



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

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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



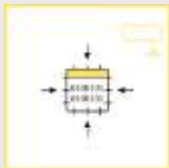
Energieverspilling door slechtwerkende gebouwinstallaties



Balanceren vraag en aanbod bij inzet hernieuwbare energie



Klachten rondom comfort en welbevinden

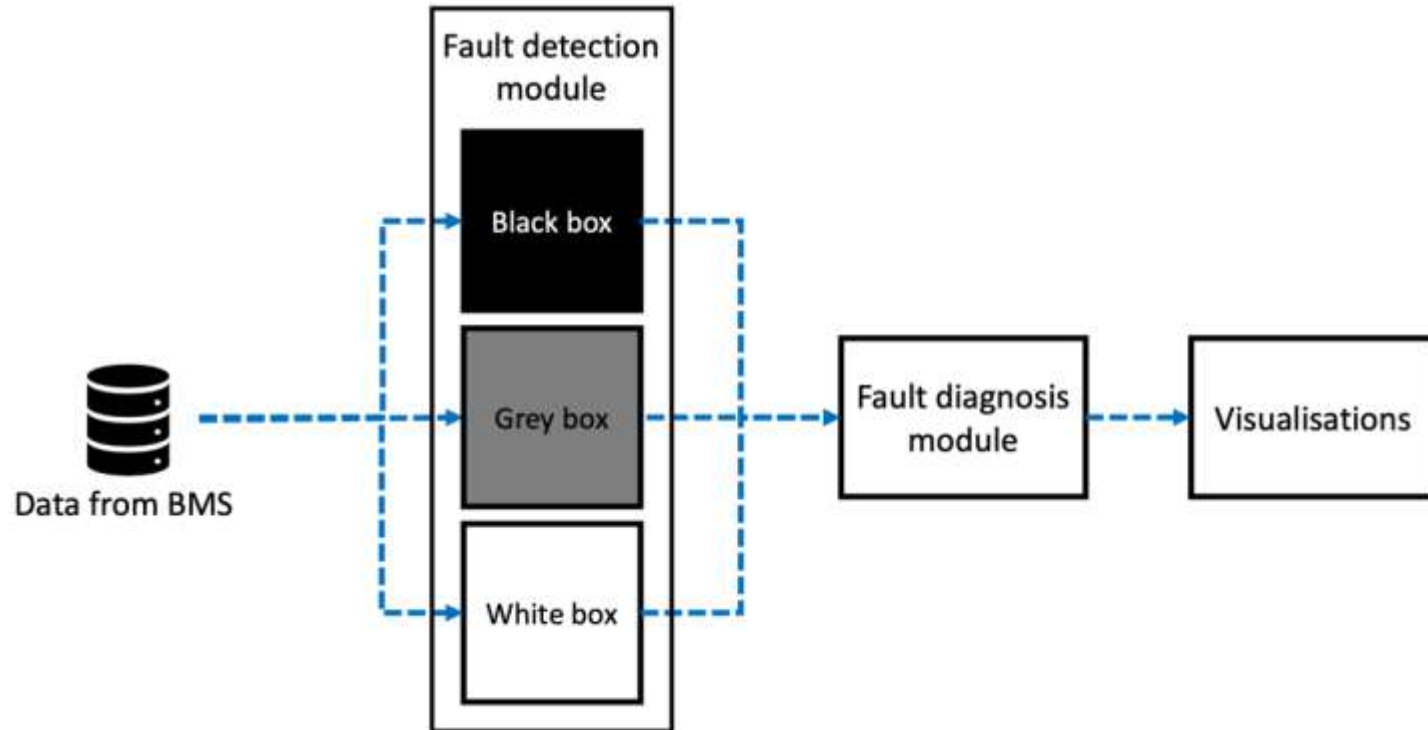


Gebrek aan interoperabiliteit van bestaande systemen

Brains4Buildings: Beoogde oplossingen



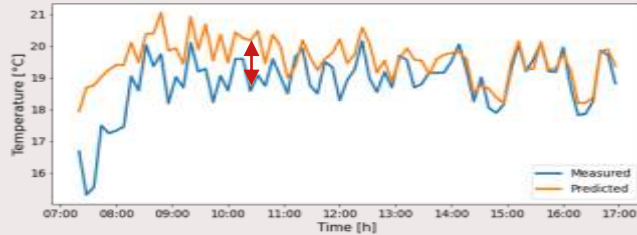
Automatische foutdetectie én foutdiagnose



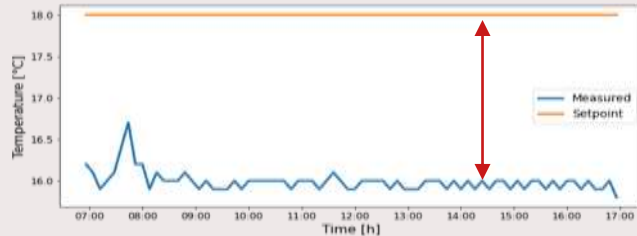
Automatische foutdetectie én foutdiagnose

Machine Learning: symptoom-DETECTIE

ML-Based
Fault
Detection

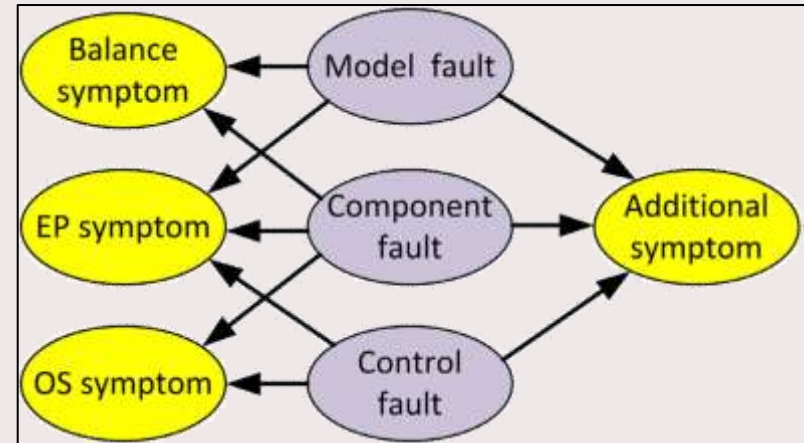


Rules-Based
Fault
Detection



(A. Thamban, 2021, TUE)

Bayesiaans Netwerk: fout-DIAGNOSE



(A. Taal, proefschrift, 2021, TUE)

Automatische foutdiagnose: Bayesiaans netwerk

Diagnose ziekten

Bijvoorbeeld:

A: Koorts

B: Hoesten

C: Vermoeidheid

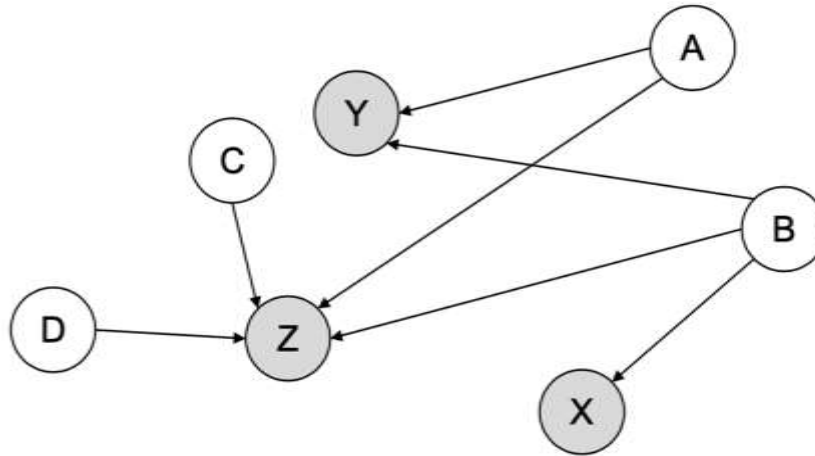
D: Smaakverlies

Diagnose:

x: Verkoudheid

y: Griep

z: Covid



Automatische foutdiagnose: Bayesiaans netwerk

Diagnose ziekten

Bijvoorbeeld:

