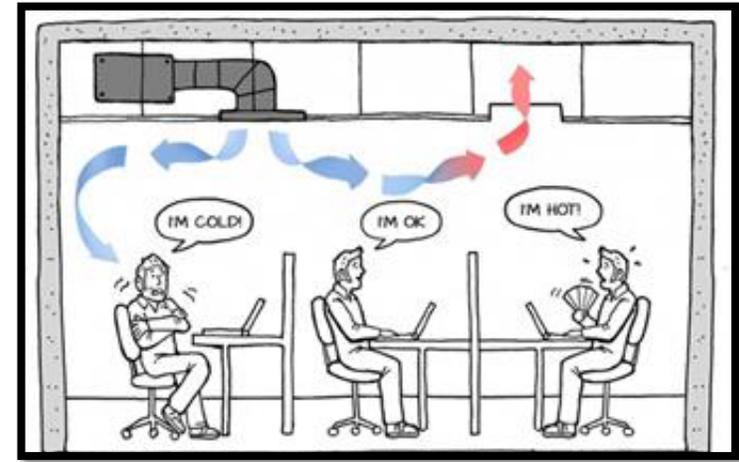
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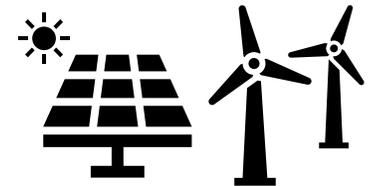
# INTRODUCTION

# Problems in the built environment

- Buildings consume **36 %** of all energy (United Nations Environment Programme, 2021)
- Operational faults in HVAC system lead to:
  - i. Up to **30%** wastage (Granderson et al. 2018)
  - ii. Poor Indoor Environmental conditions



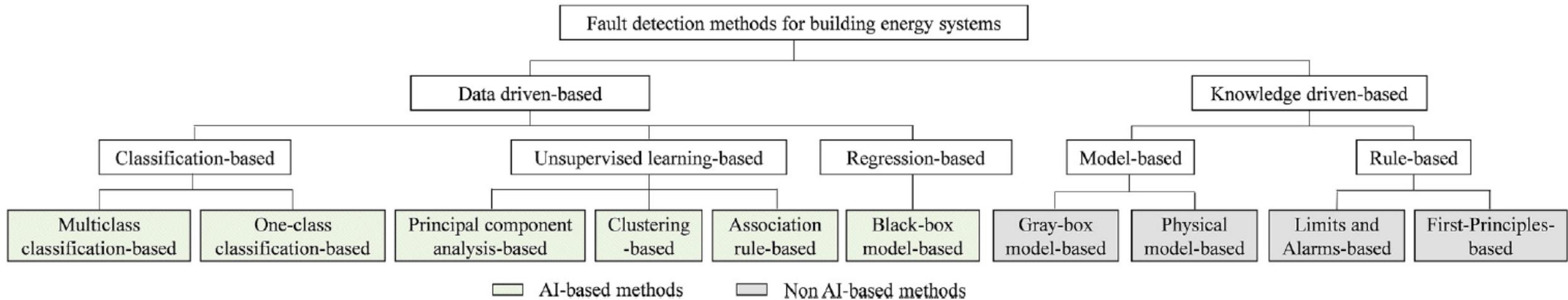
Source: ecovision.ca



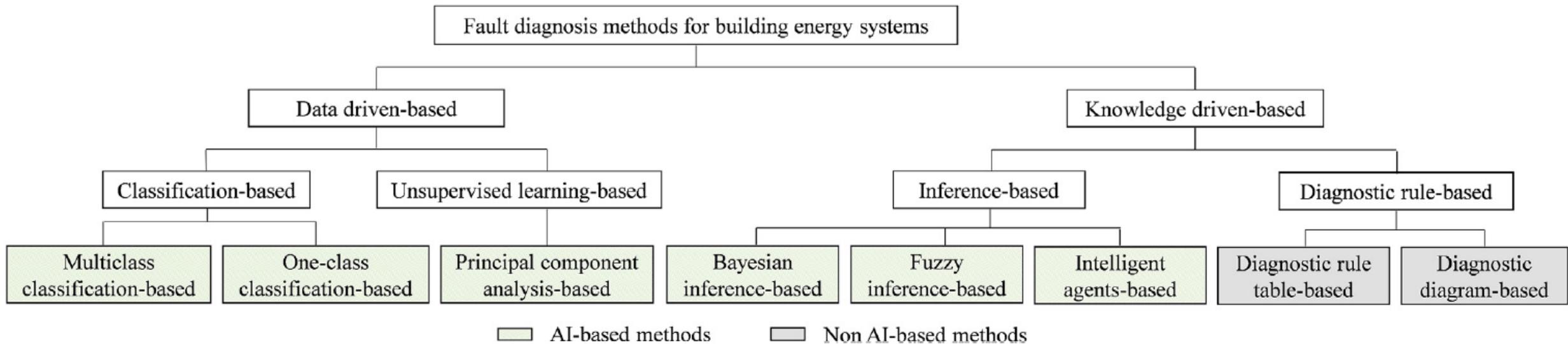
**Energy Waste** = 5 × (solar + wind) generation



