Rethinking Building Performance during the Operational Phase

Towards increased implementation and adoption of system- and occupant-centric assessments

By Kamilla Heimar Andersen
Ph.D. Defense, BUILD – Department of the Built Environment, Aalborg University
14th of November 2024

Background of the Ph.D. project

- BUILD – Department of the Built Environment, Aalborg University: 2021-2024
- Ph.D. project supported by the European Union's Horizon 2020 research and innovation programme and several partners through the research project "Self-Assessment Towards Optimization of Building Energy" (SATO)
- Main supervisor:
  - Associate Professor Anna Marszal-Pomianowska
- Co-supervisors:
  - Professor Per K. Heiselberg
  - Associate Professor Henrik K. Nielsen

Content

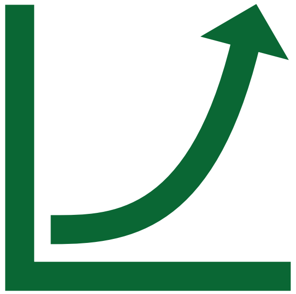
Content

Why focus on buildings?

A problem

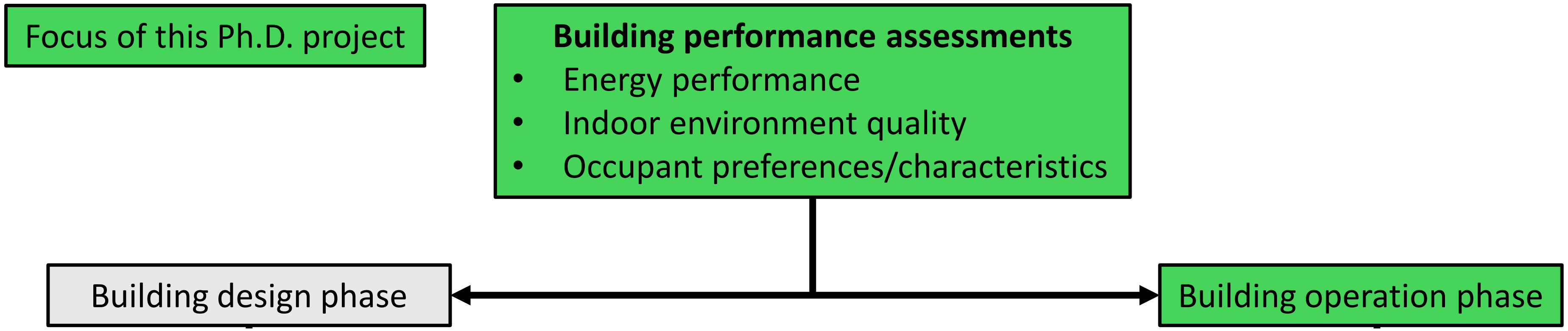
Buildings in the world:
36 % energy use

A potential solution



Increase and access to data:
Unlocking potential to rethink and perform building performance assessments

Building Performance Assessments



Building Performance Assessments

Focus of this Ph.D. project

Building performance assessments
- Energy performance
- Indoor environment quality
- Occupant preferences/characteristics

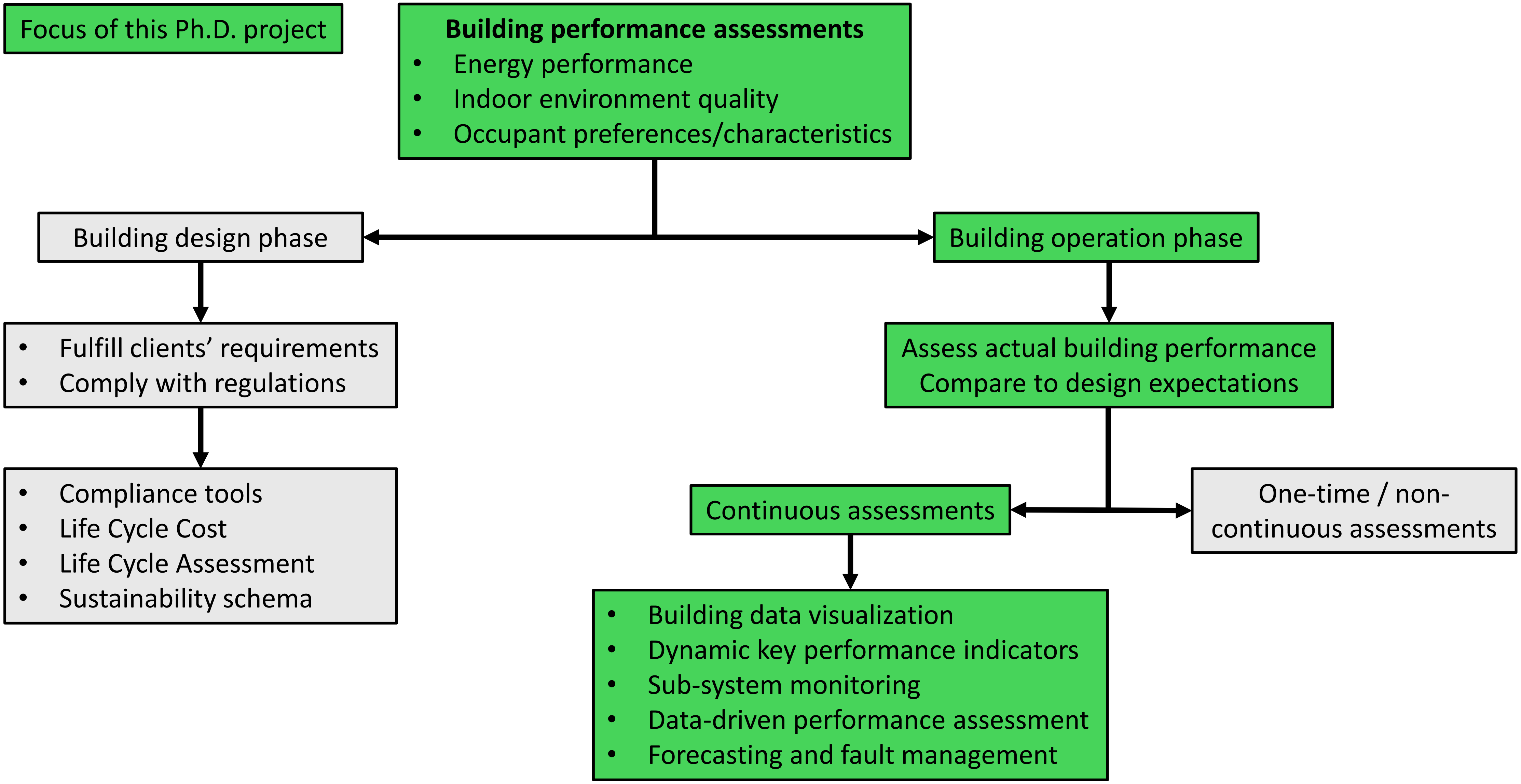
Building design phase

- Fulfill clients' requirements
- Comply with regulations

- Compliance tools
- Life Cycle Cost
- Life Cycle Assessment
- Sustainability schema