A: Koorts

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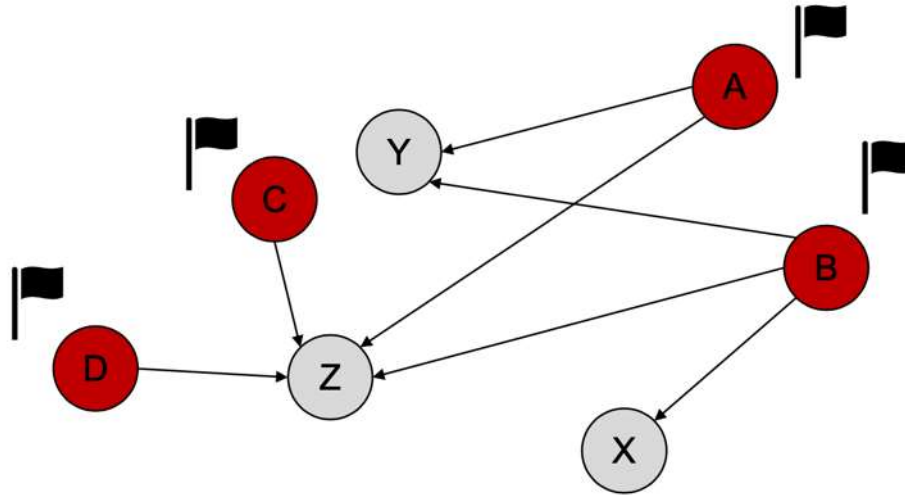
D: Smaakverlies

Diagnose:

x: Verkoudheid

y: Griep

z: Covid



Koorts + Hoesten + Vermoeidheid + Smaakverlies → COVID

Automatische foutdiagnose: Bayesiaans netwerk

Voorbeeld luchtbehandelingskast:

A: Status LBK aan/uit

B: Aandrijfriem gebroken

C: Filter gescheurd

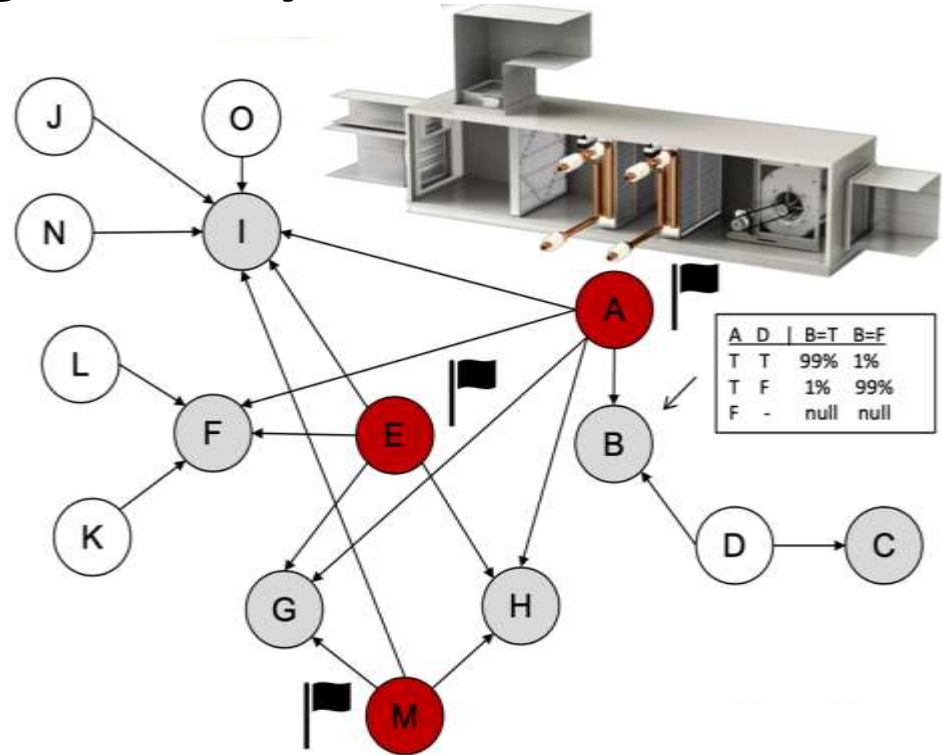
D: Druk over filter = 0

E: Te weinig capaciteit

F: Hittegolf

G: Vastzittende koelklep

H: Veel bezoekers



Ingrediënten

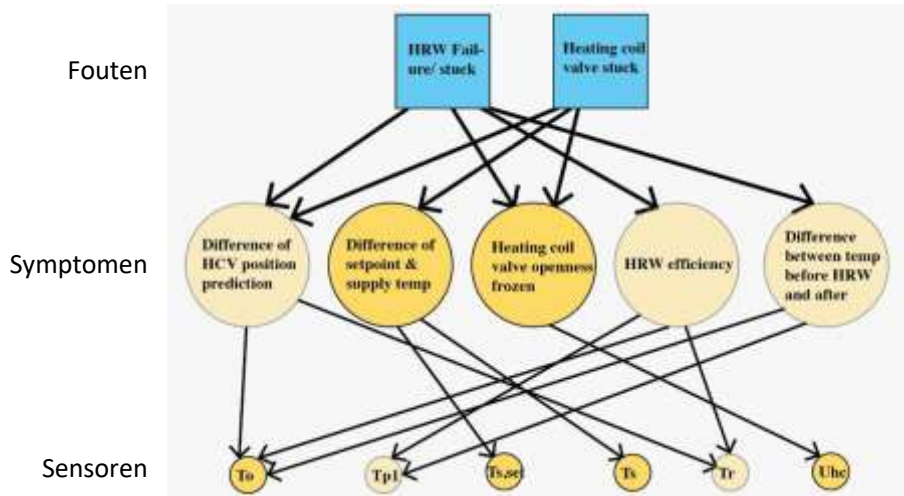
- Sensor-technologie
- Data-technologie
- Cloud: o.a. t.b.v. Machine Learning
- Dashboards: Interactief, KPI's.



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 |

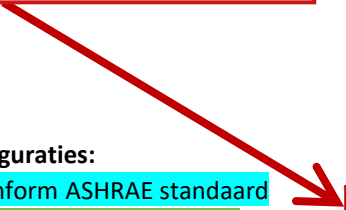
(Z. Wang, C. Lu, L. Itard, 2023, TUD)

LBK sensor-configuratie: Situatie in Nederland

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

| 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 | |

Slechts 4 LBK's conform ASHRAE standaard!