# Classification of fault detection and fault diagnosis methods

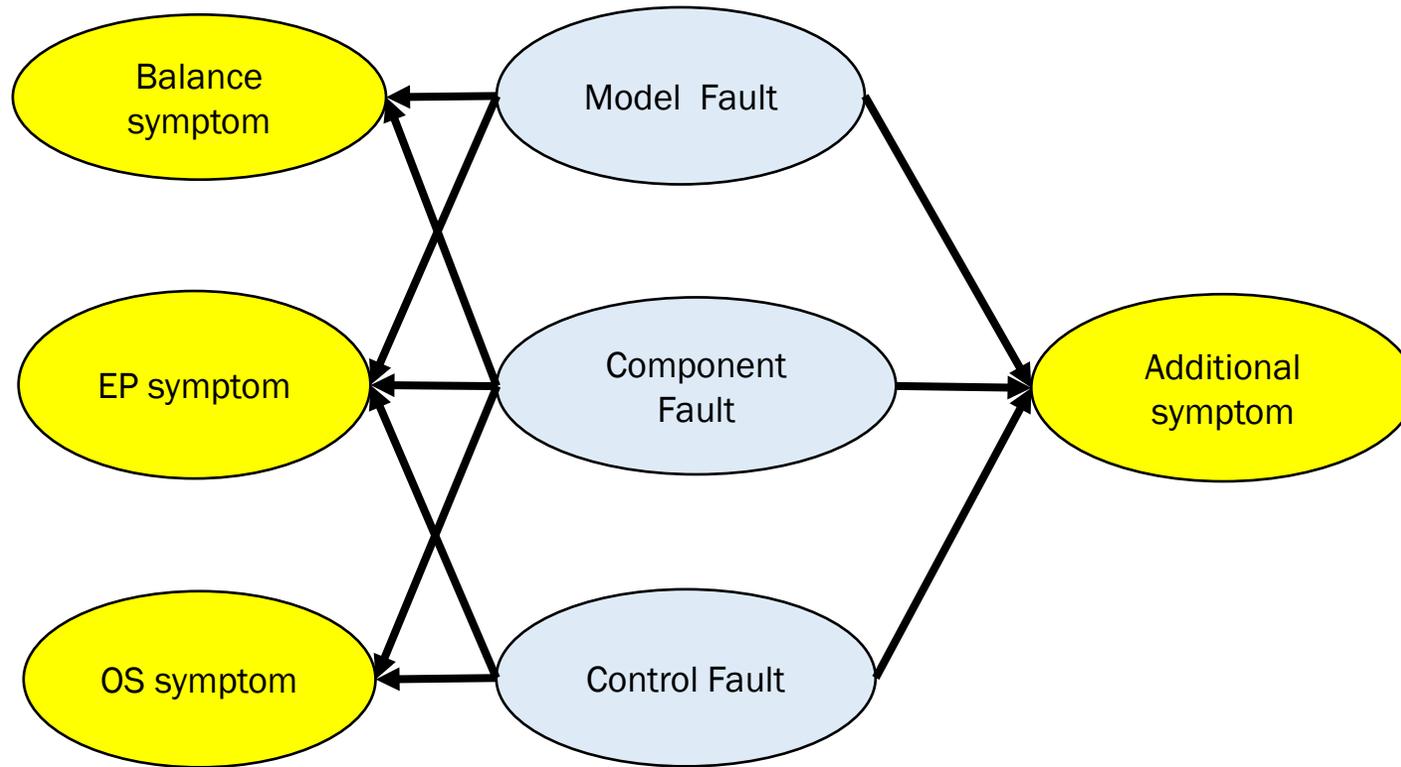


Source: Zhao et al. (2019)



Source: Zhao et al. (2019)

# 4S3F FDD method



Taal (2021)

- Diagnostic Bayesian network' with 7 types of nodes (4 symptoms 3 Faults)
- DBN is developed based on P&ID diagram
- Simultaneous diagnosis on multi-levels  
(**Top-Down, Bottom-Up, & Middle-Out**)
- Based on expert knowledge - **Static**



## Gap & Objectives

- Limited datasets publicly available with ground truth on faulty & non-faulty data (Chen et al., 2023)

### *Objective:*

- To introduce faults into the HVAC system
- To collect sensor data through BMS
- To collect occupant feedback (subjective data)



## Why AHU?

- AHU used to meet space conditioning and air distribution requirements (Yu, Woradechjumroen and Yu, 2014).
- Lack of quality system integration could lead to failure or faults (Yu, Woradechjumroen and Yu, 2014).
- Number of AHUs are 20 times that of available maintenance personnel (Bruton et al., 2014).
- Complex control strategies require expensive external consultancies for diagnosing issues (Bruton et al., 2014).



