# Data- en expertgedreven aanpak voor efficiënte én effectieve installaties: Van onderzoek naar maatschappelijke impact

SYMPOSIUM, 25 JUNI 2024

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# Inhoud

Ontwikkelingen en vooruitzichten:

- Brains4Buildings project
- IEA EBC Annex 81: Data-driven smart buildings
- Eindhoven Engine B4B-APK project

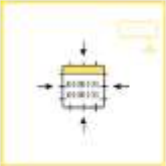
Prof.em. Wim Zeiler

# Belangrijkste uitdagingen

Energieverspilling door slechtwerkende gebouwinstallaties

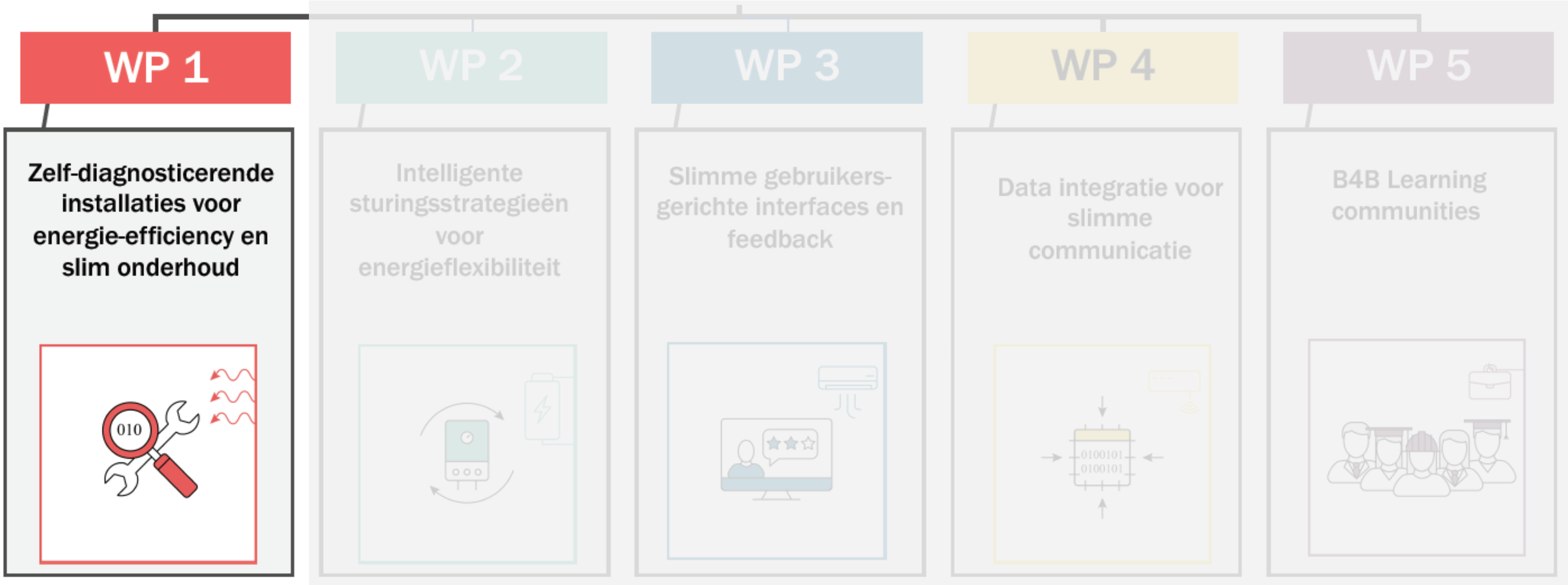
Balanceren vraag en aanbod bij inzet hernieuwbare energie

Klachten rondom comfort en welbevinden

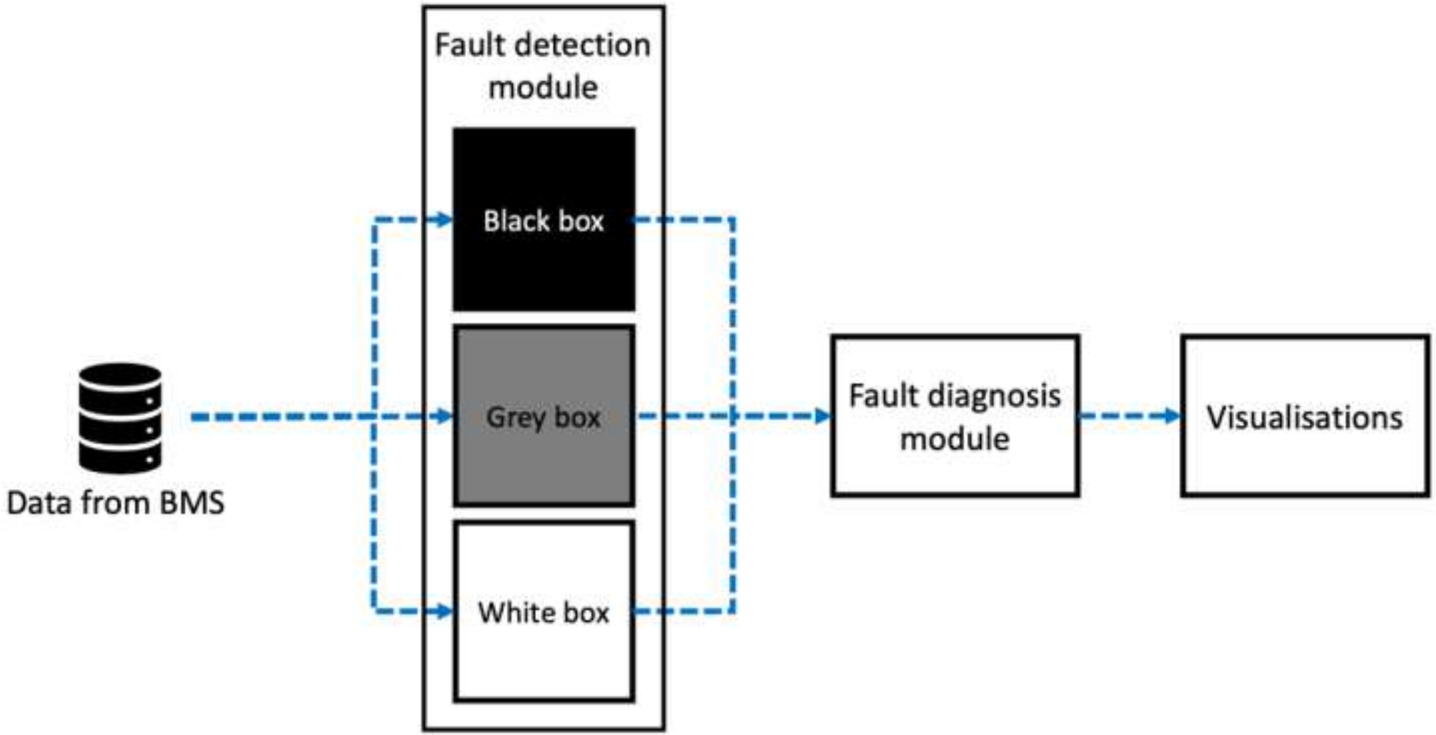


Gebrek aan interoperabiliteit van bestaande systemen

# Brains4Buildings: Beoogde oplossingen



# Automatische foutdetectie én foutdiagnose

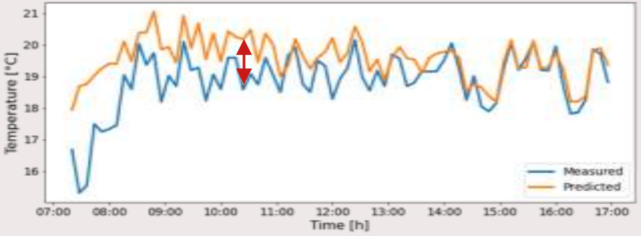


# Automatische foutdetectie én foutdiagnose

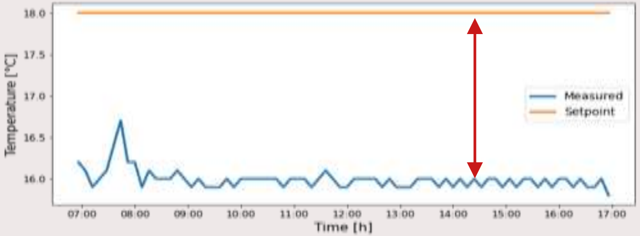
Machine Learning: symptoom-DETECTIE

Bayesiaans Netwerk: fout-DIAGNOSE

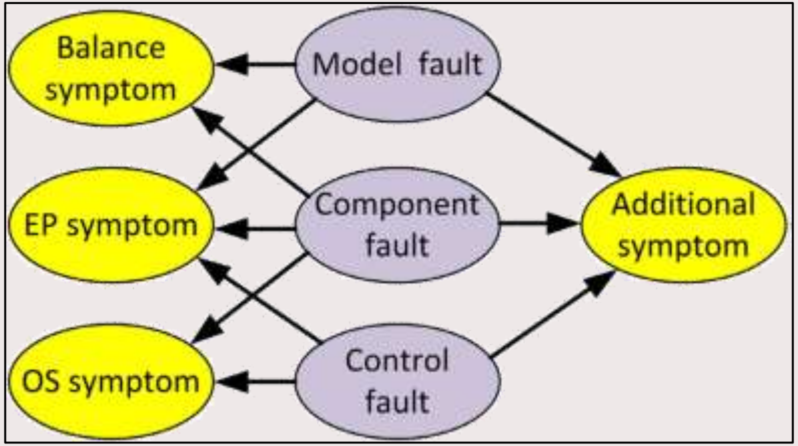
ML-Based Fault Detection




Rules-Based Fault Detection




(A. Thamban, 2021 , TUE)