Building operation phase

Building Performance Assessments



Actual building performance

Can be influenced by many factors

- Faults in building systems or control, tuning and calibration issues
- Occupant behavior (interaction wih systems)
- Outdoor conditions (temperature, precipitation)
- Renovations
- Maintenance practices
- Building not used as intended (design and layout)

Actual building performance

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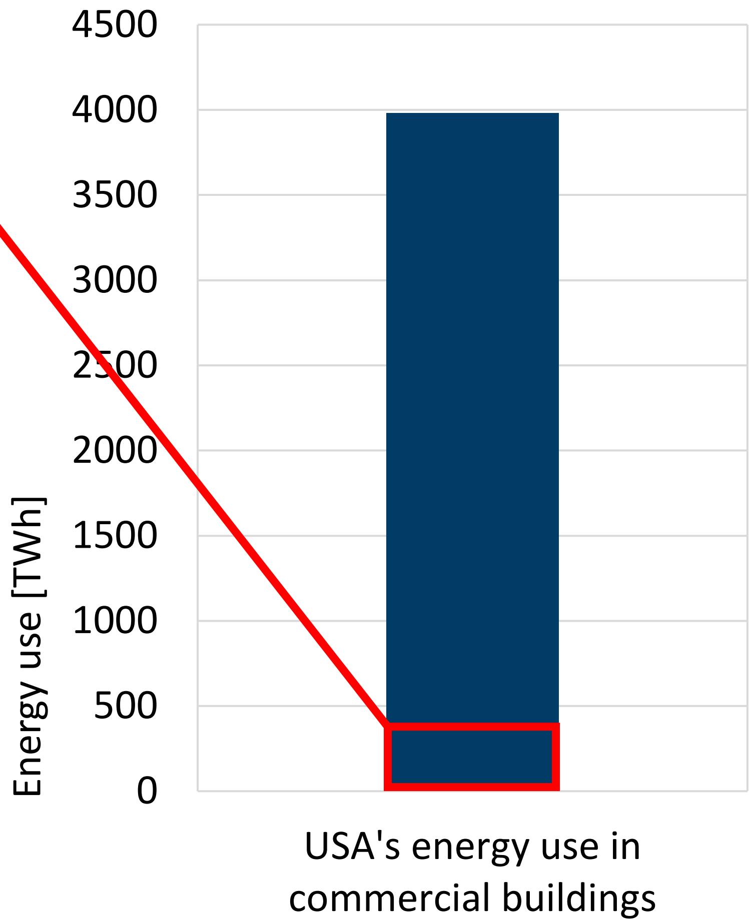
- Building not used as intended (design and layout)

Continuous System Assessments

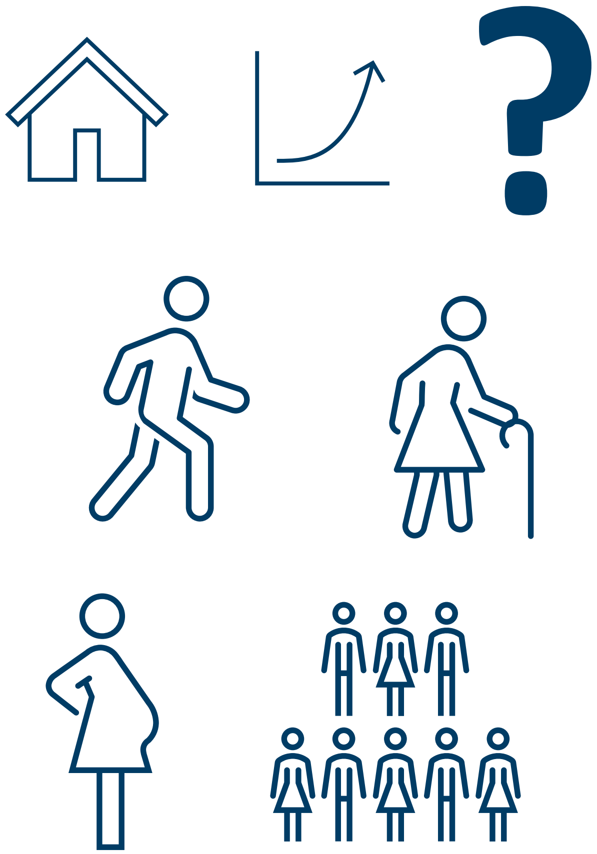
- 12 % of the energy use in commercial buildings in the USA are due to faults
- Tools for Fault Detection and Diagnose (FDD) show great promise for mitigating the latter
- **We still need to figure out**
  - Actual performance of FDD, when implemented and adopted
  - From a research and industry perspective
    - Challenges/barriers and drivers for FDD
    - Documented benefits of FDD



K. Roth et al., 2004

Occupant-Centric Assessments

- Until now in BPAs
  - Soley building and system focus
- But
  - Occupant behavior play a large role in building performance
- **We still need to figure out**
  - Identify which occupant characteristics are practical for BPAs
  - Explore how to integrate this information with energy and IEQ data
  - Consider additional characteristics or practices that could inspire improved management practices



Aim of the Ph.D. project

How can system and occupant-centric assessments contribute to informing decisions that enhance a building's operational efficiency and occupant well-being?