Definitie van sensor-configuraties:

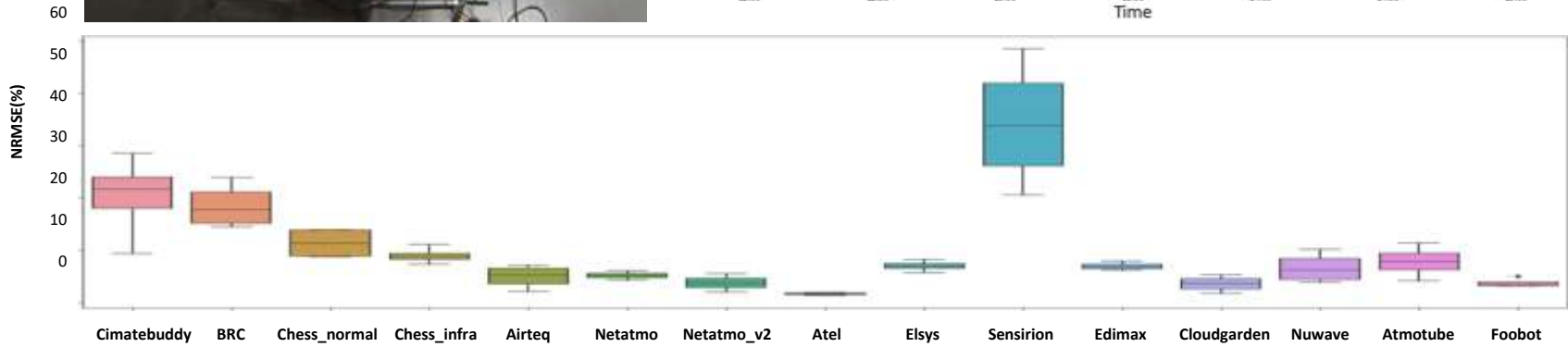
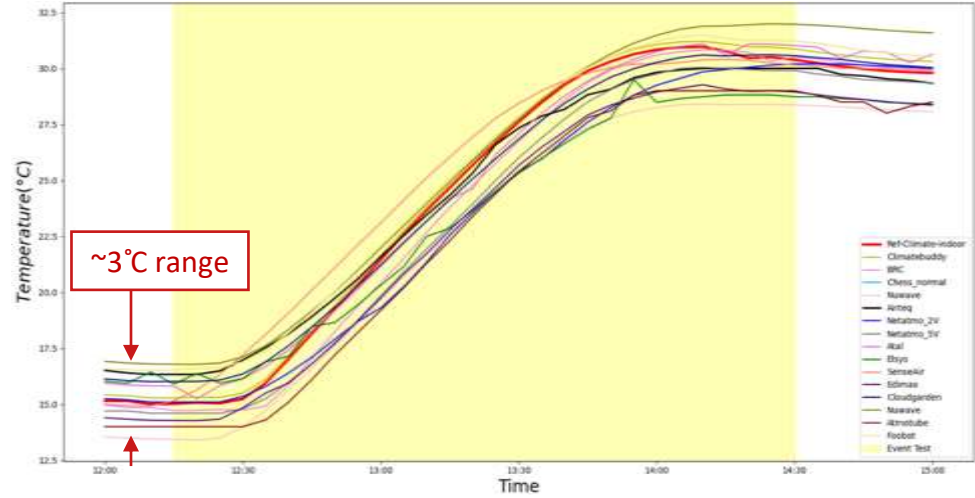
- ❑ **Limited:** LBK's niet conform ASHRAE standaard
- ❑ **Standard:** LBK's conform ASHRAE standaard
- ❑ **Redundant:** LBK's met meer sensoren dan ASHRAE

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

Smart Buildings: Sensoren

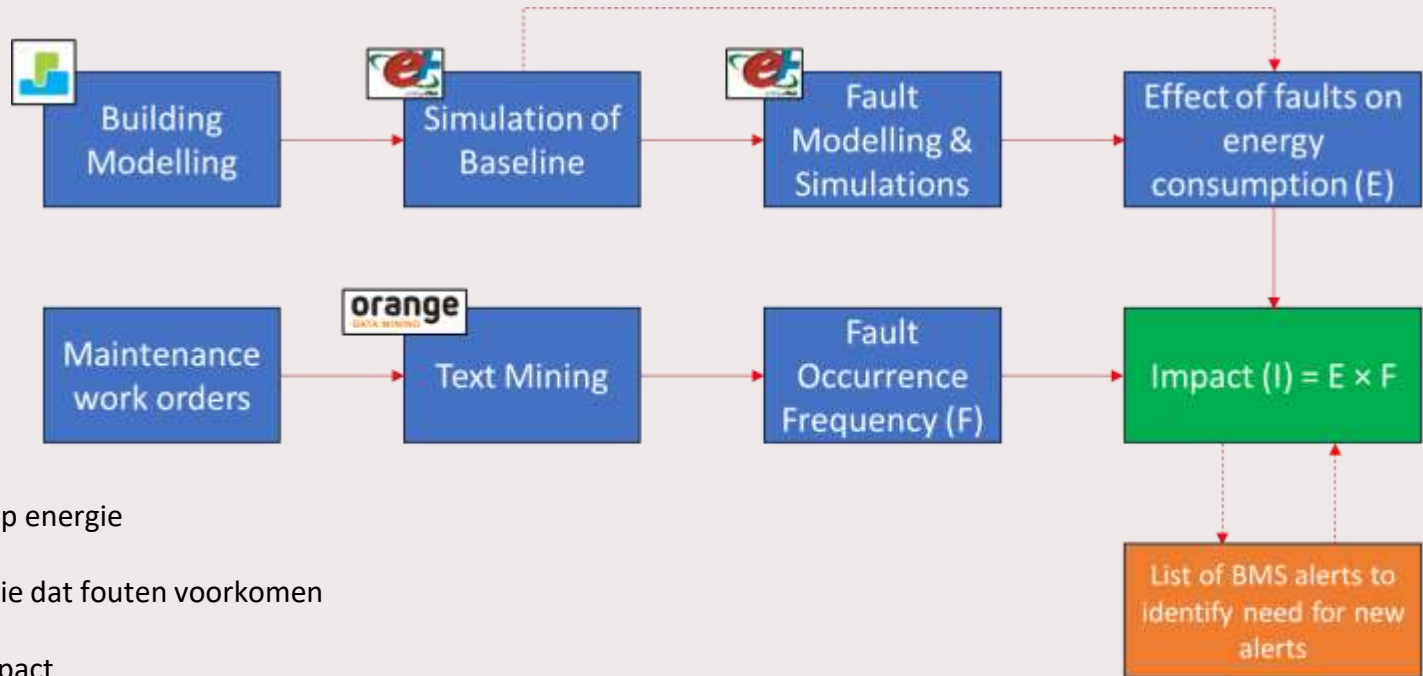
- Low-cost monitors
- Virtuele (soft) sensoren