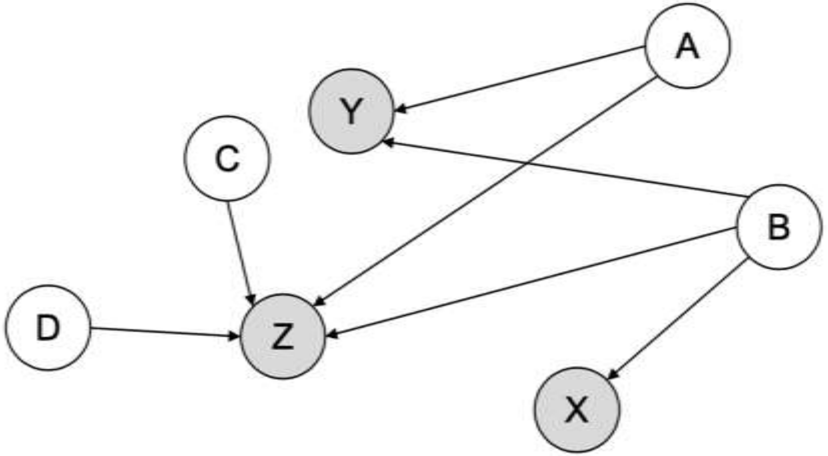

(A. Taal, proefschrift, 2021, TUE)

# Automatische foutdiagnose: Bayesiaans netwerk

Diagnose ziekten

Bijvoorbeeld:
A: Koorts
B: Hoesten
C: Vermoeidheid
D: Smaakverlies

Diagnose:
x: Verkoudheid
y: Griep
z: Covid



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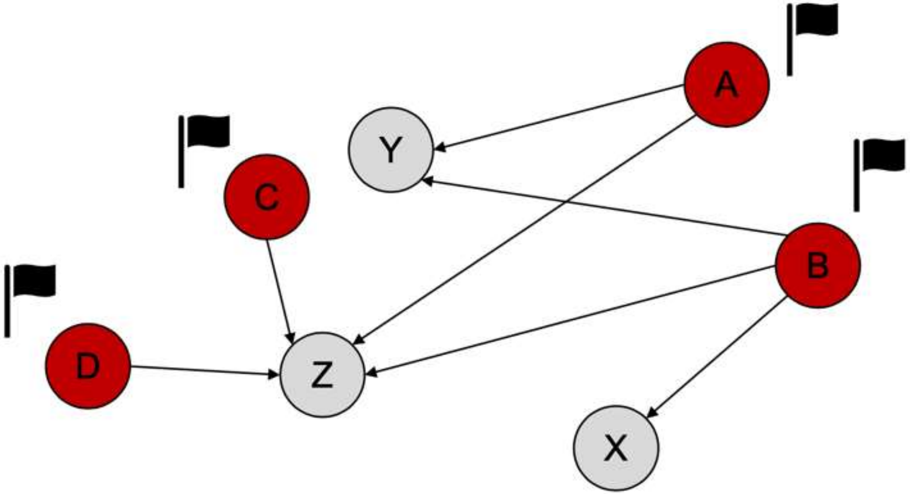



Koorts + Hoesten + Vermoeidheid + Smaakverlies → COVID

# Automatische foutdiagnose: Bayesiaans netwerk

**Voorbeeld luchtbehandelingskast:**

A: Status LBK aan/uit

B: Aandrijfriem gebroken

C: Filter gescheurd

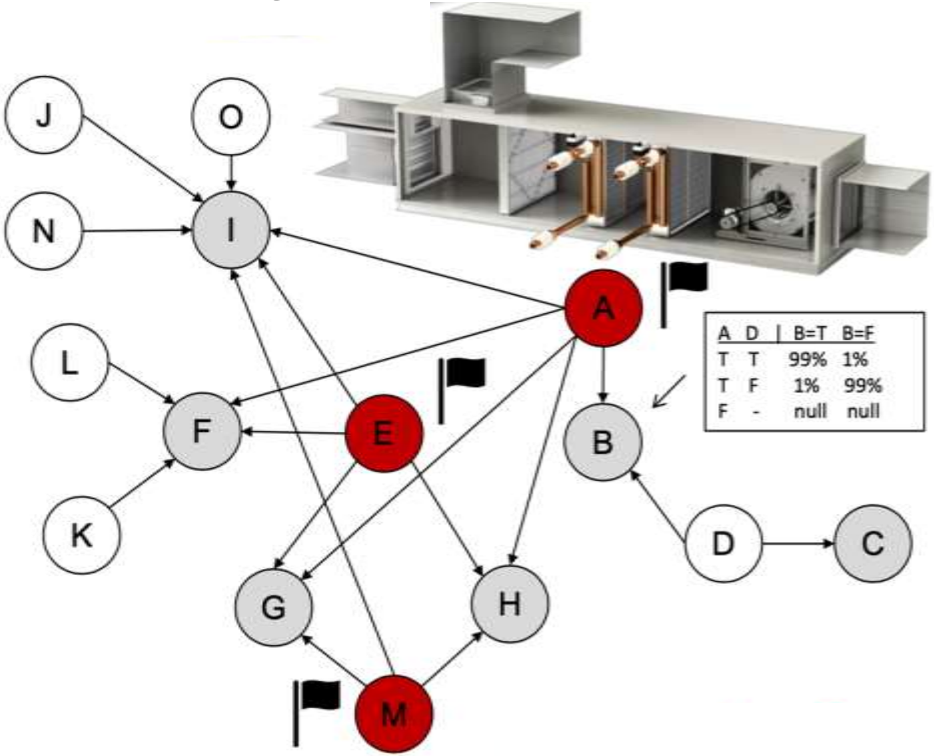
D: Druk over filter = 0

E: Te weinig capaciteit

F: Hittegolf

G: Vastzittende koelklep

H: Veel bezoekers



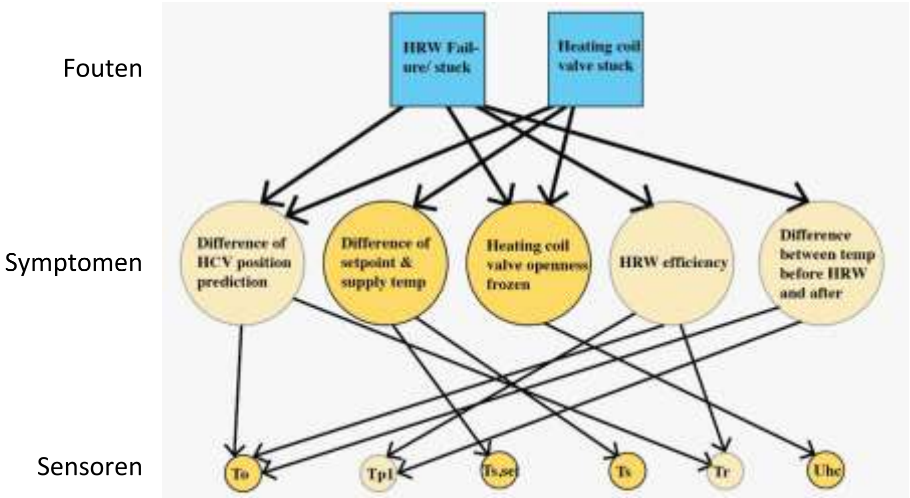
# Ingrediënten

- Sensor-technologie
- Data-technologie
- Cloud: o.a. t.b.v. Machine Learning
- Dashboards: Interactief, KPI’s.

# Meten is weten …

# DBN met diverse sensor-configuraties

- Living Lab: LBK in gebouw Kropman, Breda
- Voorbeeld: Foutdiagnose verwarming in LBK




| Case | Fault | Limited Sensor Configuration | | Standard/Redundant Sensor Configuration | |
|---|---|---|---|---|---|
| | | Post Probability | Diagnosis Result | Post Probability | Diagnosis Result |
| 1 | HRW 80% stuck | 0% | Wrong | 99% | Correct |
| 2 | HRW 50% stuck | 0% | Wrong | 89% | Correct |
| 3 | HRW 30% stuck | 0% | Wrong | 76% | Correct |
| 4 | HRW 10% stuck | 0% | Wrong | 67% | Correct |
| 5 | HRW failure | 0% | Wrong | 65% | Correct |
| 6 | HCV 40% | 67% | Correct | 76% | Correct |
| 7 | HCV 70% | 75% | Correct | 67% | Correct |
| 8 | Normal | 100% | Correct | 100% | Correct |

(Z. Wang, C. Lu, L. Itard, 2023, TUD)

# LBK sensor-configuratie: Situatie in Nederland

- ASHRAE (VS): Basiseisen.
- ISSO (NL): Uitgebreide aanbevelingen.