# PREPARATION

# Why Kropman Breda?

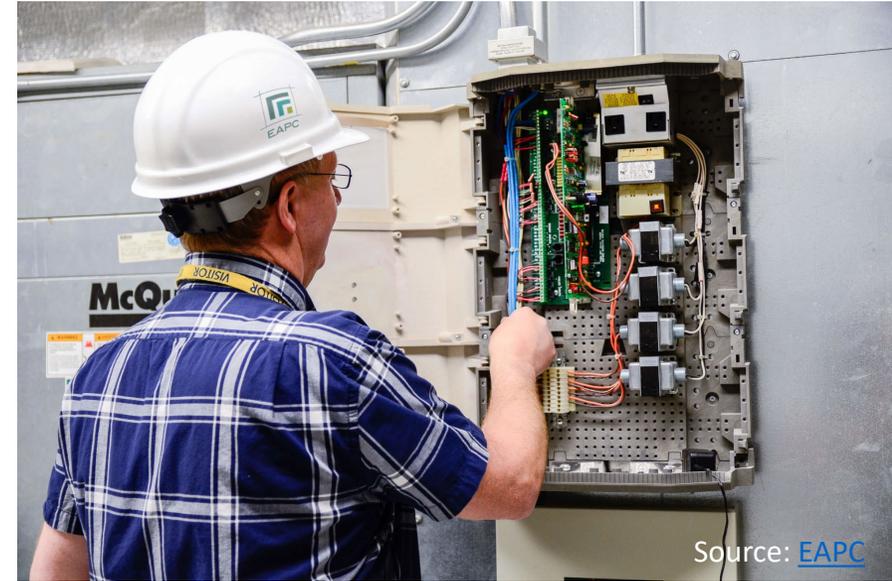
- Represents a typical Dutch Office building
- Sensor density & data granularity
- Continuity of research collaboration
- Occupants' participation
- Cooperation of technicians & engineers



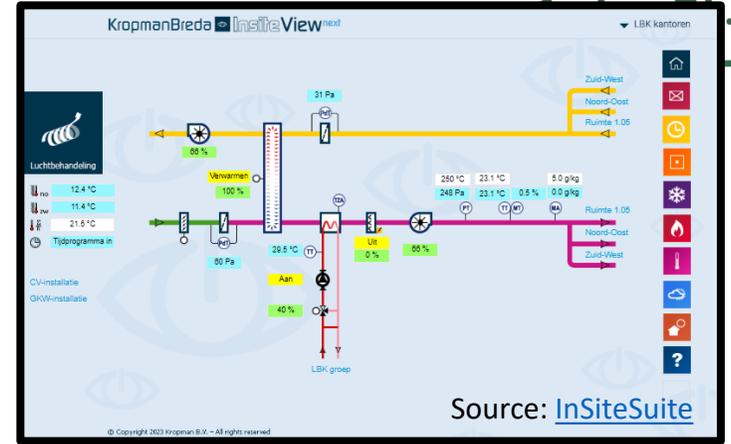
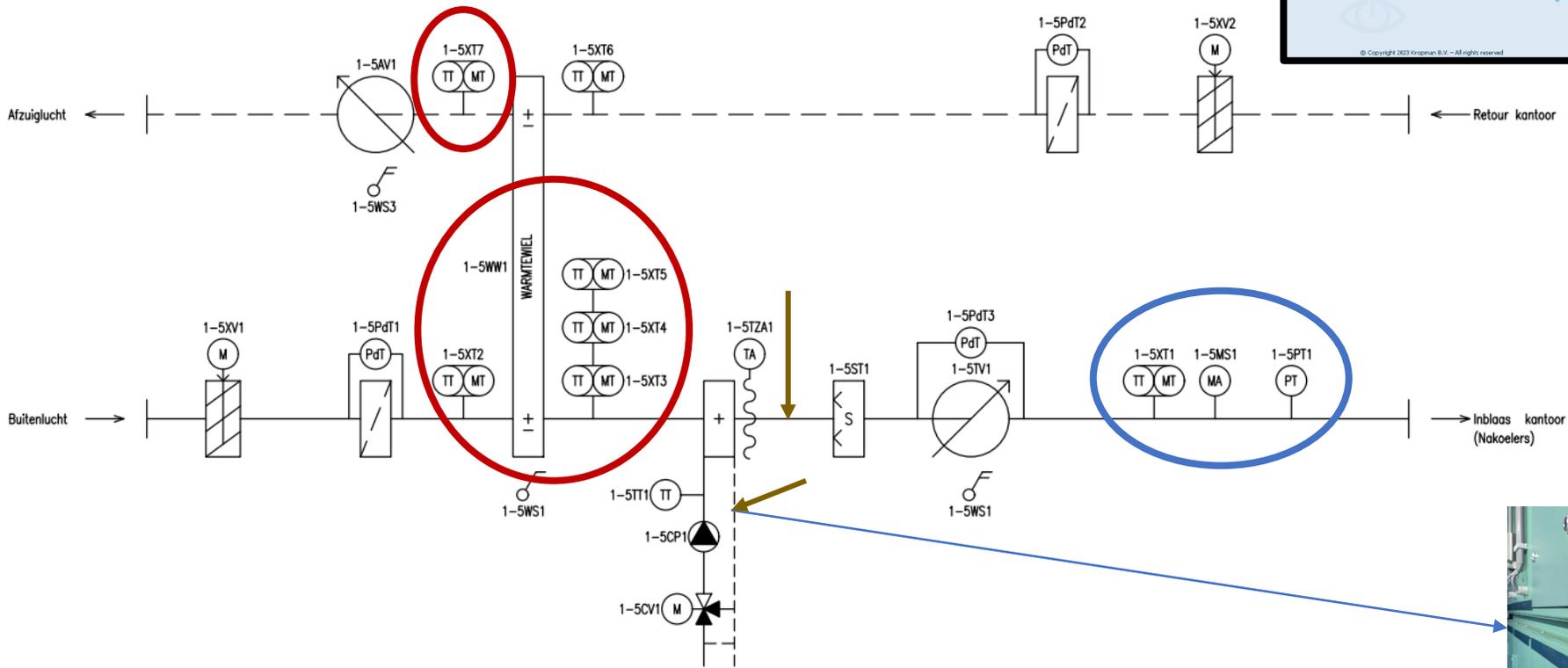
Source: Labeodan et al. (2016)