Content

Main publications

Chapter 3, Part I: System Assessments, papers 1 – 3

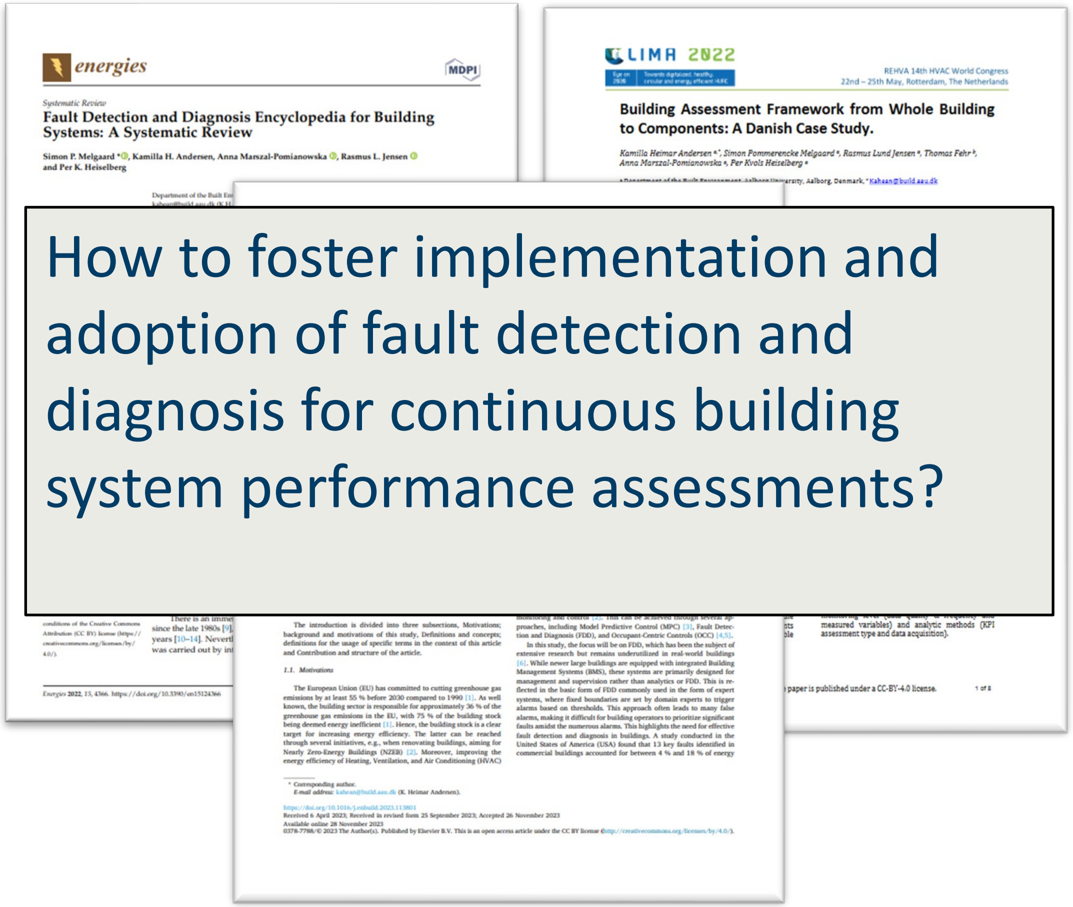
Two peer-reviewed journal articles and one conference article

Chapter 4, Part II: Occupant-Centric Assessments, papers 4 – 6

Three peer-reviewed journal articles

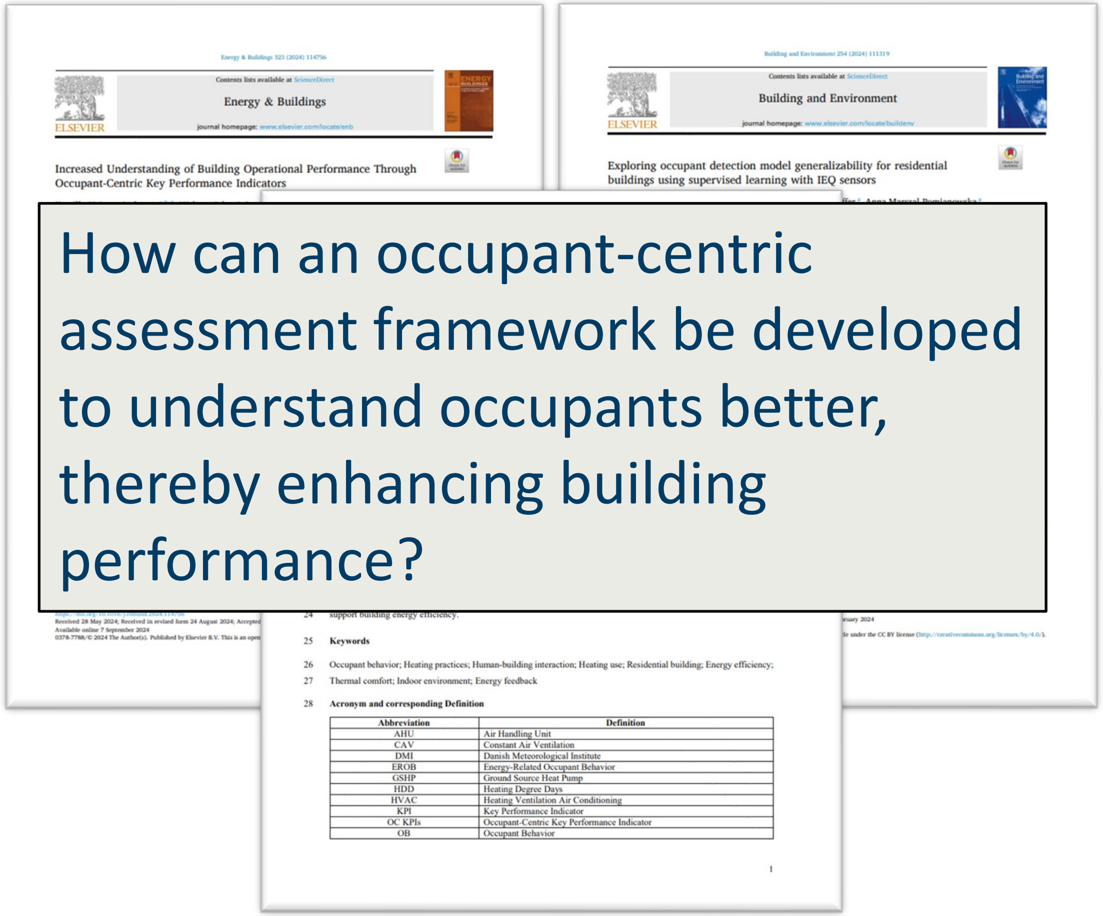
Research questions

Chapter 3, Part I: System Assessments, papers 1 – 3



How to foster implementation and adoption of fault detection and diagnosis for continuous building system performance assessments?