**Slechts 4 LBK's conform ASHRAE standaard!**

| Sensor | A | I | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outdoor air temperature | ✓ | ✓ | ✓ | | | | ✓ | | | ✓ | | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Outdoor air relative humidity | | ✓ | | | | | | | | | | | | | | | ✓ | ✓ | ✓ | ✓ |
| Preheated air temperature | ✓ | ✓ | | | ✓ | | | | | | | | | ✓ | | | ✓ | ✓ | ✓ | |
| Preheated air relative humidity | | ✓ | | | | | | | | | | | | ✓ | | | | | | |
| Supply air temperature | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Supply air relative humidity | | ✓ | | | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Return air relative humidity | | ✓ | | | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Exhaust air temperature | ✓ | ✓ | | | | ✓ | ✓ | | | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Exhaust air relative humidity | | ✓ | | | | | | | | | | | | ✓ | | | ✓ | ✓ | | |
| Supply water temperature | ✓ | ✓ | | | | | | | | | | | | ✓ | ✓ | | ✓ | | | |
| Return water temperature | ✓ | ✓ | | | | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| Pressure difference at supply air filter | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pressure difference at return air filter | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pressure difference at supply air on fan | | ✓ | | | ✓ | | | | | | | ✓ | | | | | ✓ | | | |
| Pressure difference at return air on fan | | ✓ | | | | | | | | | | ✓ | | | | | | | | |
| Supply air flow rate | ✓ | ✓ | | ✓ | | | | | | | | | | | | | ✓ | | | |
| Return air flow rate | ✓ | ✓ | | | | | | | | | | | | | | | | | | |
| Coil valve control signal | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Supply fan control signal | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Return fan control signal | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Supply damper control signal | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Return damper control signal | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Air quality sensor | | ✓ | | | | ✓ | | ✓ | | ✓ | | | | | ✓ | | | | | |
| Temperature sensor after coil | ✓ | ✓ | | | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Coil water flow | | ✓ | | | | | | | | ✓ | | ✓ | | | | | | | | |
| Fit ASHRAE recommendation | - | - | | | | | | | | | | | | Yes | | | Yes | Yes | Yes | |

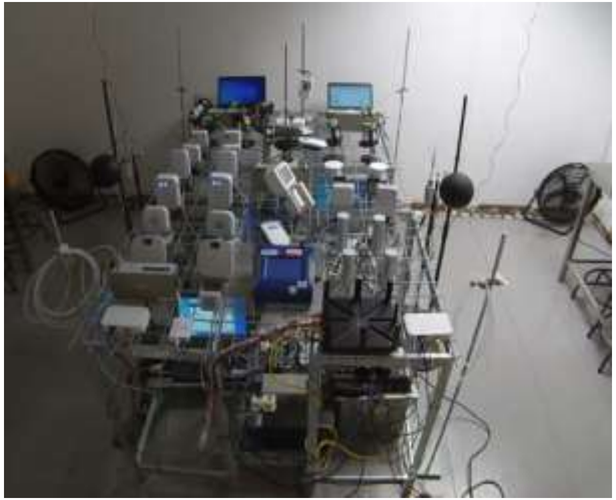
(Z. Wang, C. Lu, L. Itard, 2023, TUD)

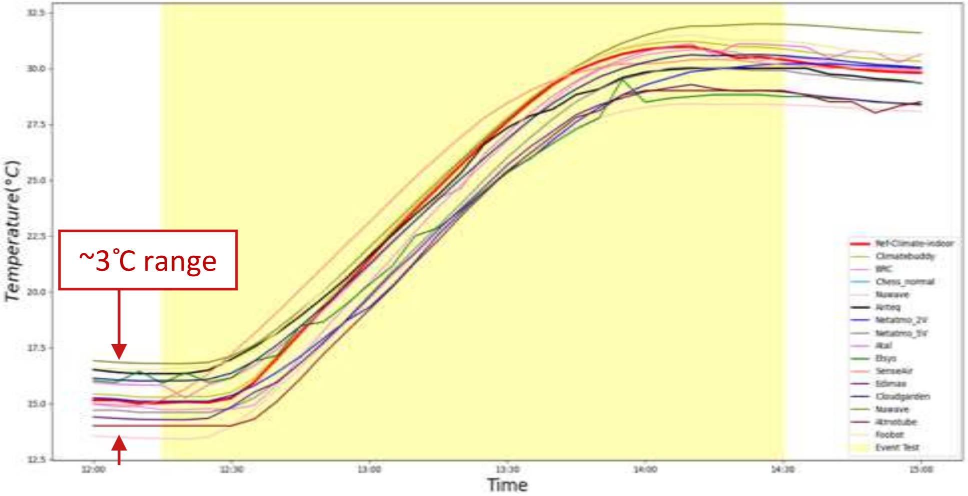
**Definitie van sensor-configuraties:**

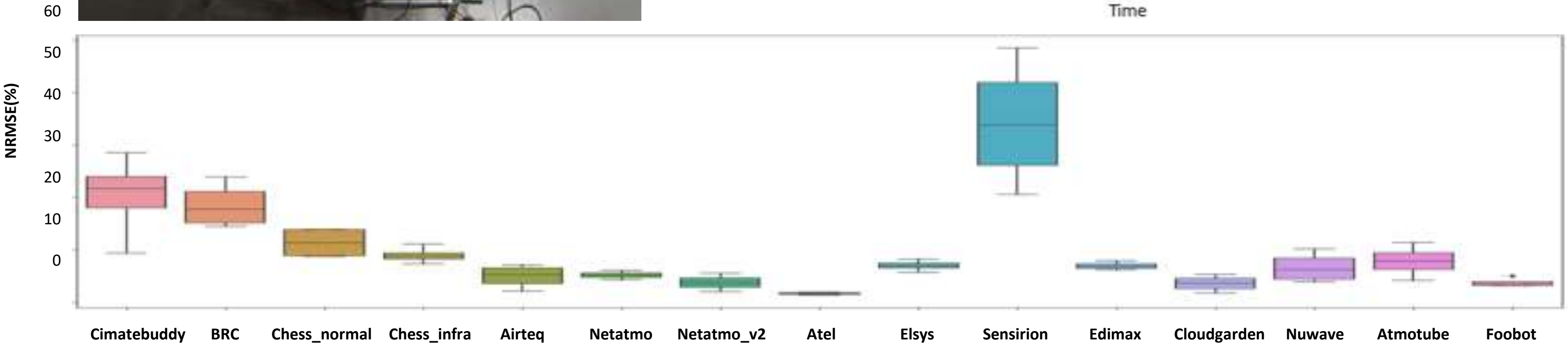
- ☐ ***Limited***: LBK's niet conform ASHRAE standaard
- ☐ ***Standard***: LBK's conform ASHRAE standaard
- ☐ ***Redundant:*** LBK's met meer sensoren dan ASHRAE