# Recommissioning

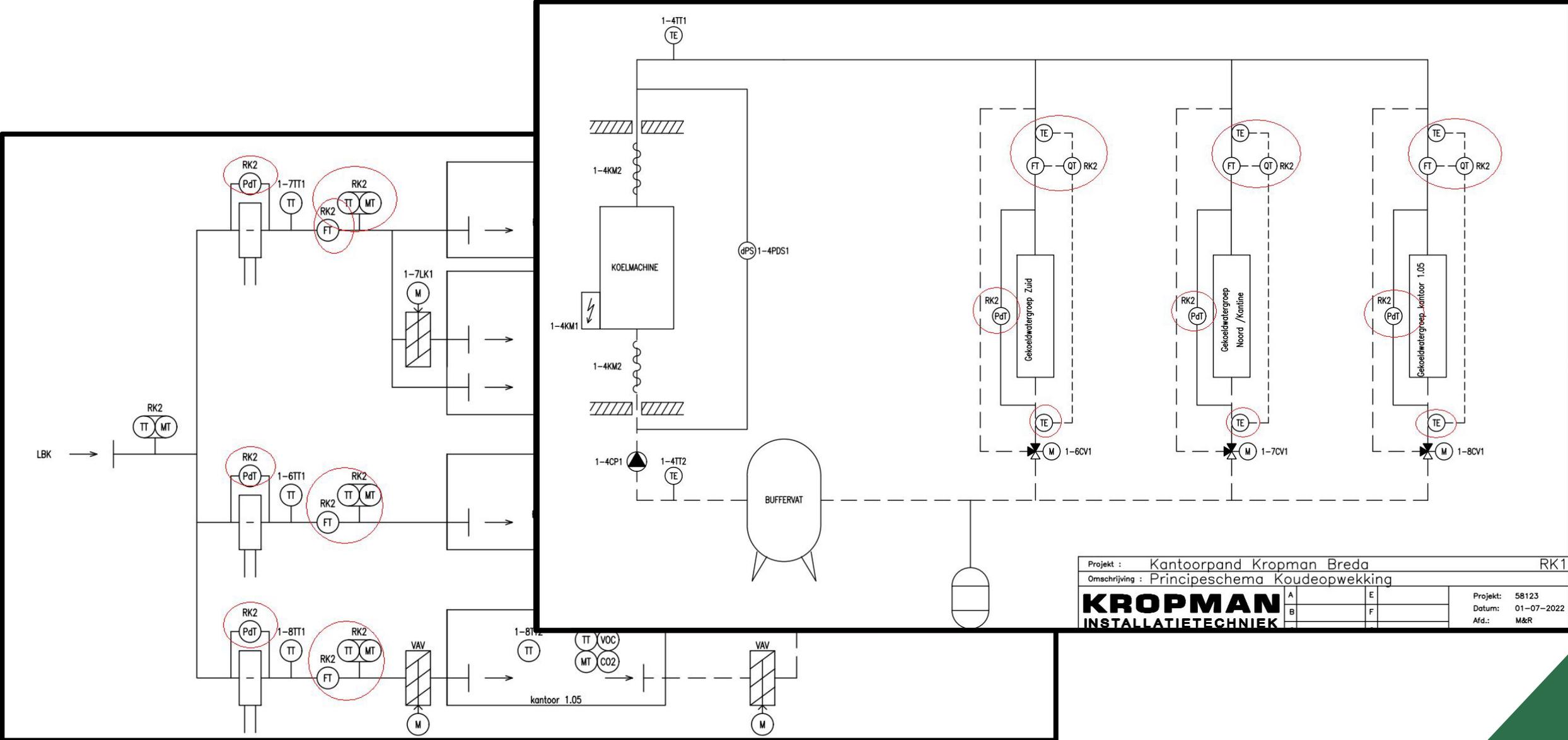
- Re-commissioning done to ensure the following:
  - (i) Sensors marked in the P&ID drawings are correct
  - (ii) Sensors record the correct value
  - (iii) Check for bias or drift in sensors
  - (iv) Identify additional sensors needed