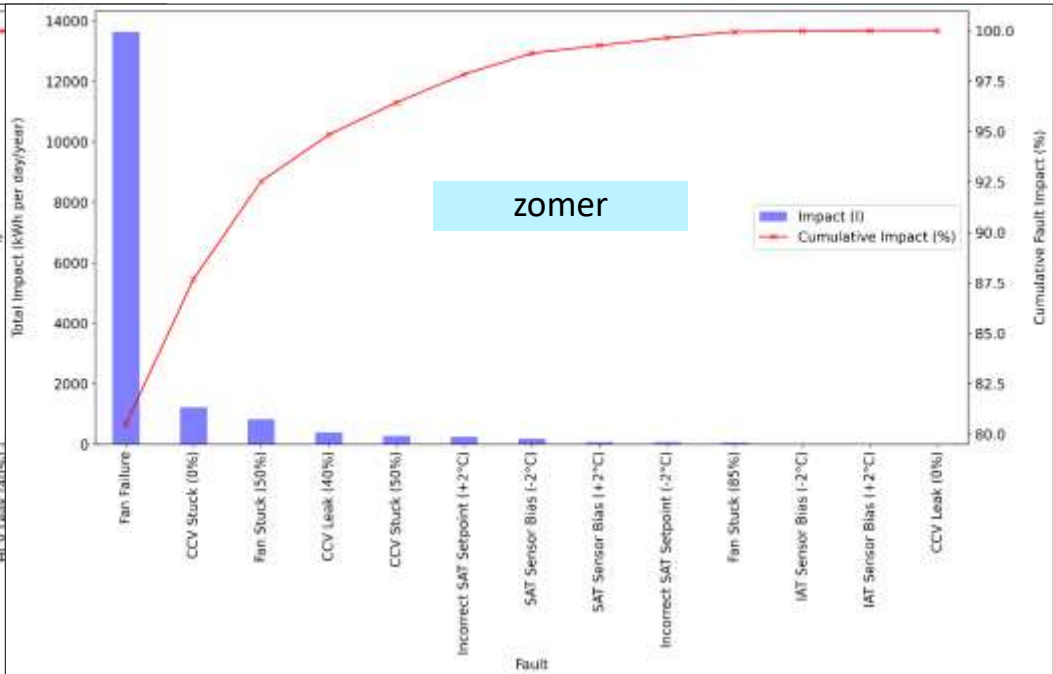
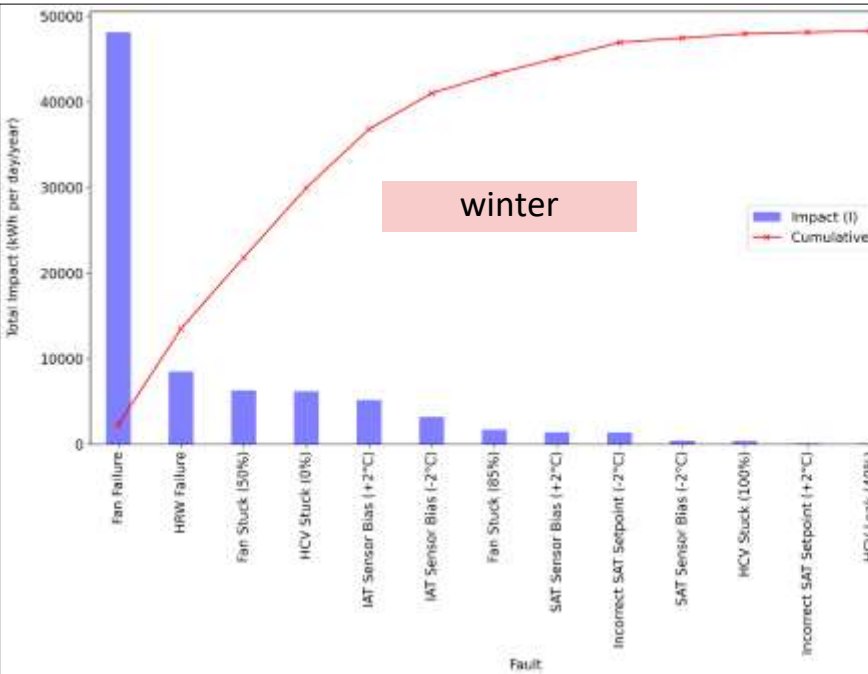
Van data naar symptoomdetectie

Fouten prioriteren



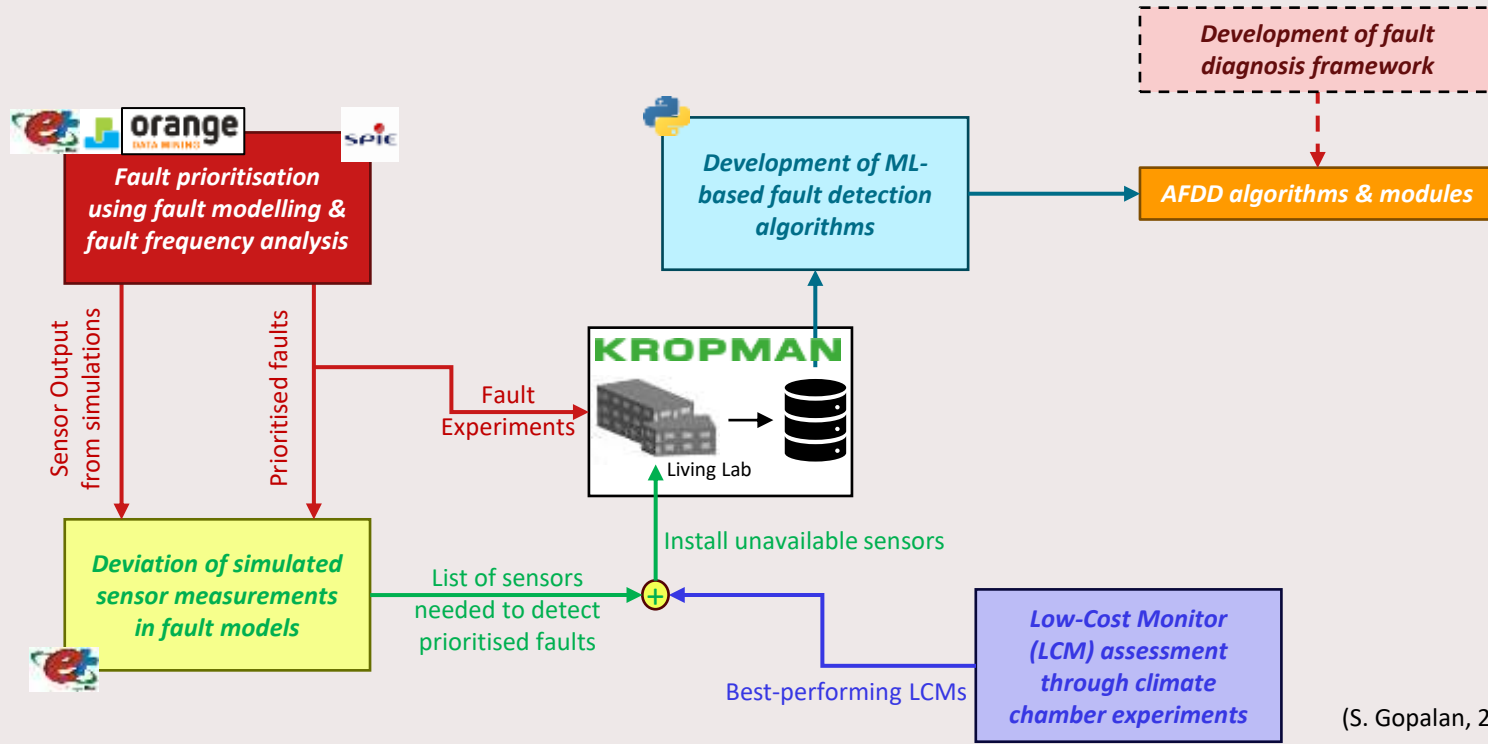
- $I = E \times F$
- 'E' = impact op energie
- 'F' = frequentie dat fouten voorkomen
- 'I' = totale impact

Fouten prioriteren



(S. Gopalan, 2024, TUE)

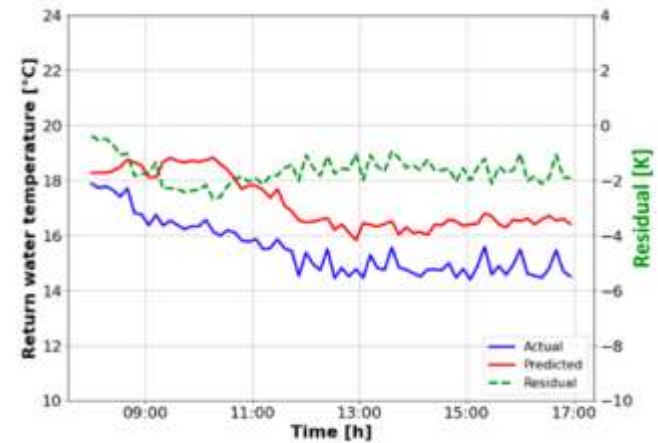
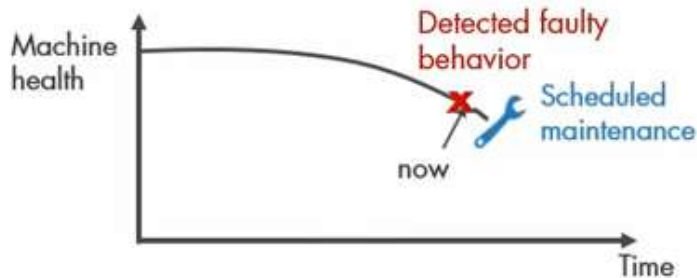
Foutdetectie: Van simulatie naar de praktijk