# Smart Buildings: Sensoren

- Low-cost monitors
- Virtuele (soft) sensoren



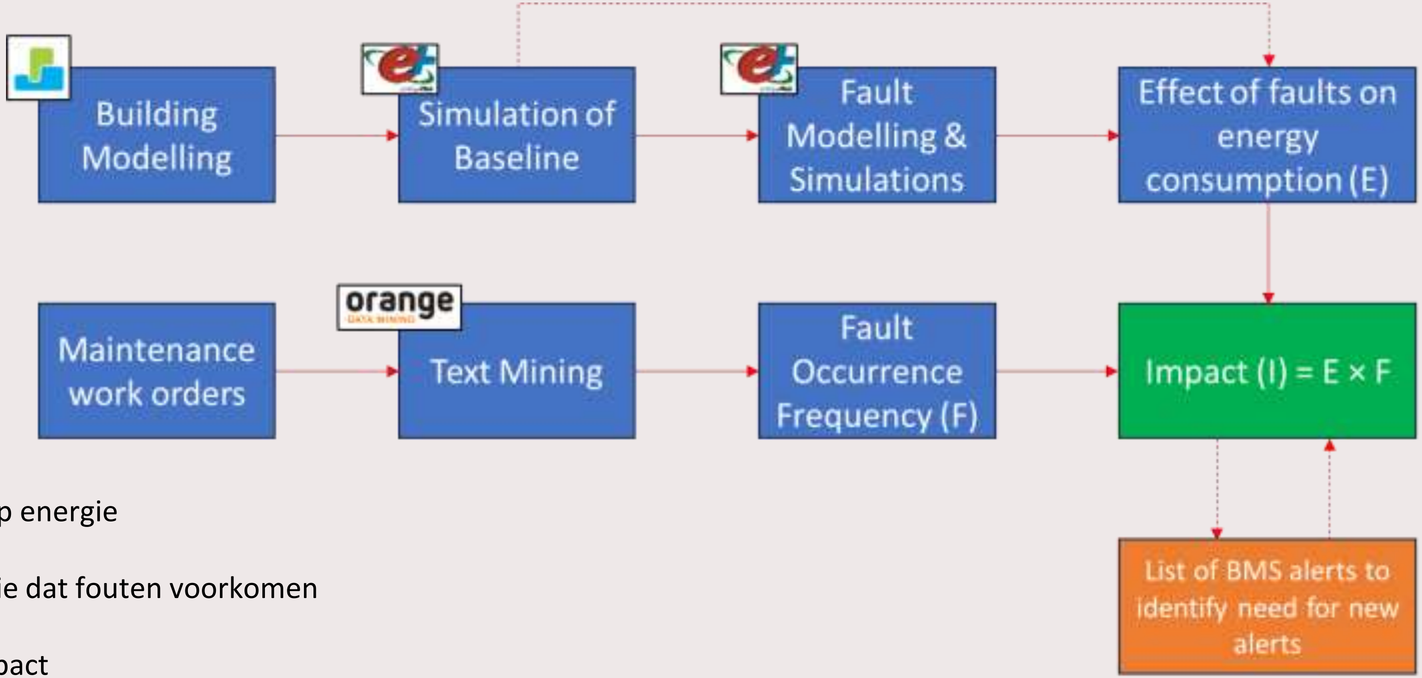



(H. Zheng, 2021 , TUE)

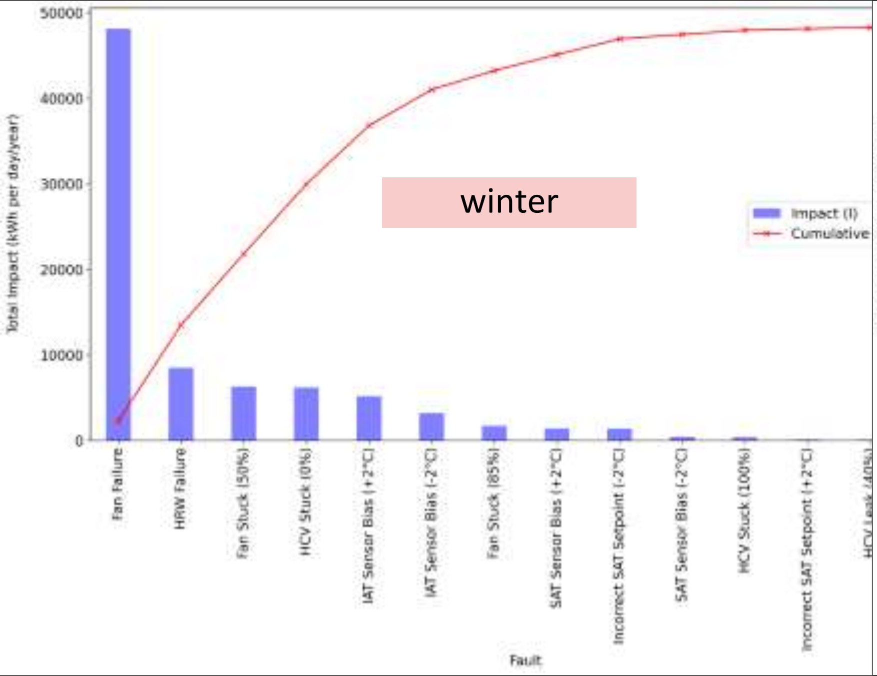
# Van data naar symptoomdetectie

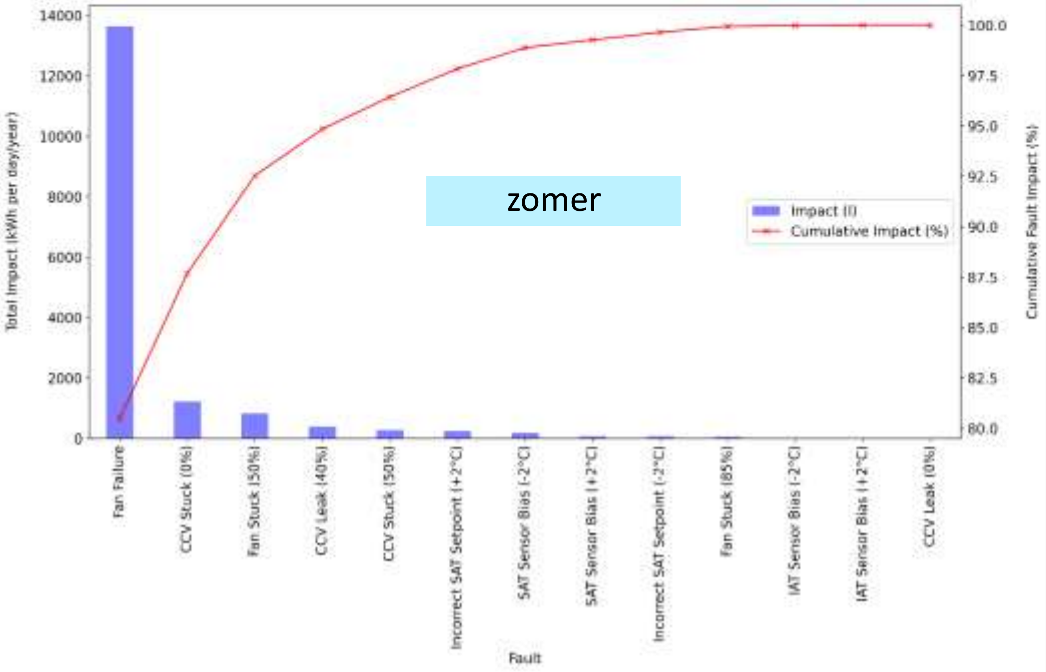
# Fouten prioriteren




- ***I = E × F***
- ‘***E***’ = impact op energie
- ‘***F***’ = frequentie dat fouten voorkomen
- ‘***I***’ = totale impact

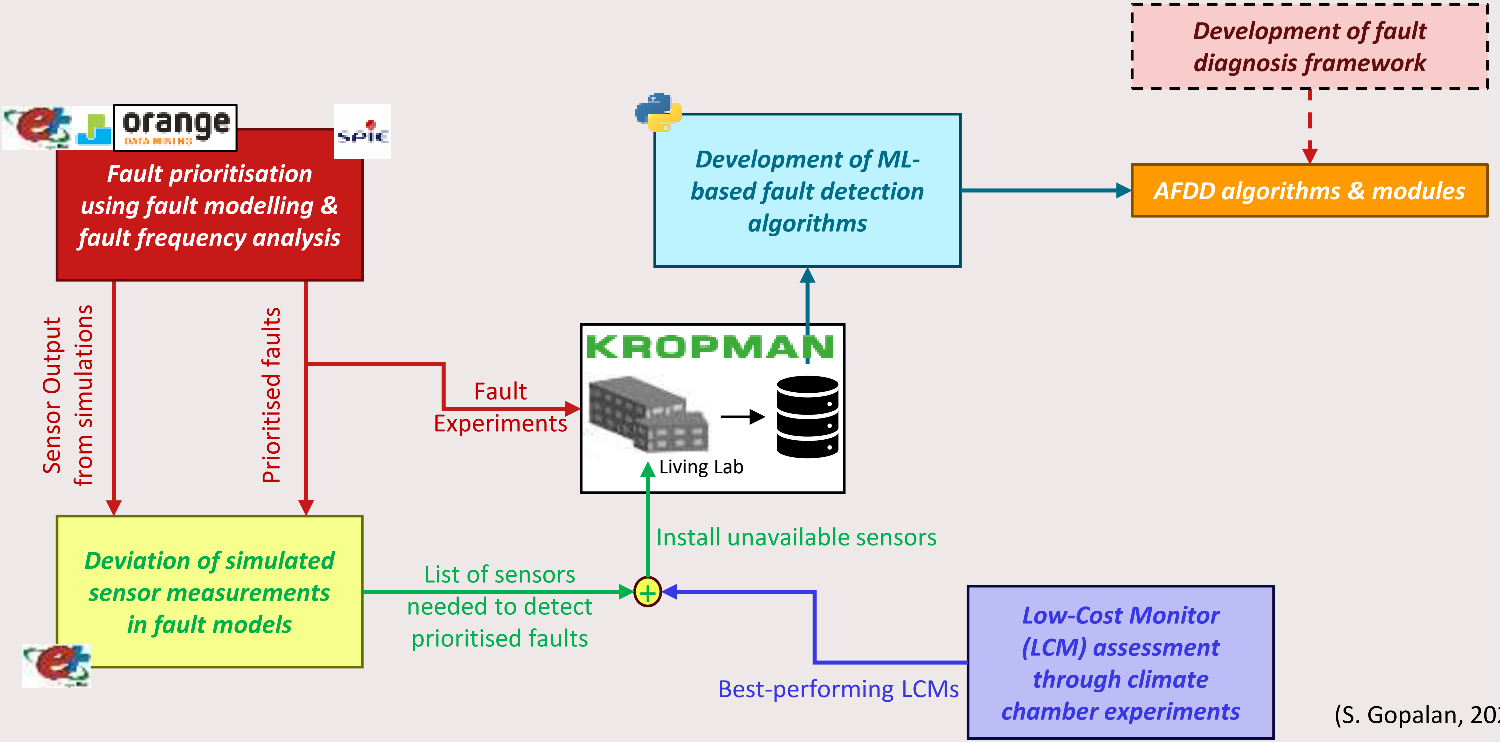
# Fouten prioriteren




(S. Gopalan, 2024, TUE)