# Installing additional sensors



# Installing additional sensors



Projekt : Kantoorpand Kropman Breda			RK1
Omschrijving : Principeschema Koudeopwekking			
<b>KROPMAN</b>	A	E	Projekt: 58123
<b>INSTALLATIETECHNIEK</b>	B	F	Datum: 01-07-2022
			Afd.: M&R

# Vibration sensors



## Installed Location

Supply Fan

Heat Recovery Wheel

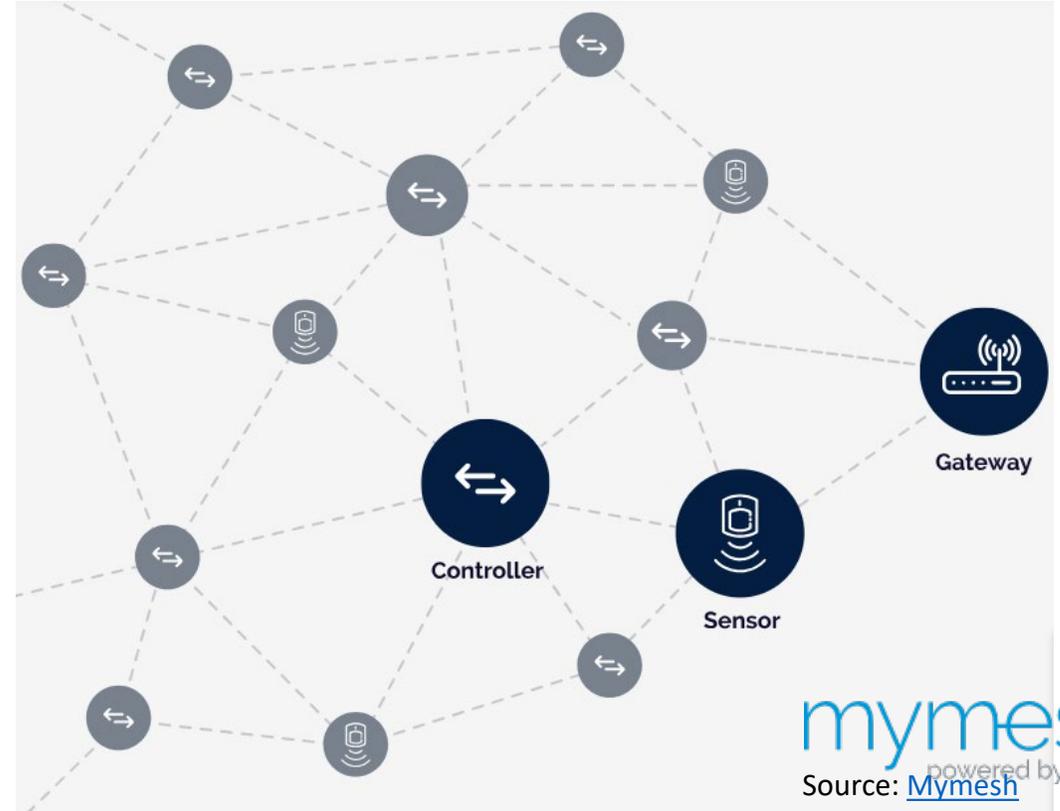
Heating Coil Valve

Supply pipe to Cooling Coil Valve

# IEQ - AFDD



Airteq low-cost monitor



- Temperature
- Relative Humidity
- LUX
- Occupancy
- Sound level



# FAULT EXPERIMENTS



# Faults Studied

- The most common AHU-VAV faults studied in literature listed in Gunay, Shen and Yang (2017)
- Fault categories: design, operational & degradation.
- Scope: non-degradational, operation faults
- Chosen focus components: (i) heating coil, (ii) cooling coil, (iii) fans, (iv) filters, (v) heat recovery wheel, (vi) sensor offset, (vii) control setpoints