Chapter 4, Part II: Occupant-Centric Assessments, papers 4 – 6

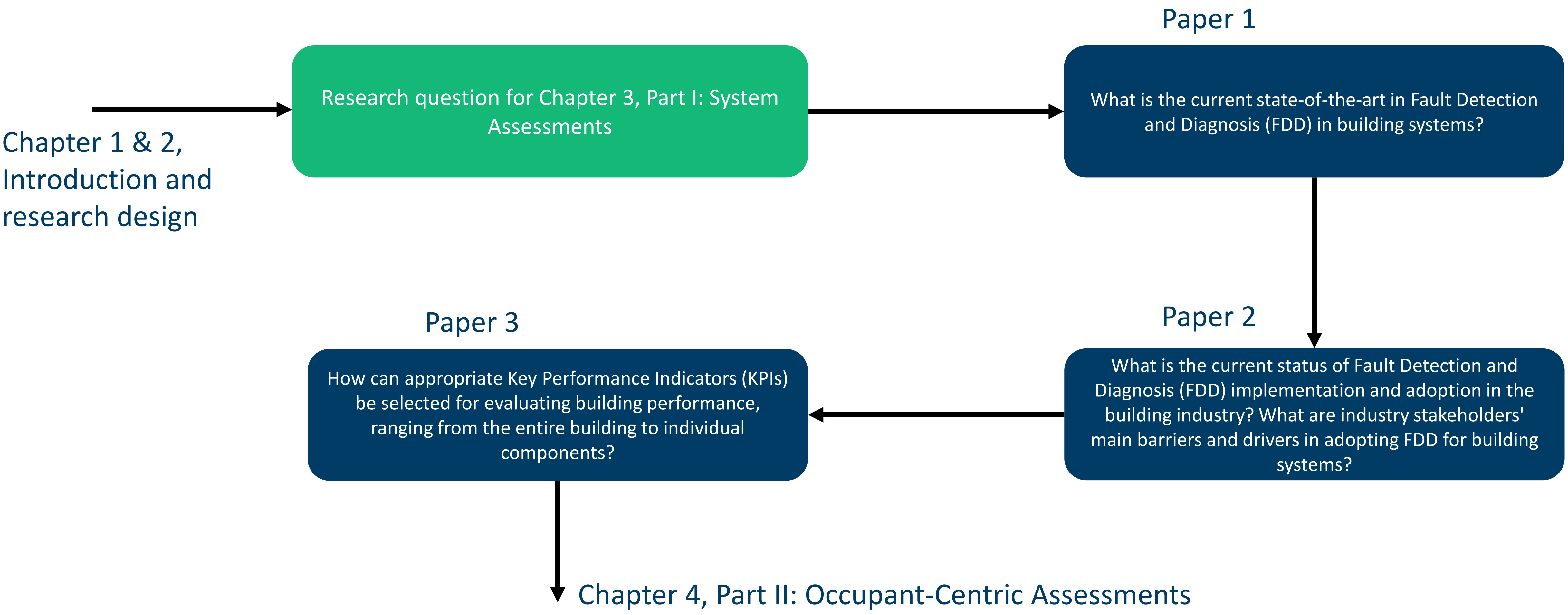


How can an occupant-centric assessment framework be developed to understand occupants better, thereby enhancing building performance?

Status on submitted papers to journals (Nov. 2024)

- Paper 5 is published with minor revision in the journal «Energy and Buildings» per September 2024
  - «*Increased Understanding of Building Operational Performance Through Occupant-Centric Key Performance Indicators*» is **published** in the special issue «*Innovations in Increasing Health, Comfort & Wellbeing, and Energy Performance of Building: Designs, Strategies and Future Directions*».
- Paper 6 is under 2nd round of review with minor revision in the journal «Energy and Buildings» per November 2024 (deadline December 1st , 2024)
  - «*A Mixed-Method Approach to Understand Energy-Related Occupant Behavior and Everyday Practices in Multi-Story Residential Buildings*» is under **2nd revision** in the special issue «*Challenges, Solutions, and Methods for the Energy Transition in the Existing Housing Stock*».

Sub-research questions
Part I: System Assessments



Sub-research questions
Part II: Occupant-Centric Assessments

Chapter 3, Part I:
System Assessments

Research question for Chapter 4, Part II: Occupant-Centric Assessments

Paper 4

To account for occupancy in Building Performance Assessments (BPAs), what are possible ways of detecting occupancy from typical existing sensors in buildings?

Paper 5

To what extent can Occupant-Centric Key Performance Indicators (OC KPIs) enhance our understanding of building performance, residential energy-related occupant behavior, and Indoor Environmental Quality (IEQ)?

Paper 6

What factors affect energy-related occupant behavior, and how do they contribute to energy efficiency?

Chapter 5 & 6, Conclusions and suggestion for further work

Overview of building types and research method

Paper no.	Building type	Research method
1	-	Literature review
2	-	Literature review & Semi-structured qualitative interviews
3	Office	Quantitative data analysis (sensor data)
4	Residential	Mixed methods: Semi-structured qualitative interviews & quantitative data analysis (sensor data)
5	Residential	Quantitative data analysis (sensor data)
6	Residential	Questionnaire & quantitative data analyses (sensor data)

Content

Sub-research questions
Part I: System Assessments

Chapter 1 & 2, Introduction and research design

Chapter 3, Part I: System Assessments

RQ: How to foster implementation and adoption of fault detection and diagnosis for continuous building system performance assessments?

Paper 1

What is the current state-of-the-art in Fault Detection and Diagnosis (FDD) in building systems?