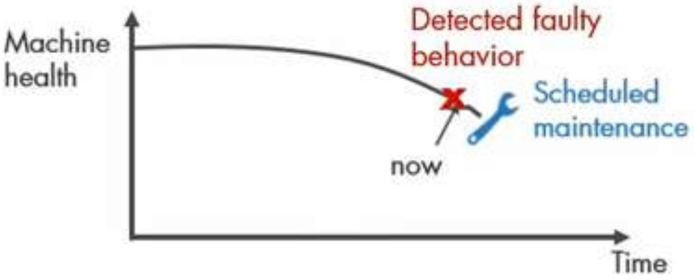
# Foutdetectie: Van simulatie naar de praktijk

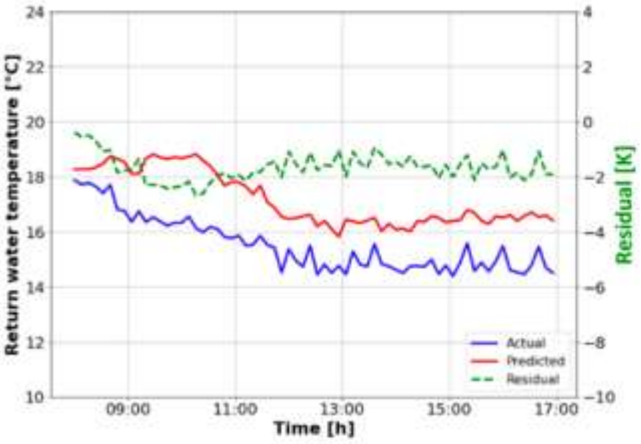



(S. Gopalan, 2024, TUE)

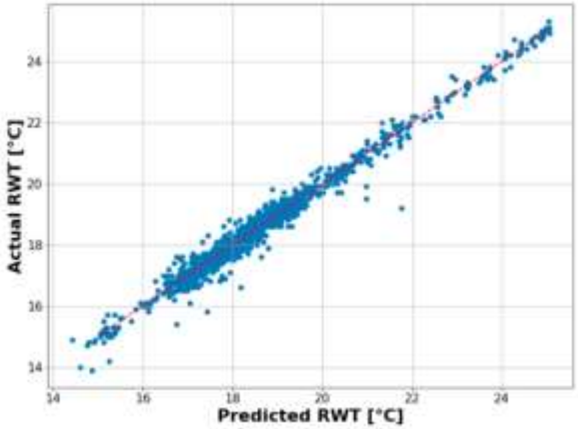
# Foutdetectie: Volgende stappen

- Vergelijken ML-modellen: XG Boost, SVR, ANN.
- Off-line testen op data set Living Labs.
- Koppelen aan diagnose modules.
- Conditie-afhankelijk onderhoud.




*Fault-free prediction (9 hours) using ML model*




*Performance evaluation of ML model (3 months fault-free data)*

(A. Thamban, 2021 , TUE)

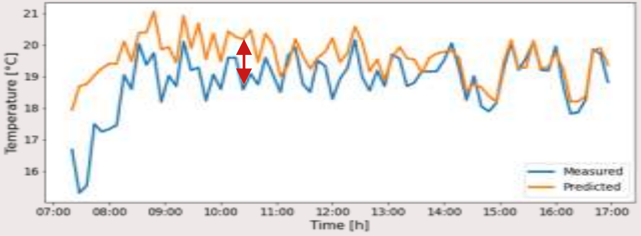
# Van symptoomdetectie naar foutdiagnose

# Automatische foutdetectie én foutdiagnose

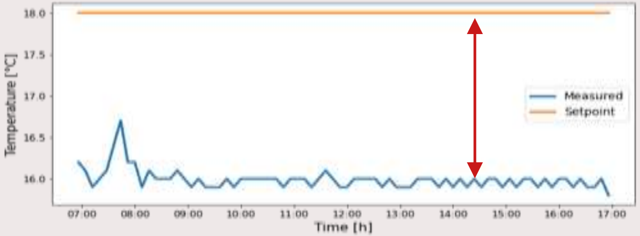
Machine Learning: symptoom-DETECTIE

Bayesiaans Netwerk: fout-DIAGNOSE

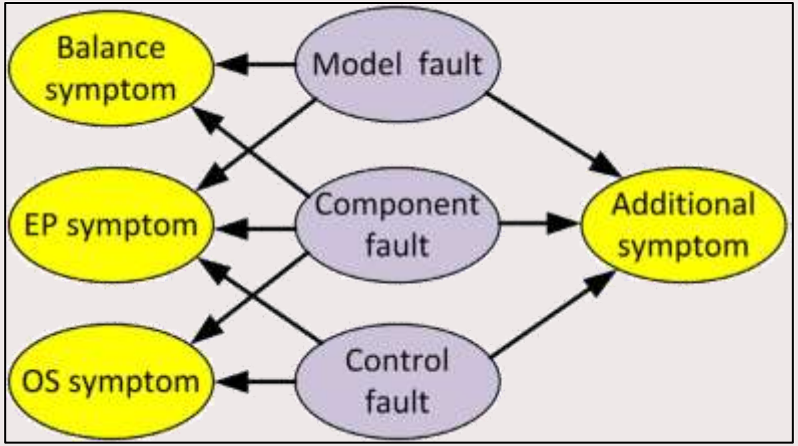
ML-Based Fault Detection




Rules-Based Fault Detection




(A. Thamban, 2021 , TUE)

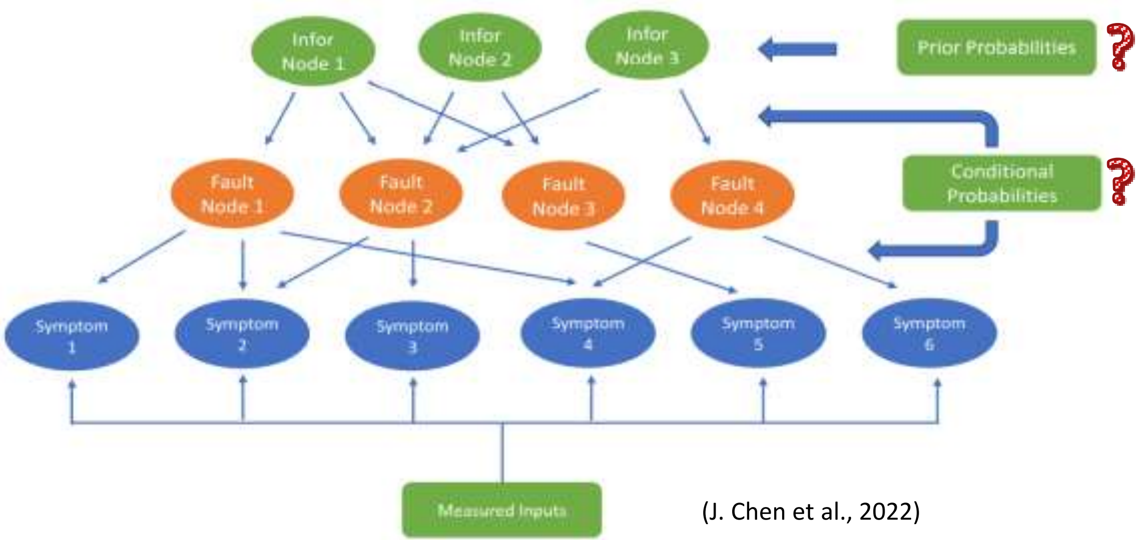



(A. Taal, 2021, TUE)

# Data-gedreven en op kennis gebaseerde DBN’s

Interviews met experts:

- DBN structuur
- Prior probabilities
- Conditional probabilities




(J. Chen et al., 2022)