# Implemented Faults

Fault implemented during operation hours; 1 day per fault

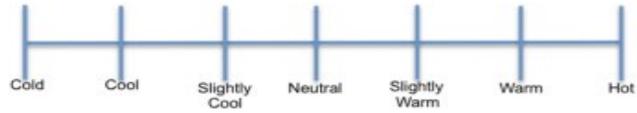


Category	Fault
Heating Coil Valve	Valve Stuck
	Unstable valve Control
Fan	Fan Stuck
Heat Recovery Wheel	Failure
	Stuck
Sensor Offset	Supply Air temperature Sensor
	Indoor Air Temperature Sensor
	Supply Air Pressure Sensor
	Supply Water temperature Sensor
Incorrect Setpoints	Maximum Supply Air Temperature
	Supply Air Pressure

Category	Fault
Cooling Coil Valve	Valve Stuck
	Unstable valve control
Fan	Fan Stuck
	Fan Failure
Heat Recovery Wheel	Stuck
	Failure
Sensor Offset	Supply Air temperature Sensor
	Indoor Air Temperature Sensor
	Supply Air Pressure Sensor
	Supply Water temperature Sensor
Incorrect setpoints	Maximum Supply Air Temperature
	Supply Air pressure Setpoint
Filter	Filter fouled
	Filter broken



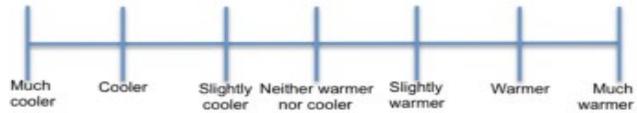
5. How do you feel at this moment?



6. How do you perceive this...?

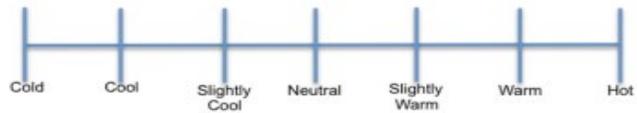


7. Would you like it to be?



8. How do your local body parts feel?

a.1. your hands



a.2. How do you perceive this...?



## QUESTIONNAIRE SNAPSHOT

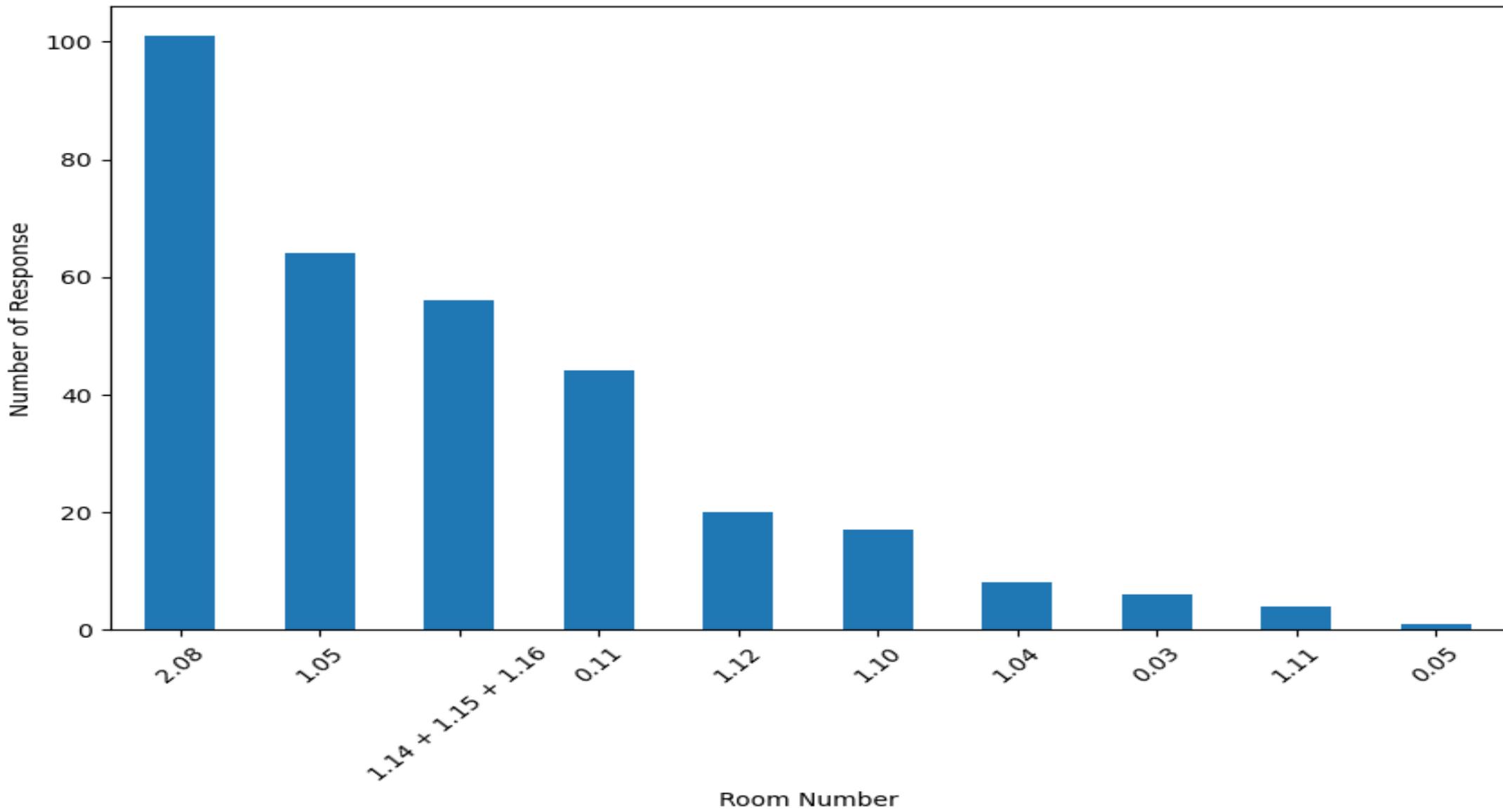
*A snapshot of the questionnaire to be used for the experiments.*