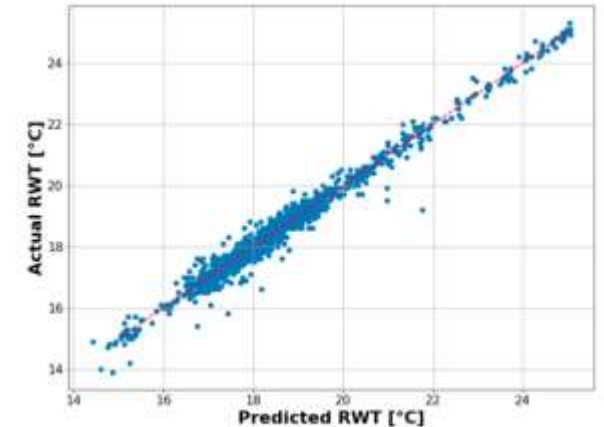
(S. Gopalan, 2024, TUE)

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



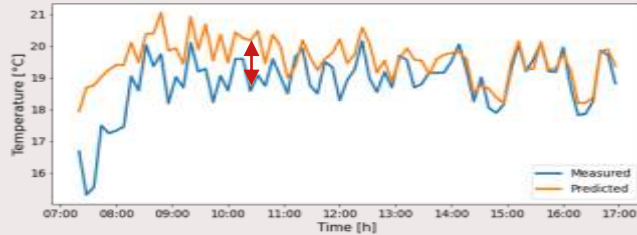
Performance evaluation of ML model (3 months fault-free data)

Van symptoomdetectie naar foutdiagnose

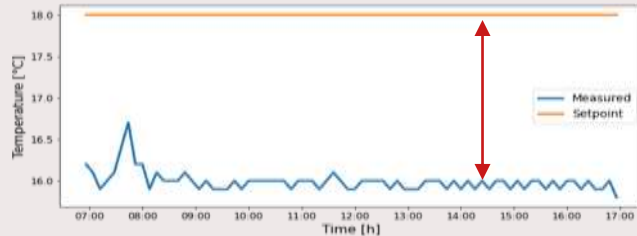
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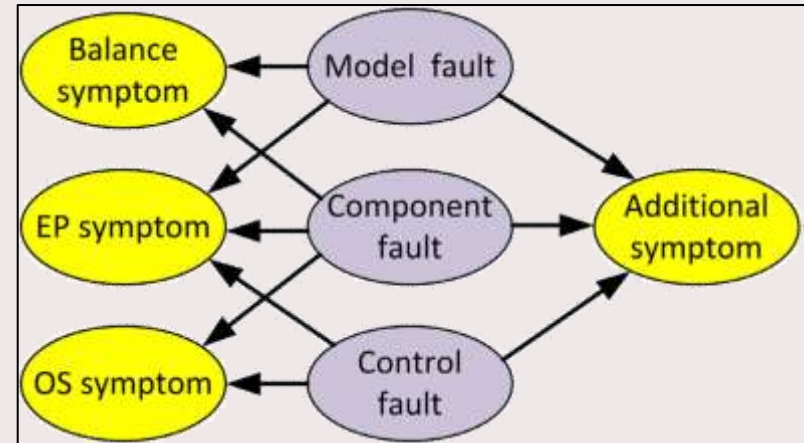


Rules-Based
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(A. Thamban, 2021, TUE)

Bayesiaans Netwerk: fout-DIAGNOSE

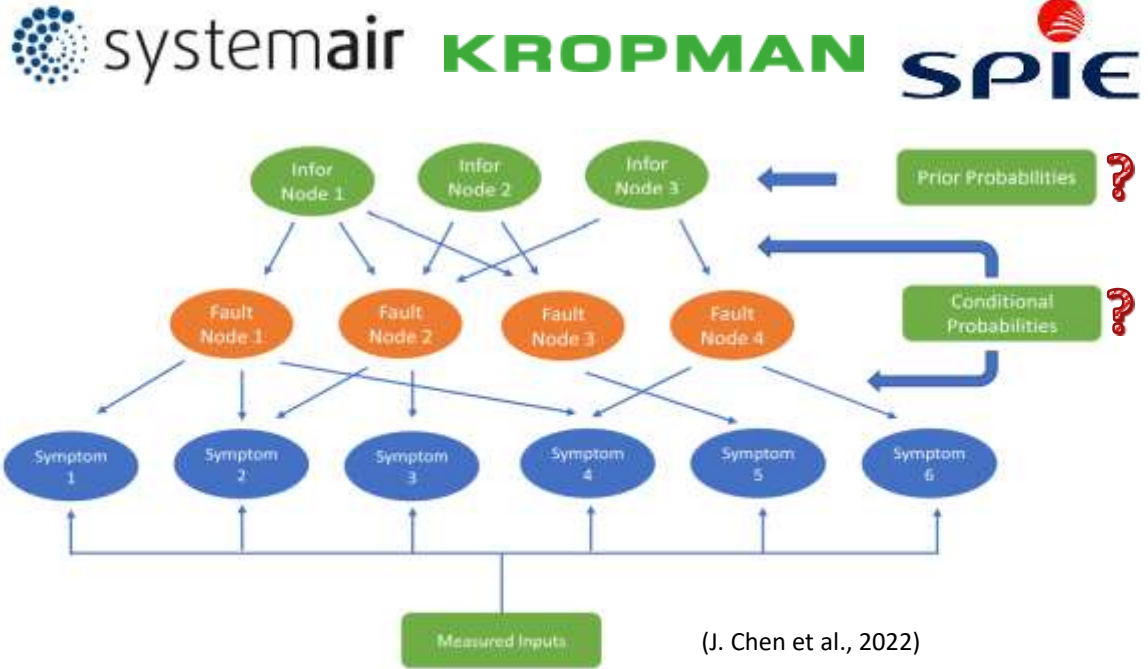


(A. Taal, 2021, TUE)

Data-gedreven en op kennis gebaseerde DBN's

Interviews met experts:

- DBN structuur
- Prior probabilities
- Conditional probabilities



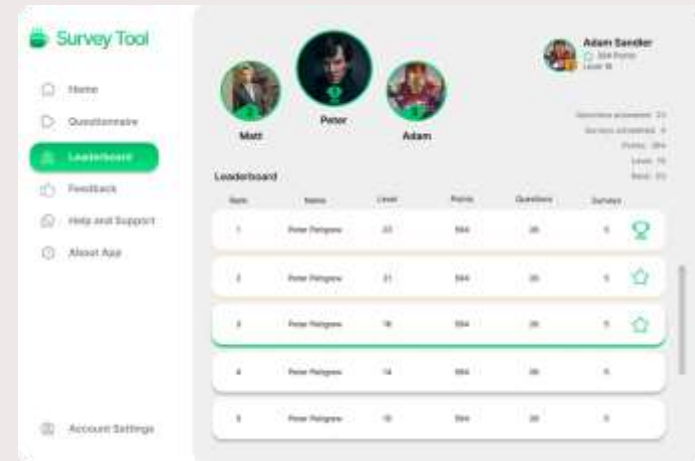
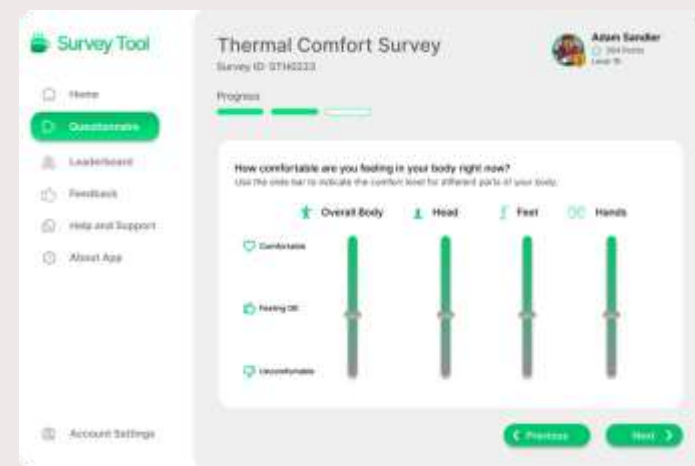
Gebouwgebruiker centraal: Subjectieve data

- 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

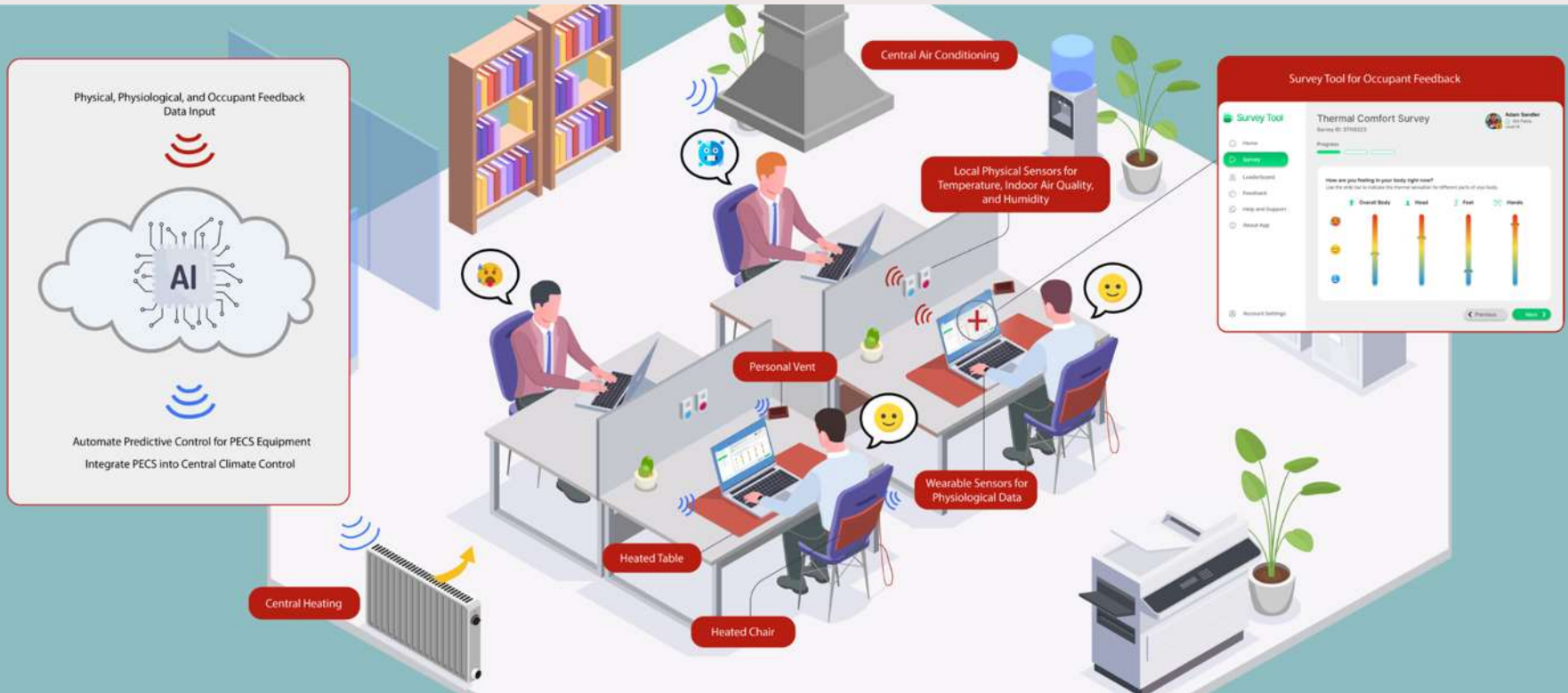
Engageren van gebouwgebruikers

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

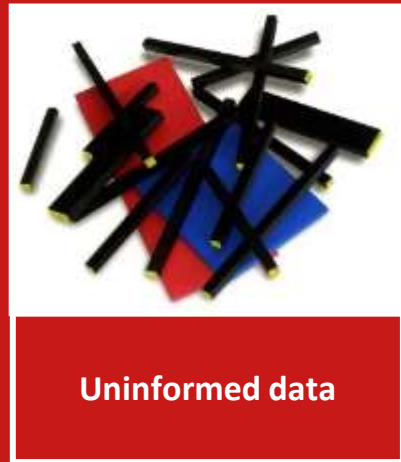


(S. Atulugama, EngD-kandidaat, 2024, TUE)