Paper 2

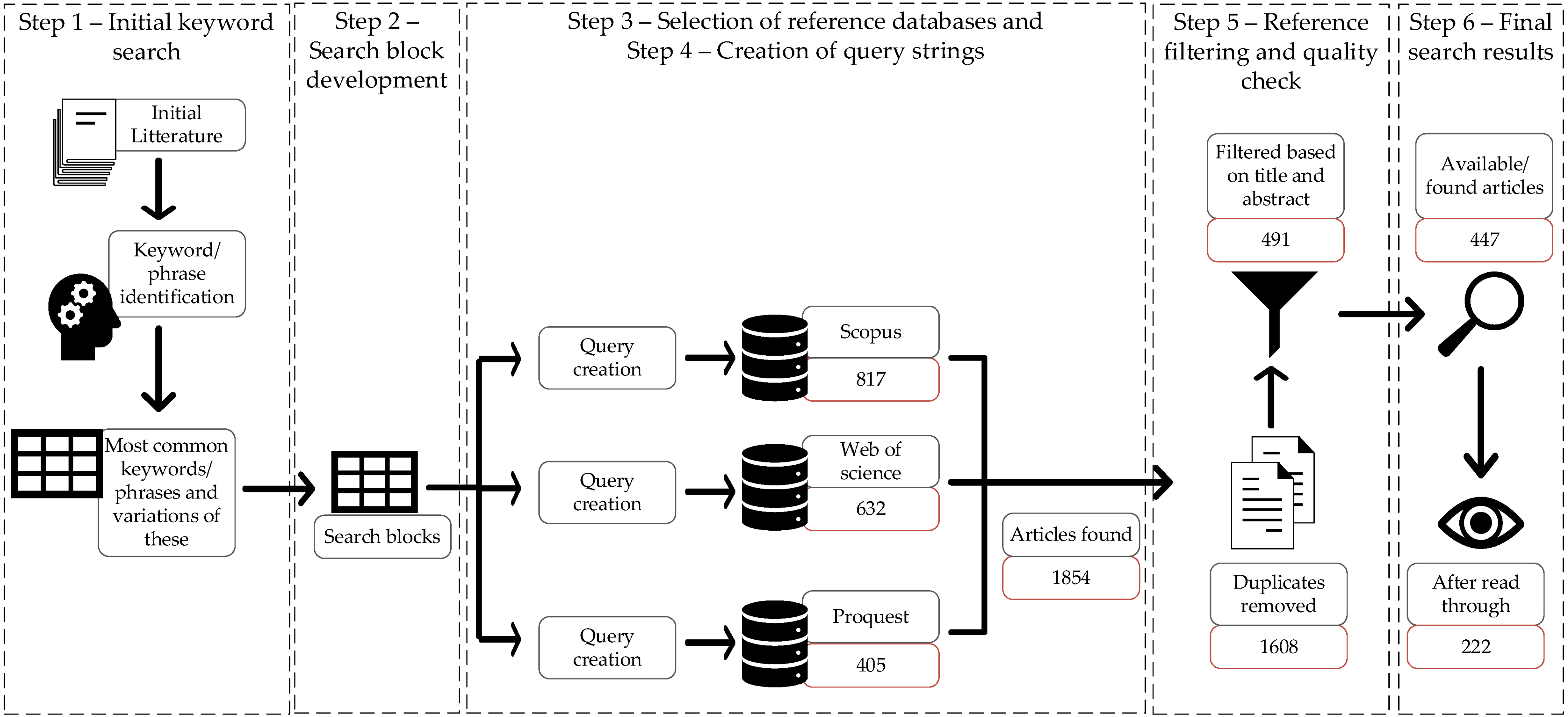
What is the current status of Fault Detection and Diagnosis (FDD) implementation and adoption in the building industry? What are industry stakeholders' main barriers and drivers in adopting FDD for building systems?

Paper 3

How can appropriate Key Performance Indicators (KPIs) be selected for evaluating building performance, ranging from the entire building to individual components?

Chapter 4, Part II: Occupant-Centric Assessments

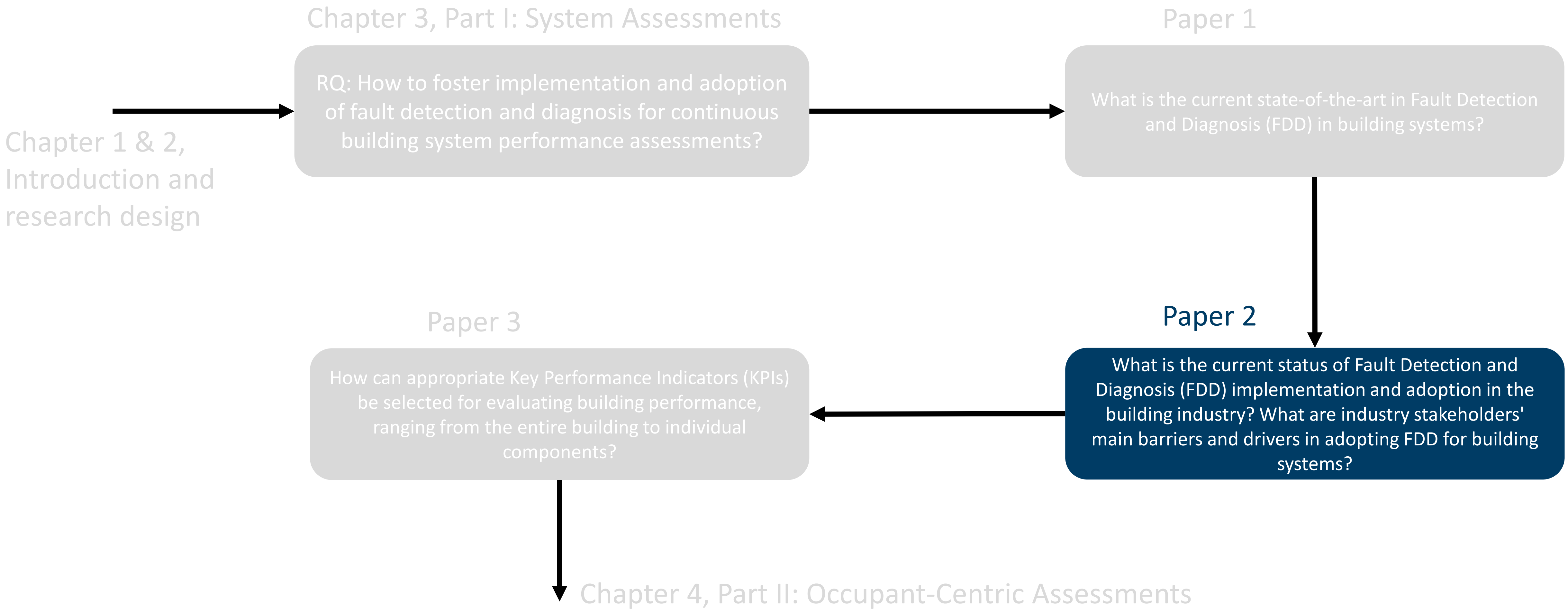
Current Status of Fault Detection and Diagnosis in Building Systems
Methodology



Current Status of Fault Detection and Diagnosis in Building Systems
Key findings

1. Research on FDD in building systems remains in its development phase
2. The most studied building systems were centralized cooling system (41 %) and air handling units (34 %)
3. Significant lack of reproducible content (29 %)
4. FDD-related datasets fosters research activity in the field, but there are few open datasets