*Occupant feedback requested 3 times a day.*

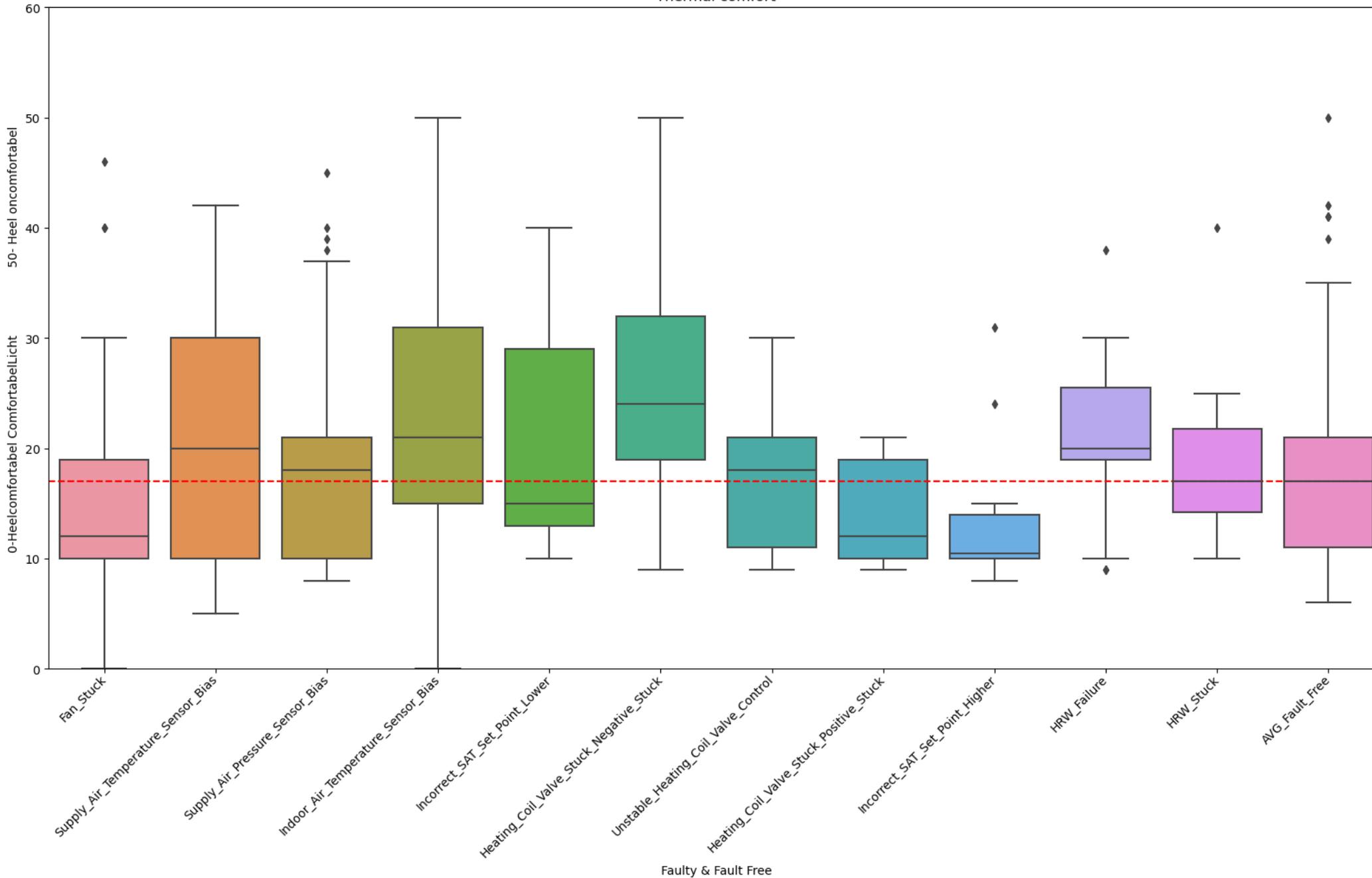


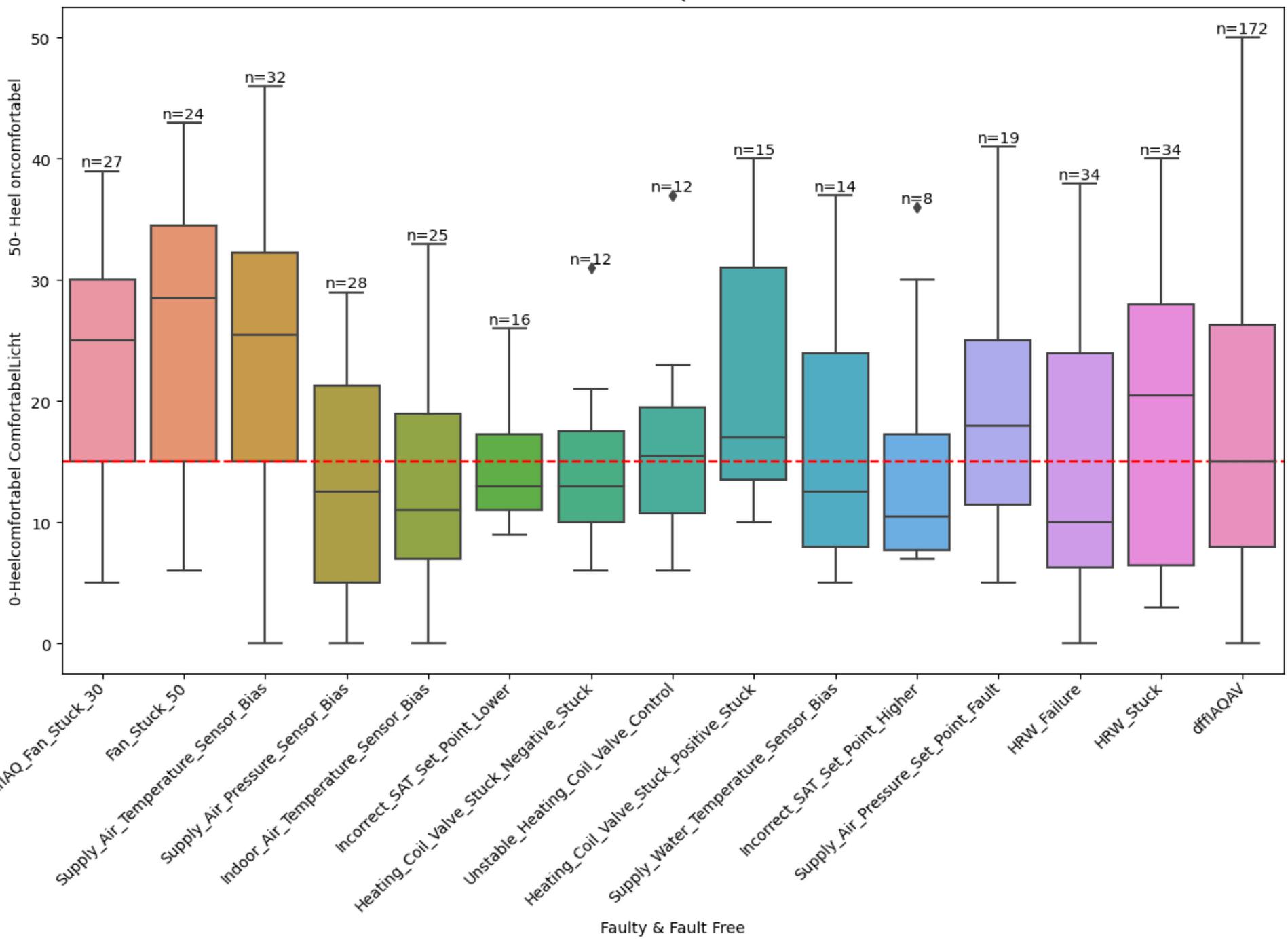
# DATA EXPLORATION

Number of Responses per Room Number



# Thermal comfort





Faulty & Fault Free



# REFLECTIONS & FUTURE PLANS



# Reflections

- Ground truth & algorithms will be for the operation of Kropman Breda
- Control strategy: small commercial buildings often keep changing the operating settings; difficult to have a fixed baseline, non-faulty operational data
- Subjective data: pain points of occupants; research-friendly vs occupant-friendly questionnaire; collecting data at diff. levels (room, zone etc.)



## Future Plans

- Develop machine learning-based fault detection algorithms with focus on data quality, sensor requirements, and ability to adapt to different buildings.
- Connecting Occupant feedback to BMS data and use it to diagnose faults.



THANK YOU