# Gebouwgebruiker centraal: Subjectieve data

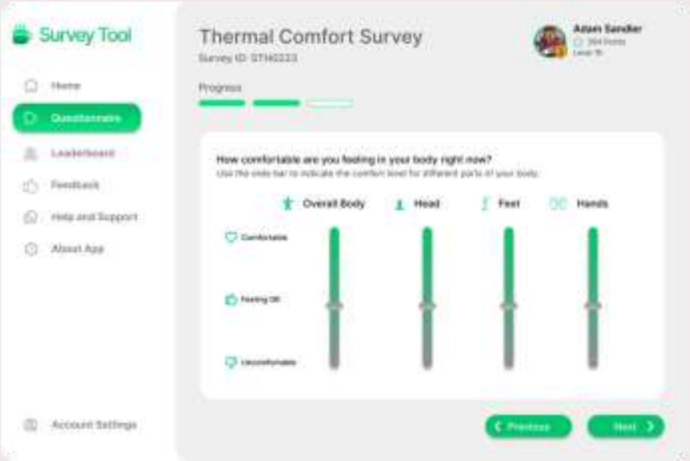
- Recent veldonderzoek met 3892 pers. in 60 kantoorgebouwen in de VS: Ongeveer 40% ontevreden over thermische omgeving, ver boven doelstelling van 20% (ASHRAE 55). (L. Pérez-Lombard, J. Ortiz, C. Pout- 2008, Z. Wang, B. Lin, Y. Zhu - 2015, Y. Long, S. Liu, L. Xie, K.H. Johansson – 2014, Y. Long, S. Liu, L. Xie, K.H. Johansson-2016)

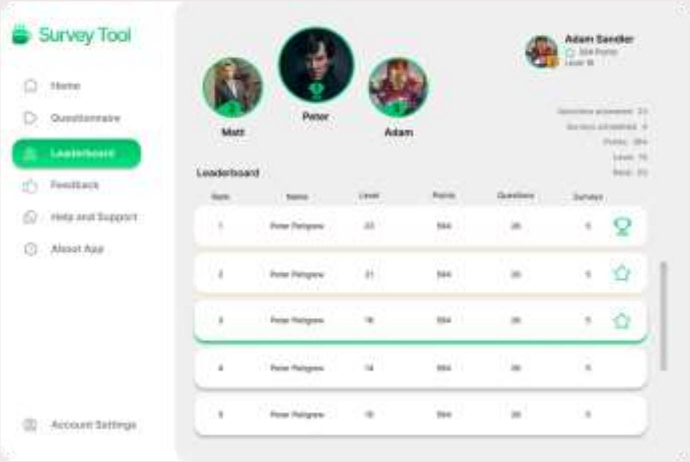
- Integreren gebruikersfeedback kan thermisch comfort verbeteren én energie besparen met wel 20%-40% in kantooromgevingen. (Y. Murakami, M. Terano, K. Mizutani, M. Harada, S. Kuno – 2007, Jazizadeh Farrokh, Ghahramani Ali, Becerik-Gerber Burcin, Kichkaylo Tatiana, Orosz Michael – 2014)

# Survey tool

Engageren van gebouwgebruikers

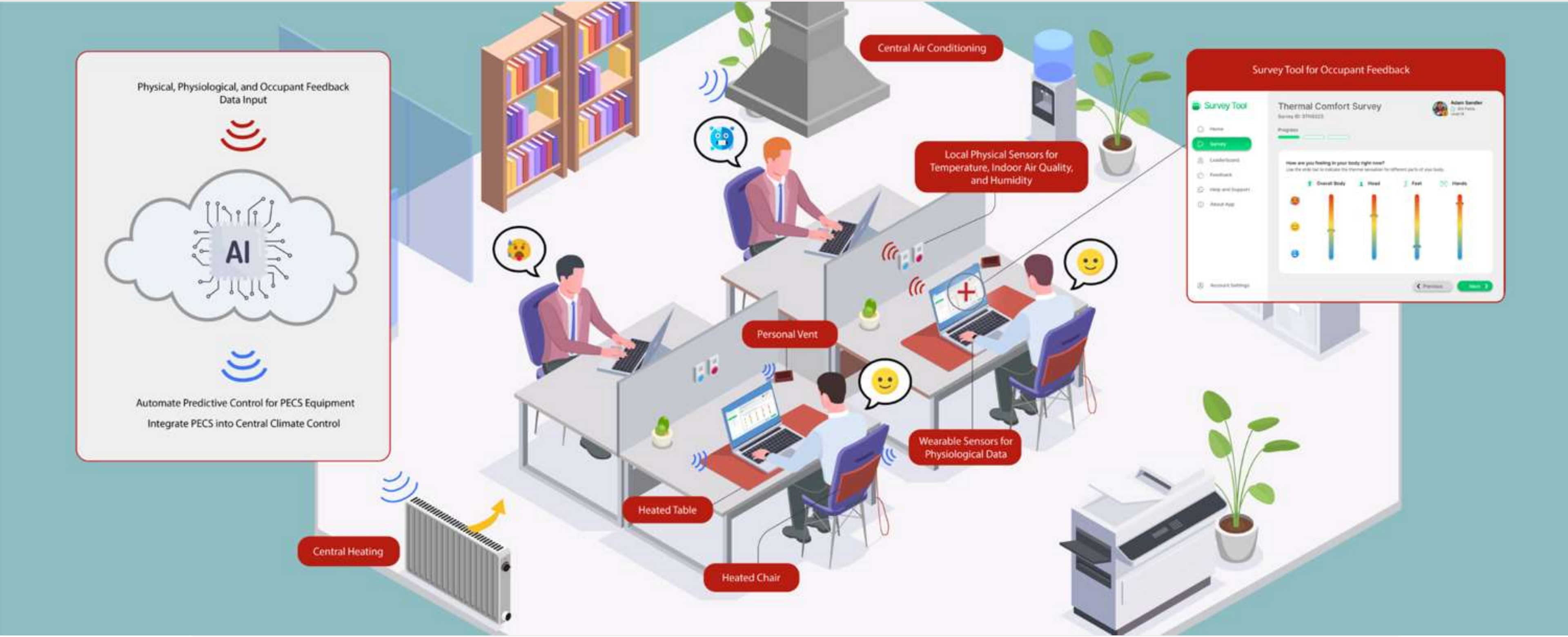
- Responsieve vragenlijsten: Gericht vragen.
- Automatische notificaties: Alleen wanneer nodig.
- Gamification: Verbeterde betrokkenheid.




(S. Atulugama, EngD-kandidaat, 2024, TUE)

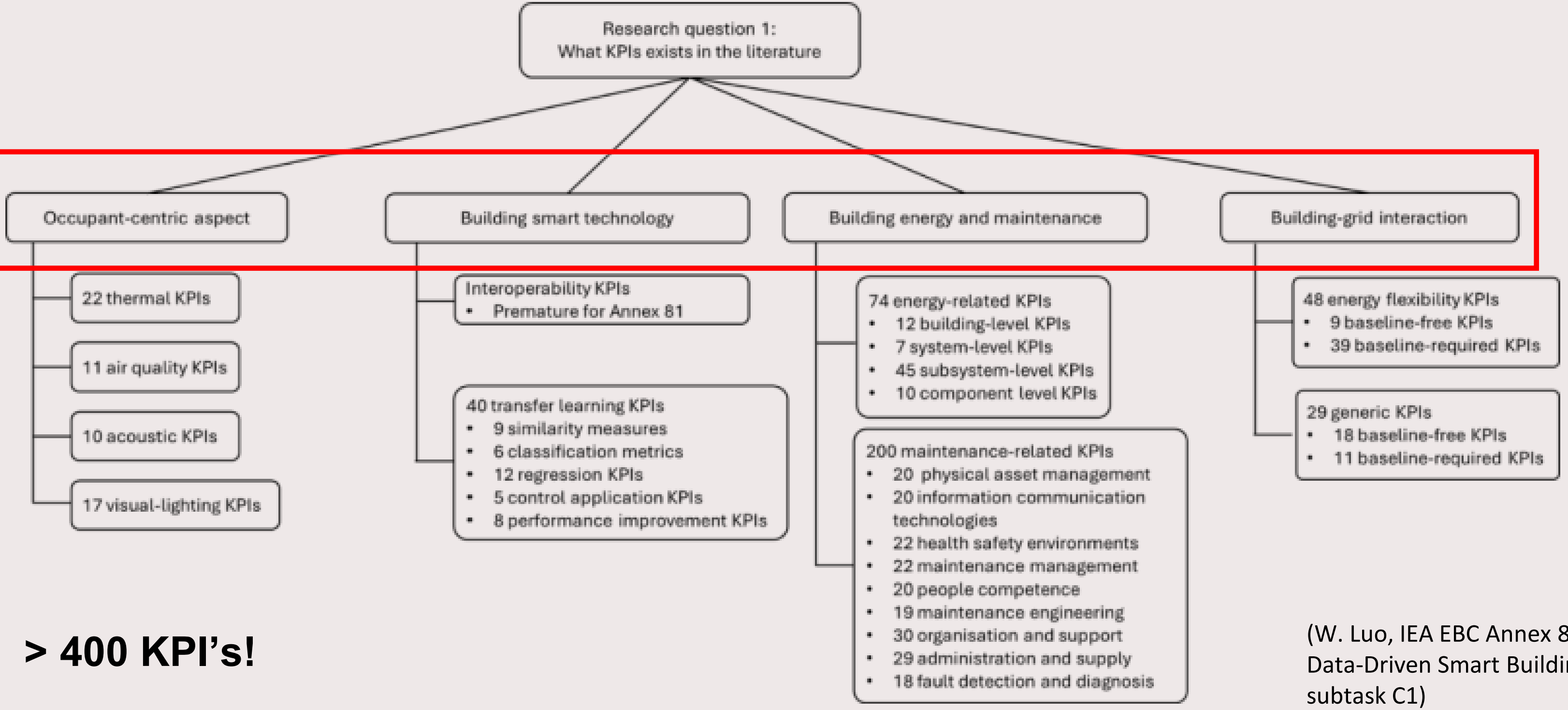
# Vooruitzicht



# Van data naar KPI’s: Voor wie en wanneer?

**Uninformed data** → **Key Performance Indicators**

# Bestaande KPI's: Literatuurstudie




**Link met SRI**

**> 400 KPI's!**

(W. Luo, IEA EBC Annex 81 - Data-Driven Smart Buildings, subtask C1)