Sub-research questions
Part I: System Assessments



What Hinders the Adoption and Implementation of System Assessments in the Building Industry?
Methodology

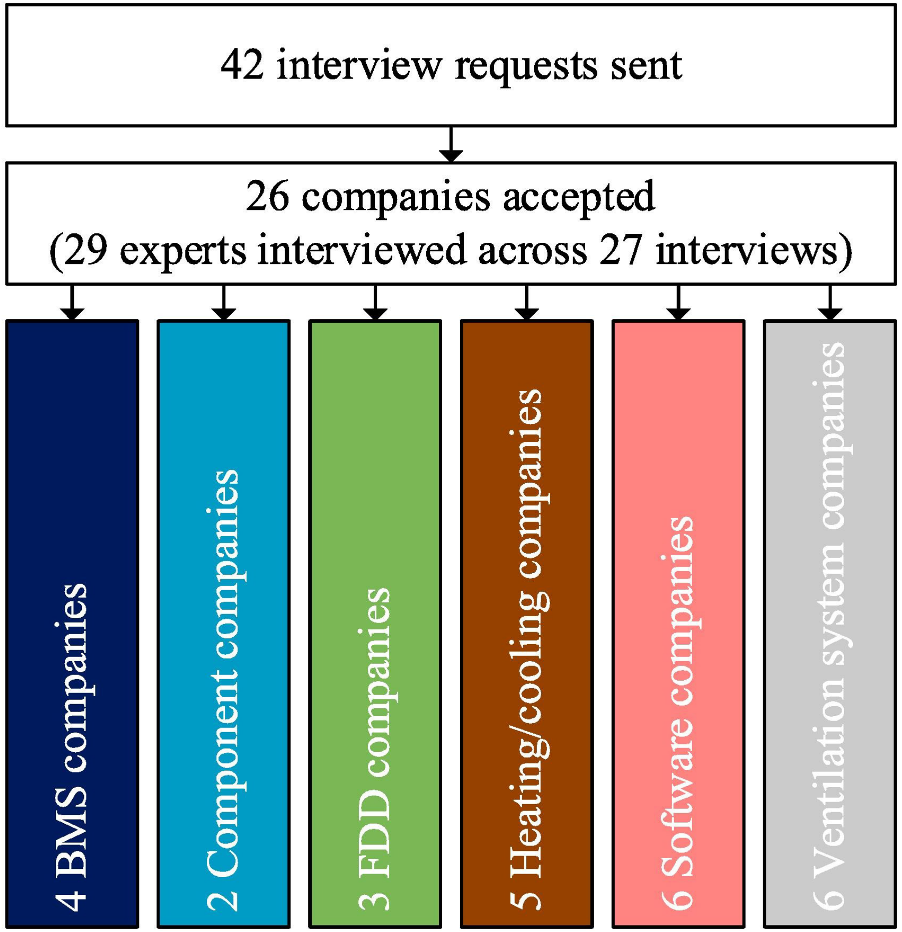
- How different types of HVAC producers facilitate finding faults in their technical systems
- What methods they use
- What their challenges are
- What their customers request

- 2-fold approach
  - Research perspective: Continuation of the literature review in paper 1 to investigate the focus on implementation
  - Industry perspective: Semi-structured qualitative interviews

What Hinders the Adoption and Implementation of System Assessments in the Building Industry?