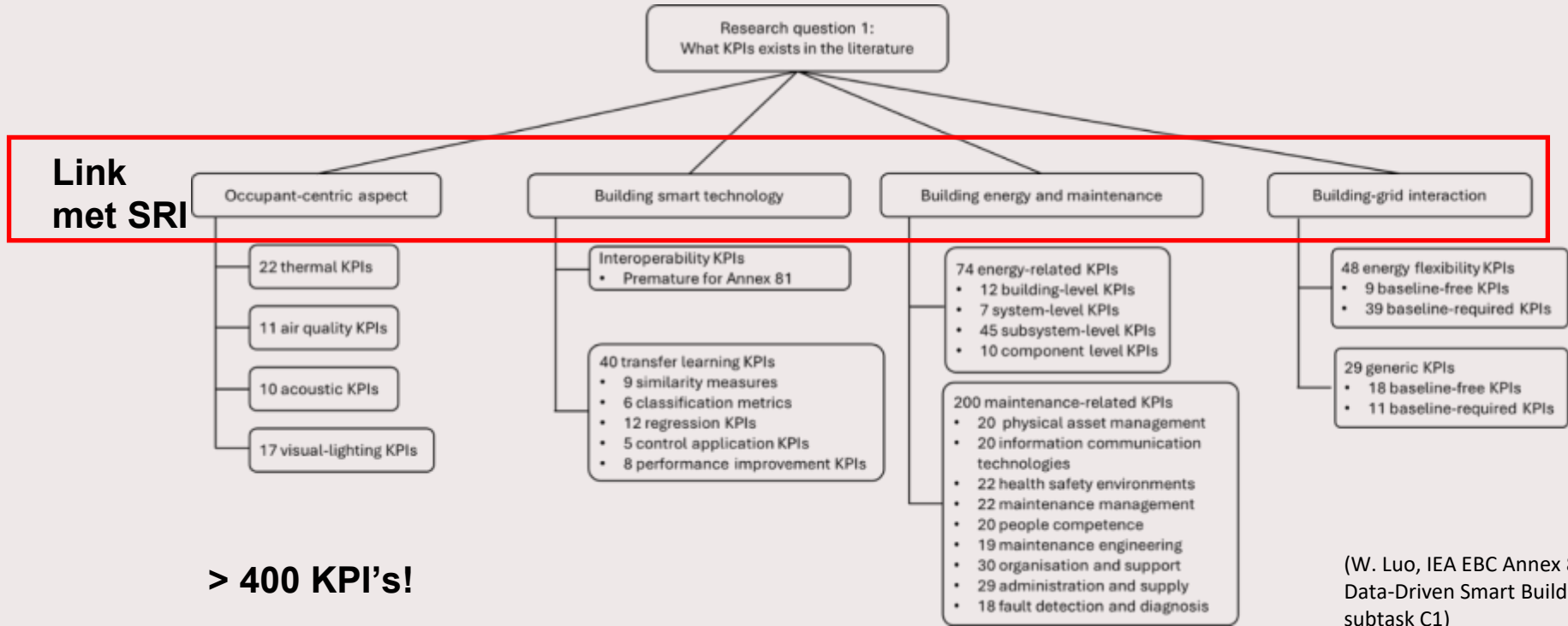
Vooruitzicht



Van data naar KPI's: Voor wie en wanneer?



Bestaande KPI's: Literatuurstudie



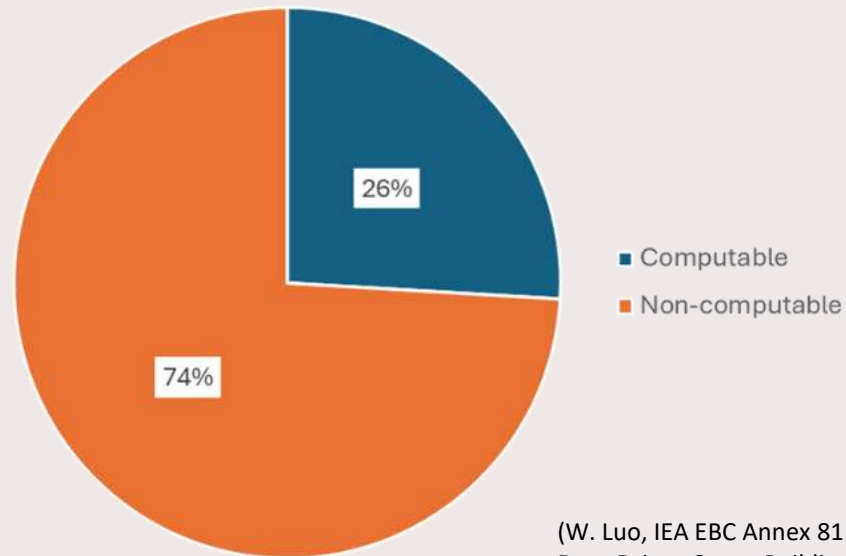
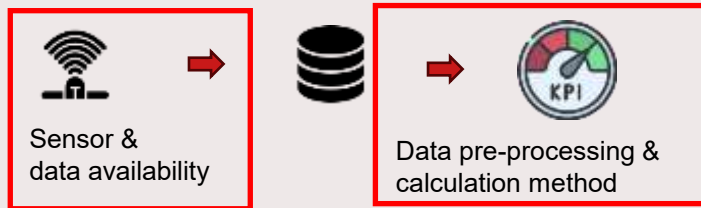
Welke KPI's kunnen bepaald worden?

Gebaseerd op GBS data

Gebouwen:

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

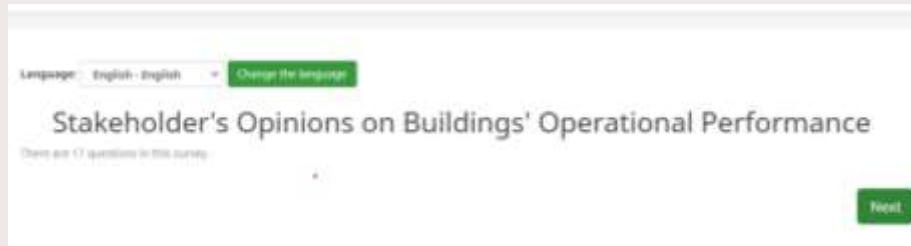
Uitdagingen:



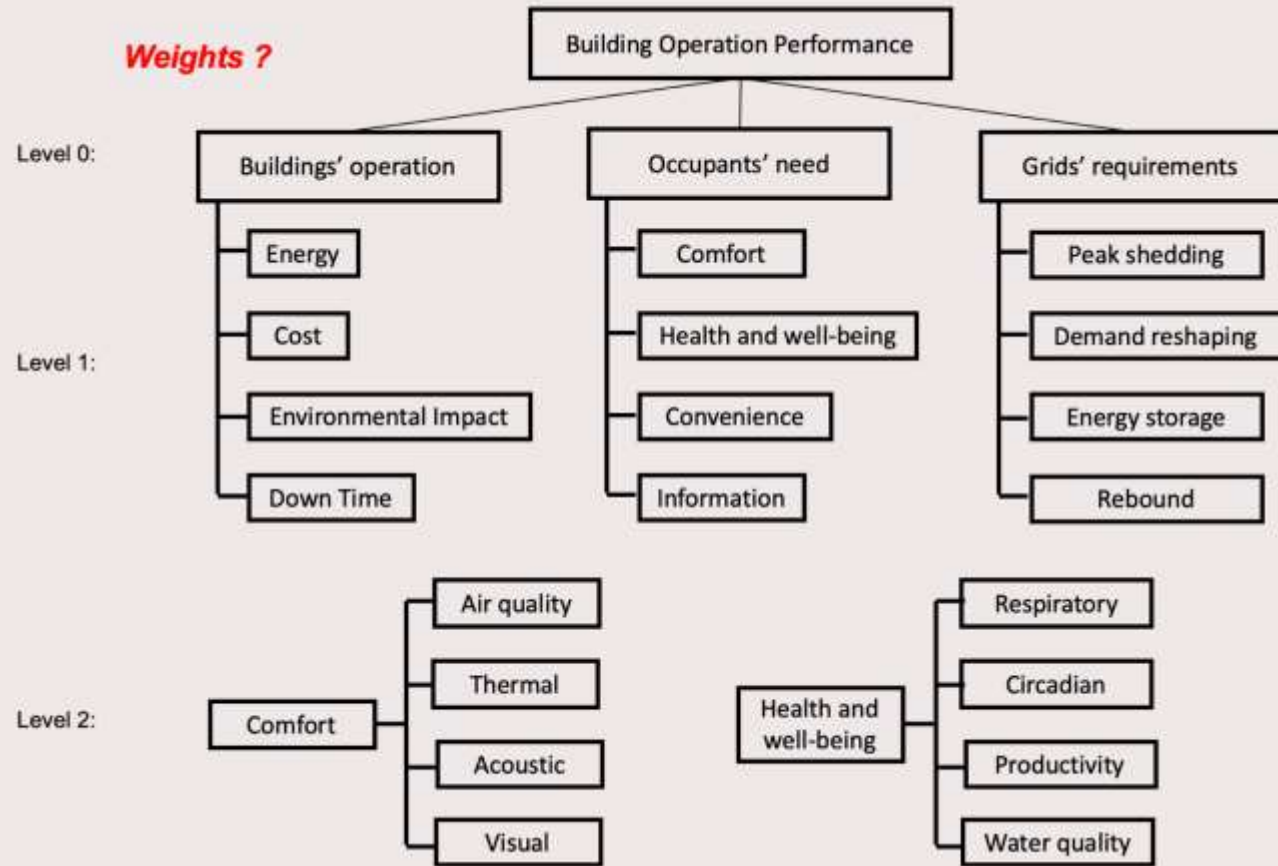
(W. Luo, IEA EBC Annex 81 - Data-Driven Smart Buildings, subtask C1)