# Welke KPI’s kunnen bepaald worden?

Gebaseerd op GBS data

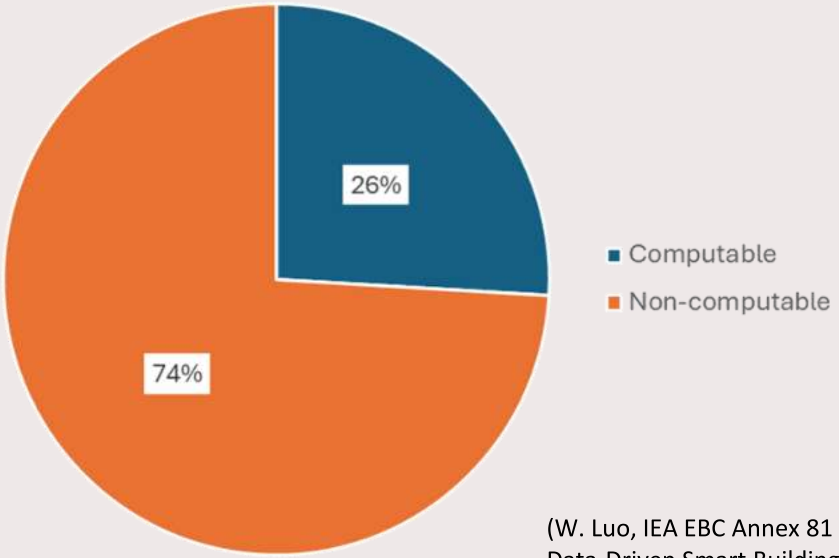
Gebouwen:

- 4 in Nederland
- 1 in Zwitzerland
- 2 in Denemarken
- 7 in Noorwegen

Uitdagingen:


Sensor & data availability

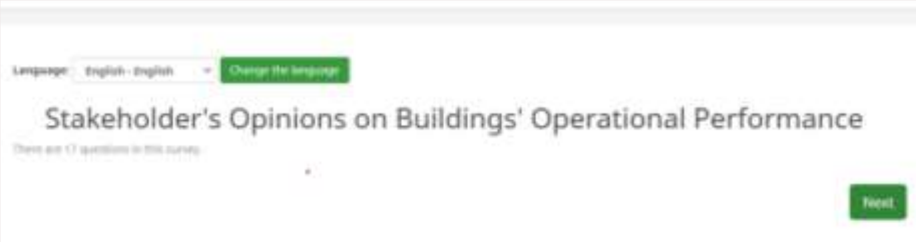
Data pre-processing & calculation method

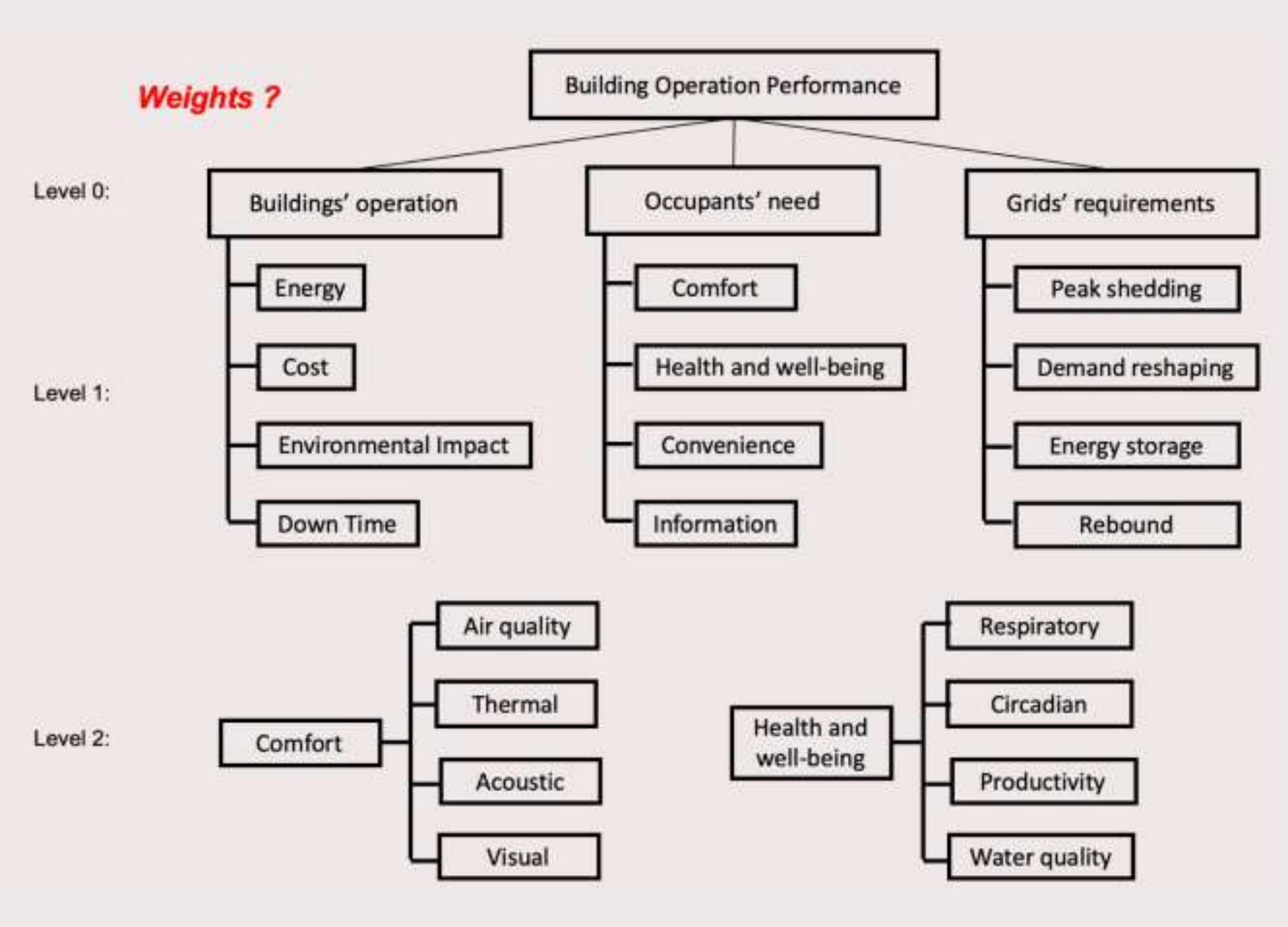


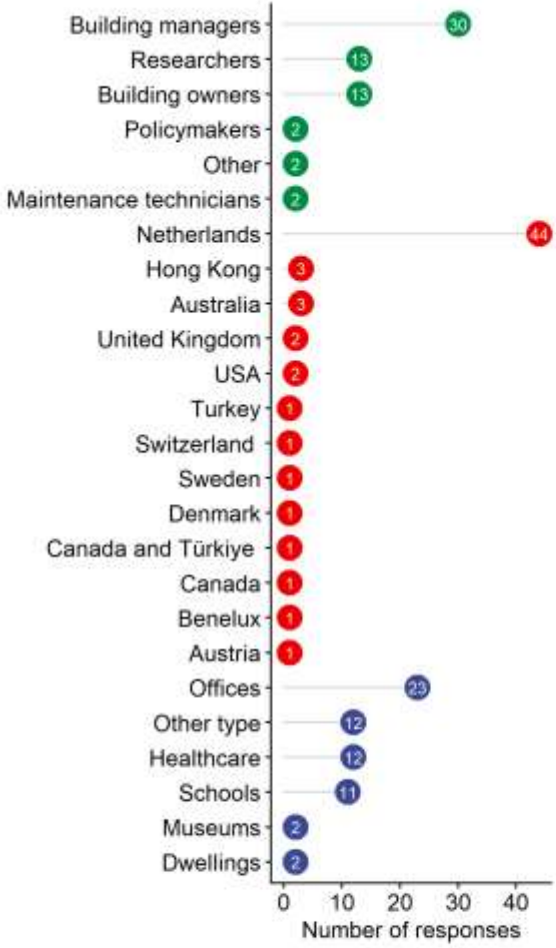

(W. Luo, IEA EBC Annex 81 - Data-Driven Smart Buildings, subtask C1)