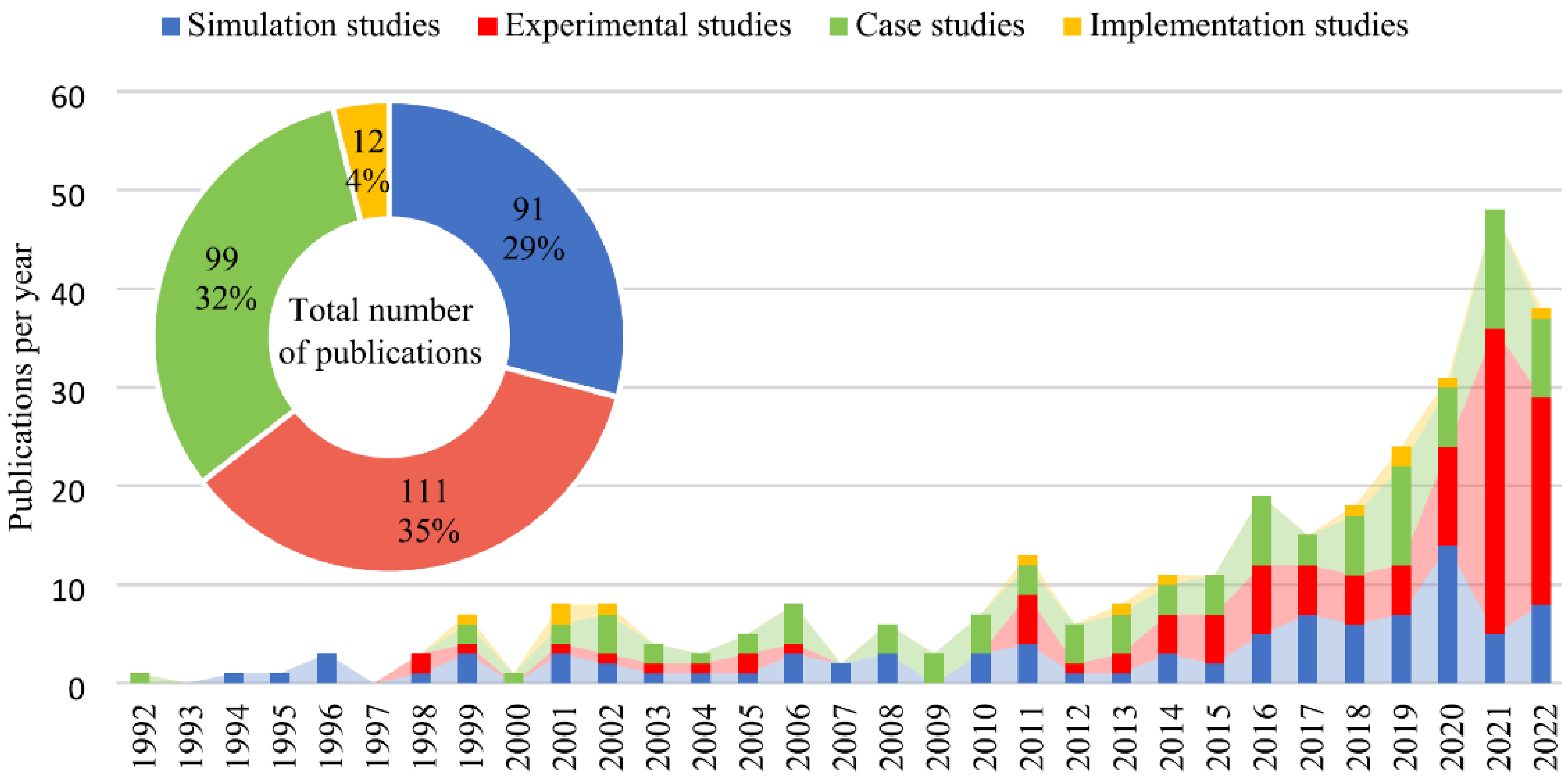
Methodology

- 62 % acceptance rate for interviews
- 26 companies located in
  - Scandinavia
  - Europe
  - USA
- Interview implementation
  - Majority online and a few physical
  - English, Danish and Norwegian



What Hinders the Adoption and Implementation of System Assessments in the Building Industry?

Results: Research perspective



What Hinders the Adoption and Implementation of System Assessments in the Building Industry?

Results: Industry perspective

Top three barriers

1. Lack of common knowledge, standardized methods, and tools for FDD.
2. General lack of understanding of what AFDD is, what it can achieve, and what customers can benefit from.
3. Trust in the FDD system from a user perspective

Top three drivers

1. Boosting the general digitalization and digitalization of the built environment.
2. Specifiers on large projects are gaining experience with FDD and are increasingly requiring it in future projects.
3. Increase building service relability

Sub-research questions
Part I: System Assessments

Chapter 1 & 2, Introduction and research design

Chapter 3, Part I: System Assessments

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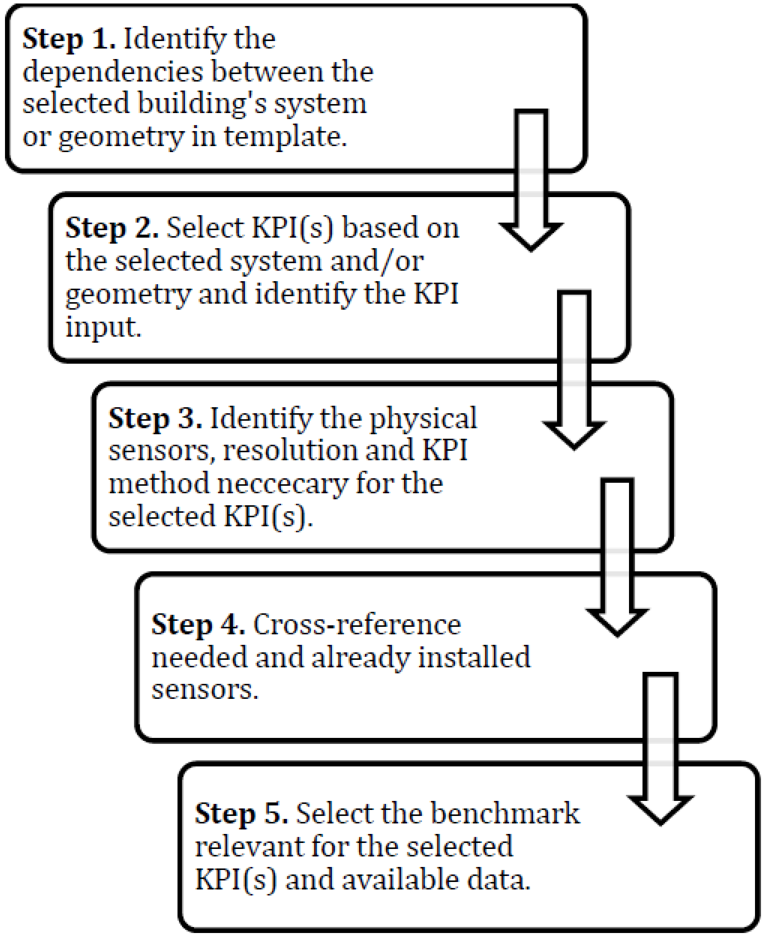
Chapter 4, Part II: Occupant-Centric Assessments