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

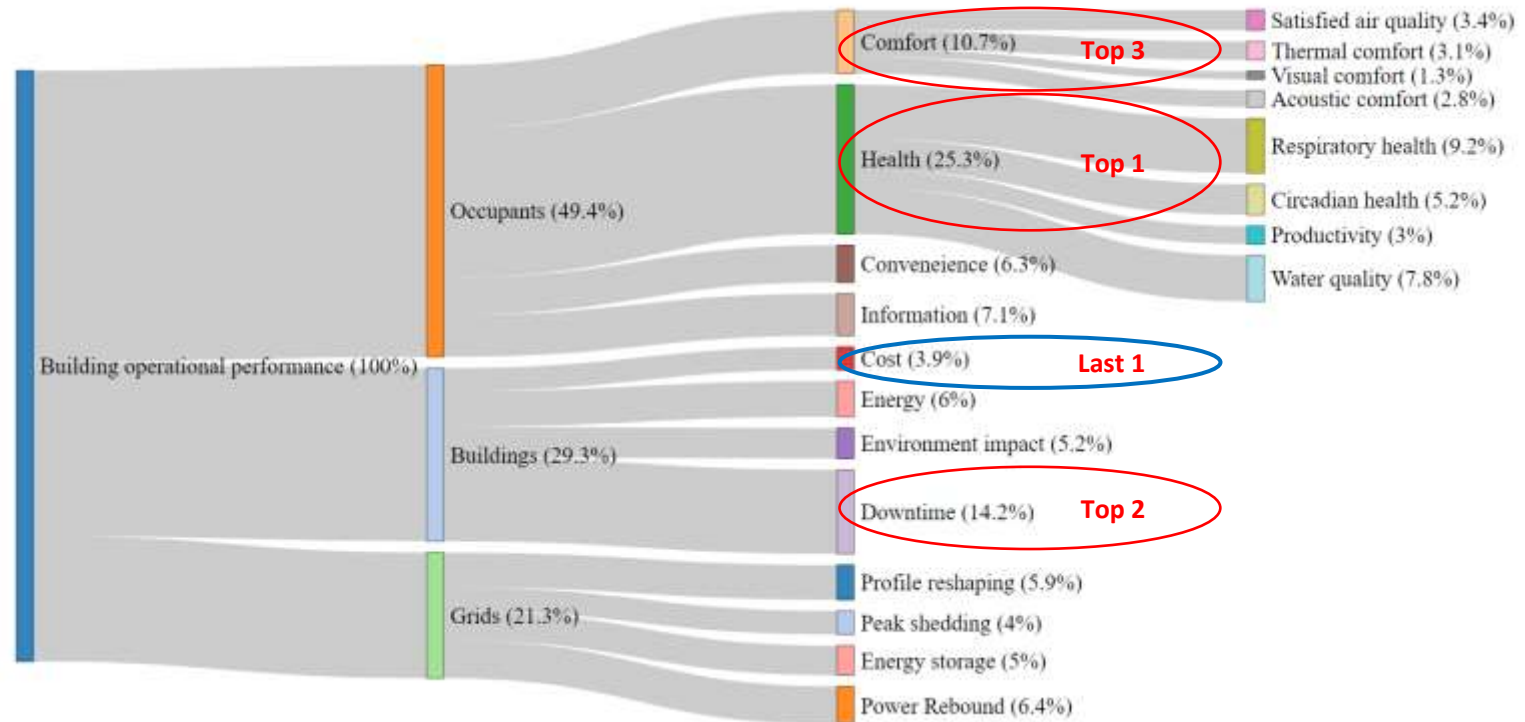
Vragenlijst uitgezet door Building G100:



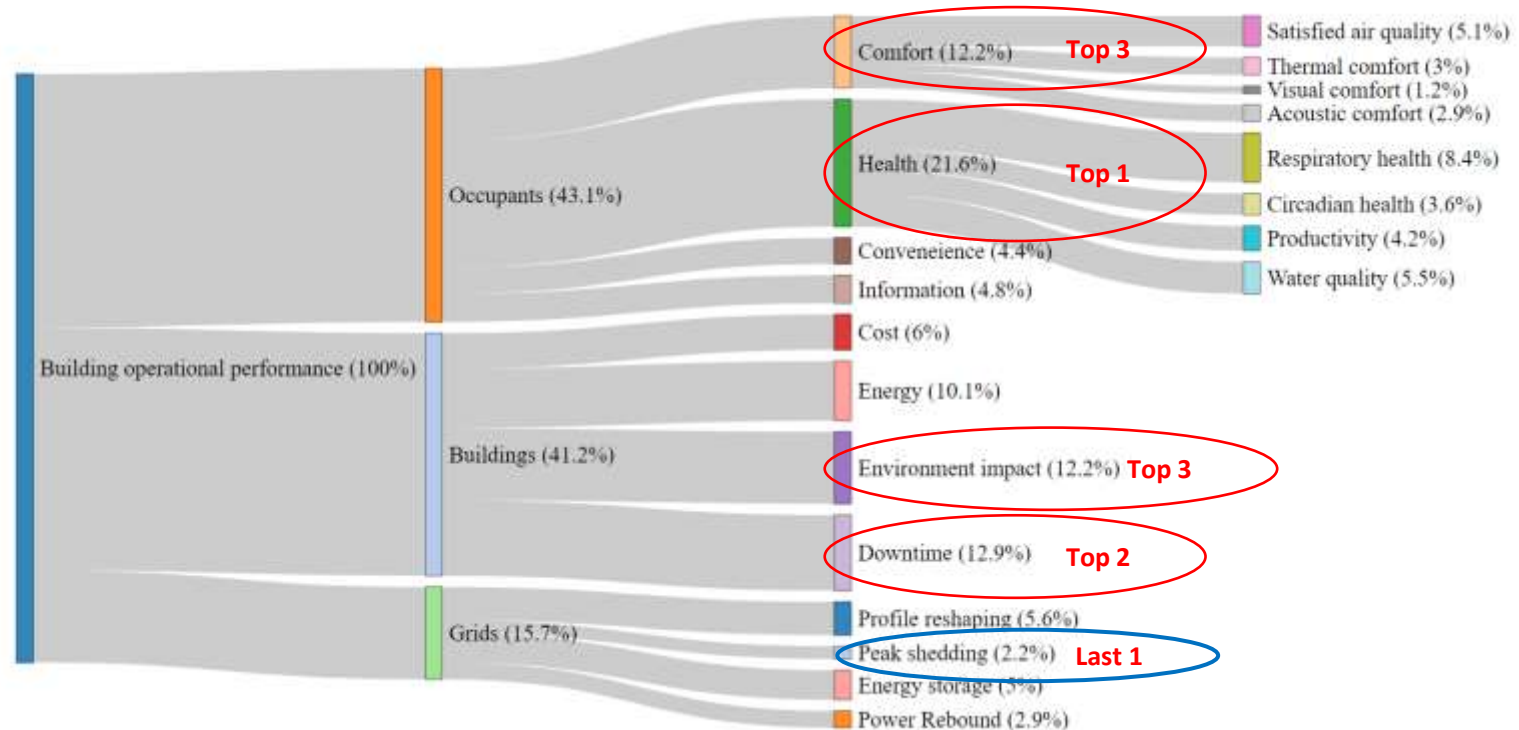
Weights ?



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