# Welke (meta)KPI’s zijn belangrijk en voor wie?

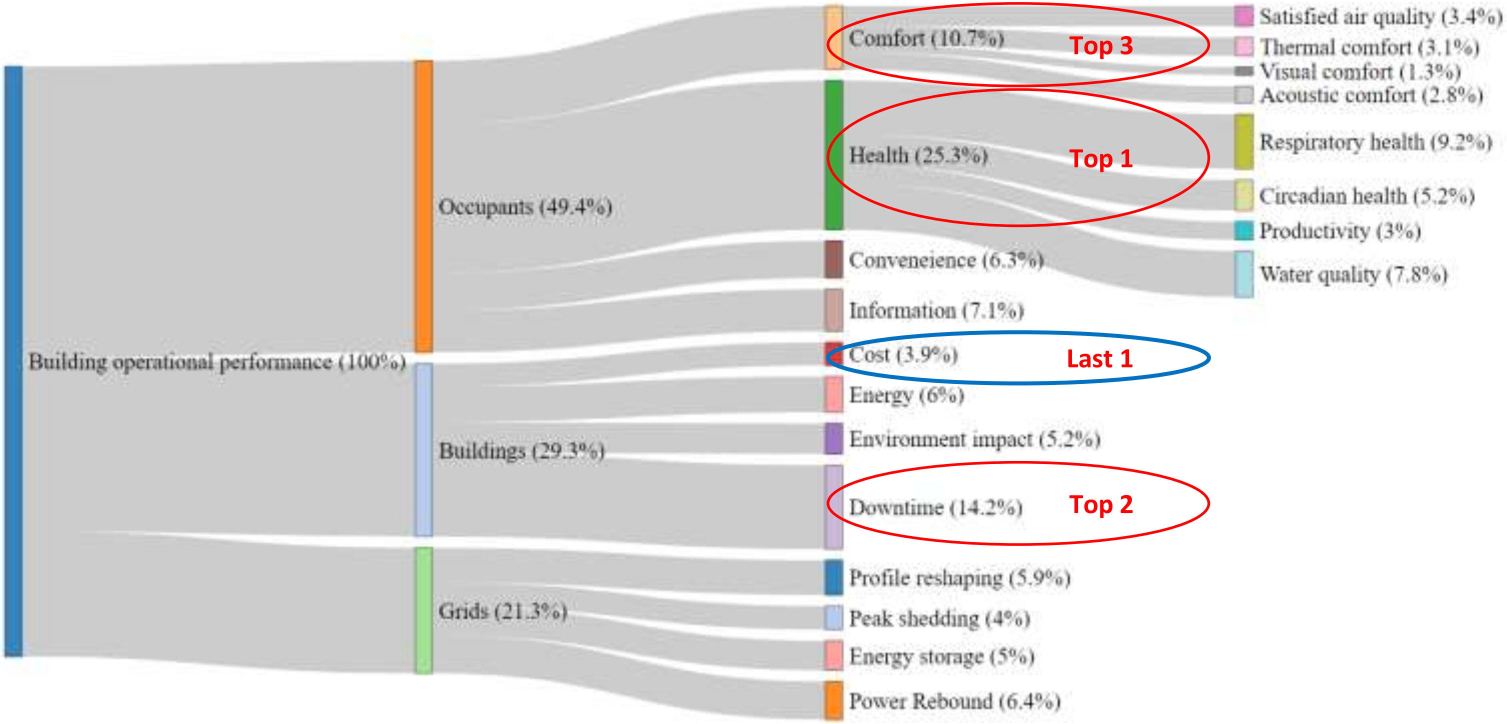
Vragenlijst uitgezet door Building G100:



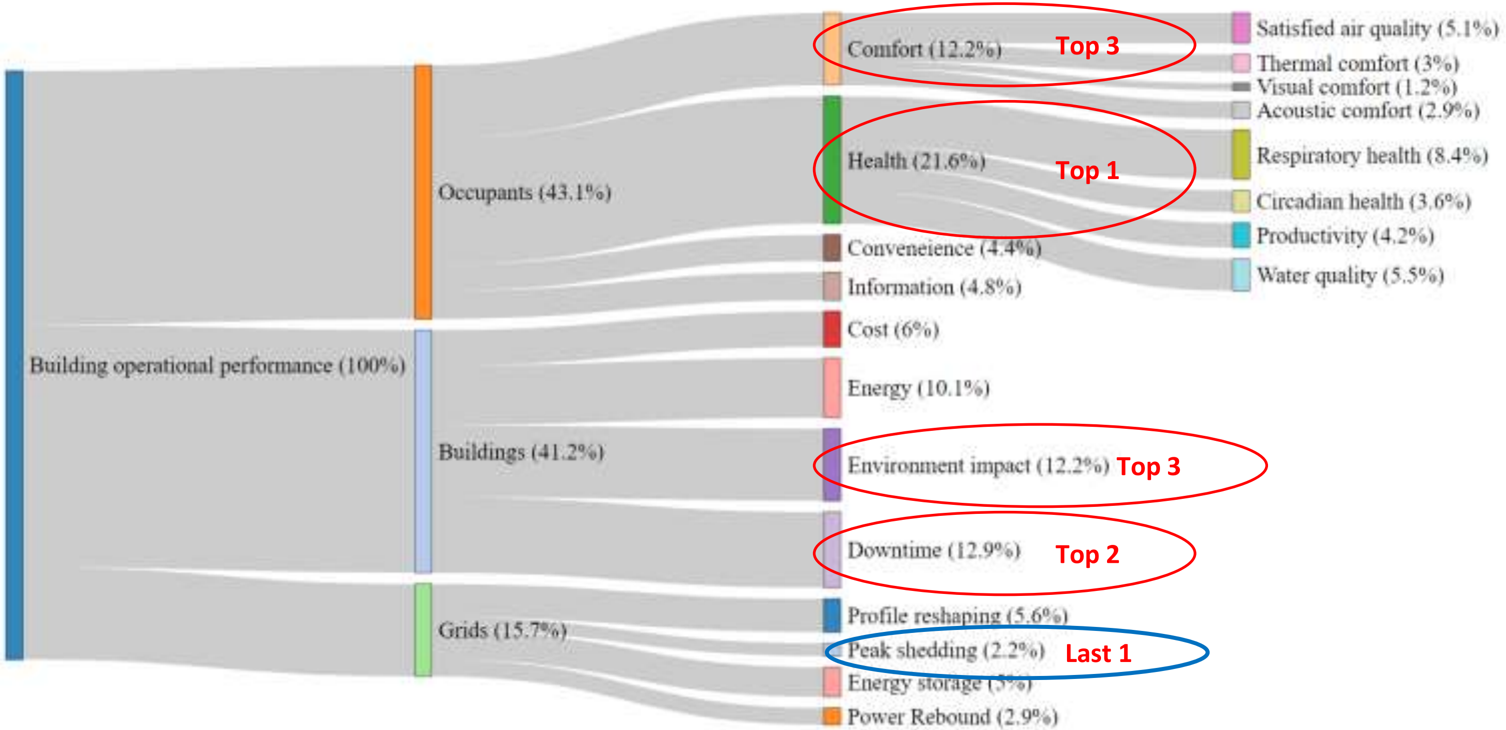


Weights ?
Building Operation Performance
Level 0:
Buildings' operation
Occupants' need
Grids' requirements
Level 1:
Energy
Cost
Environmental Impact
Down Time
Comfort
Health and well-being
Convenience
Information
Peak shedding
Demand reshaping
Energy storage
Rebound
Level 2:
Comfort
Air quality
Thermal
Acoustic
Visual
Health and well-being
Respiratory
Circadian
Productivity
Water quality


Building managers 30
Researchers 13
Building owners 13
Policymakers 2
Other 2
Maintenance technicians 2
Netherlands 44
Hong Kong 3
Australia 3
United Kingdom 2
USA 2
Turkey 1
Switzerland 1
Sweden 1
Denmark 1
Canada and Türkiye 1
Canada 1
Benelux 1
Austria 1
Offices 23
Other type 12
Healthcare 12
Schools 11
Museums 2
Dwellings 2
0
10
20
30
40
Number of responses

# Resultaten gebouwbeheerders (N=27)



# Resultaten gebouweigenaren (N=13)



# Afsluitend

**Partners: Kennisinstellingen, installatiebedrijven, adviesbureaus, platform & interface-ontwikkelaars, gebouweigenaren en -beheerders, leveranciers en  branche-organisaties.**

# Ter discussie

- Data maakt veel mogelijk, maar gerichte aanpak is essentieel:
  - Wat moeten we meten en waar?
  - Hoe halen we informatie uit data?
  - Hoe presenteren we die informatie: Voor wie?

- Machine Learning maakt veel mogelijk, maar:
  - Hoe borgen we interpreteerbaarheid en schaalbaarheid?
  - Hoe sluiten we aan met (beroeps)opleidingen?
  - Hoe sluiten marktpartijen aan? Nieuwe business modellen?

# Data- en expertgedreven aanpak voor efficiënte én effectieve installaties: Van onderzoek naar maatschappelijke impact