A Tool for Assessing Building Performance
Methodology

A Tool for Assessing Building Performance
Methodology

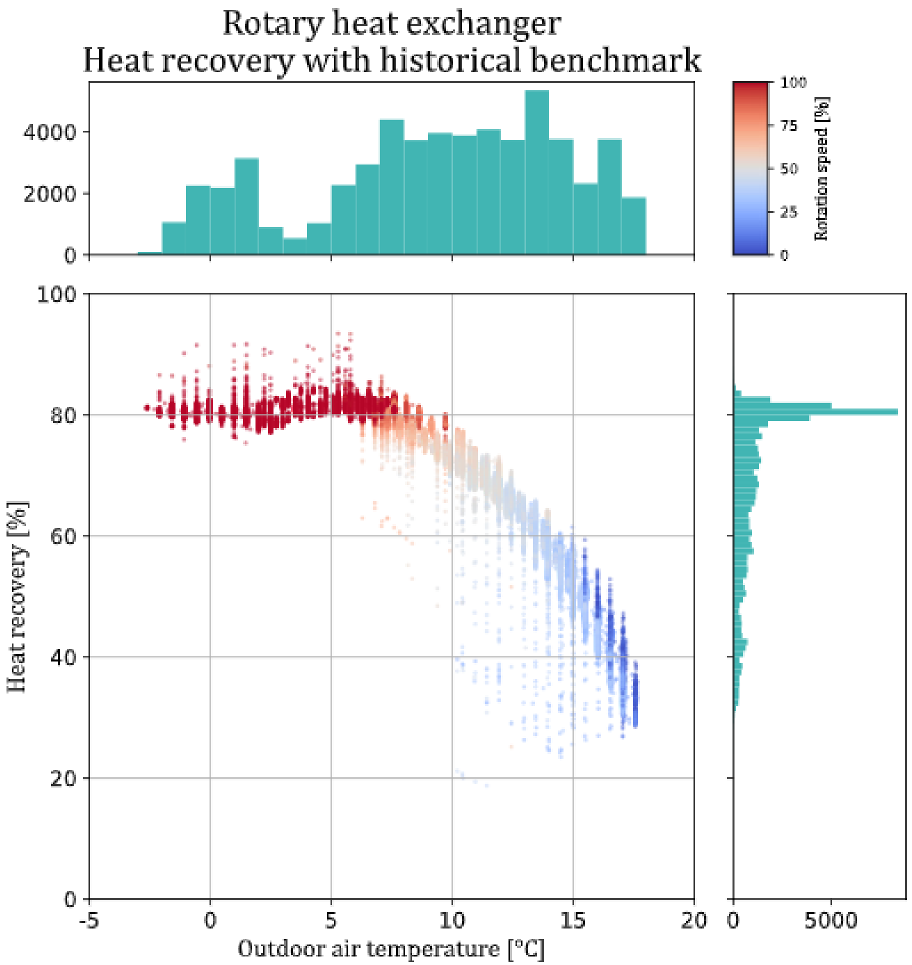


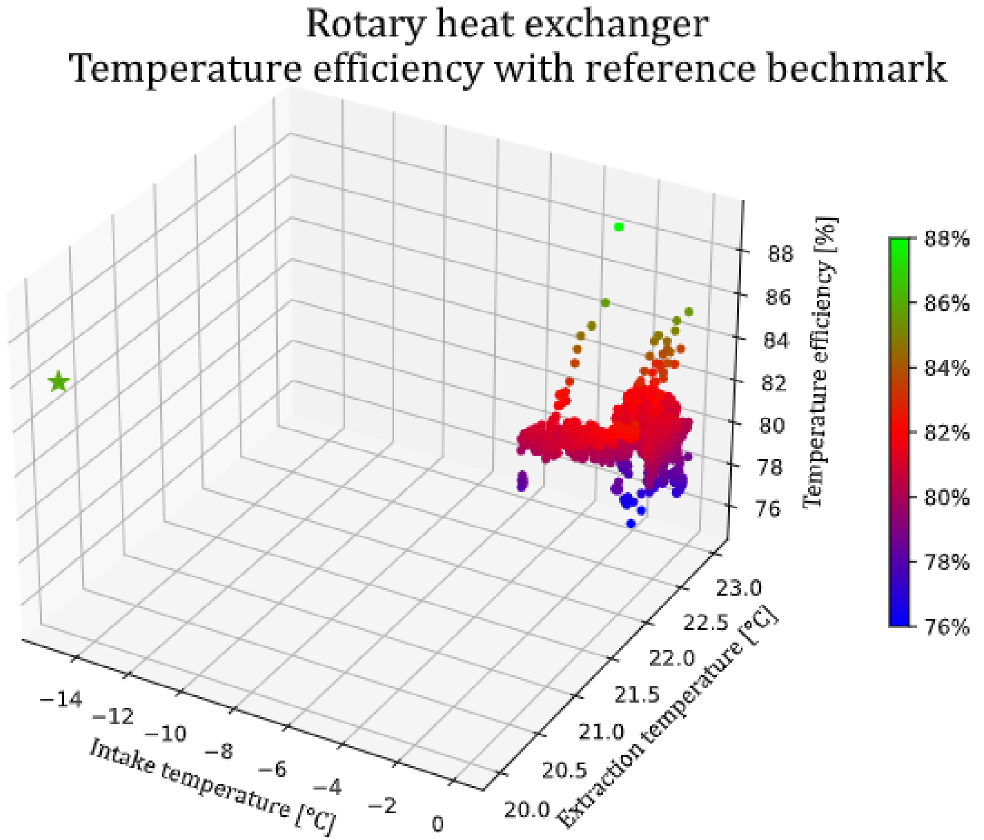
- Benchmarking methods
  - **Historical**
  - **Reference**
  - Contextual
- Three KPIs were selected for a ventilation system at TMV23

Location	KPI	Input needed
Subystem (AHU)	1) Specific AHU power (electricity use per m^3 air)	Electricity use, air flow
Component (RHx)	2) Temperature efficiency and 3) Heat recovery	Efficiency, outdoor air temperature

A Tool for Assessing Building Performance

Results





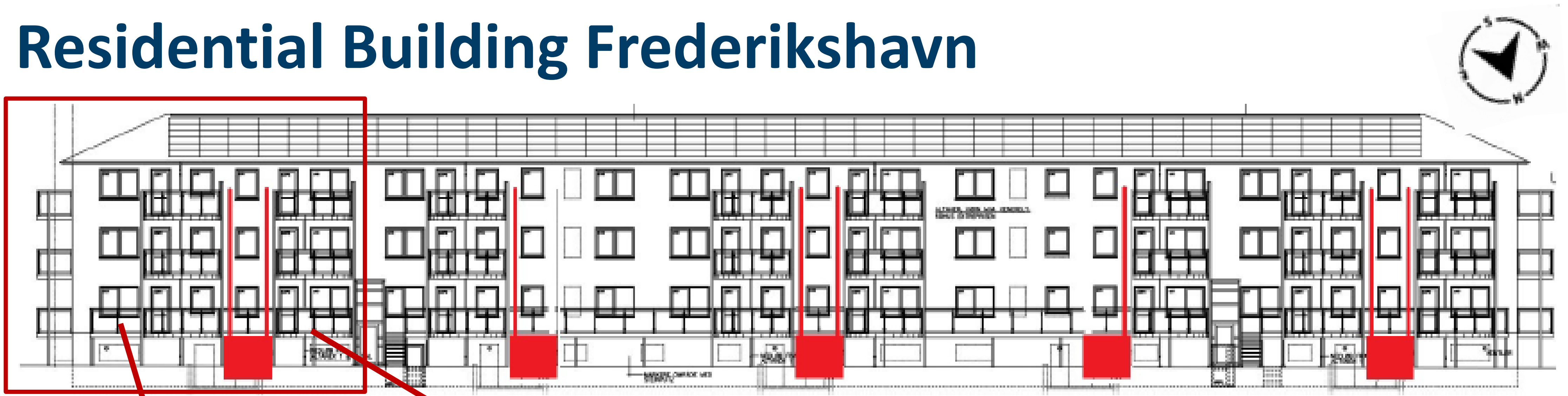
The measured values are based on 2912 points	Manufacturer value	Measured average value	Measured standard deviation
Temperature efficiency	86%	80.4%	0.8%
Intake temperature	-15°C	-1.4°C	1.1°C
Extraction temperature	20°C	22.6°C	0.2°C

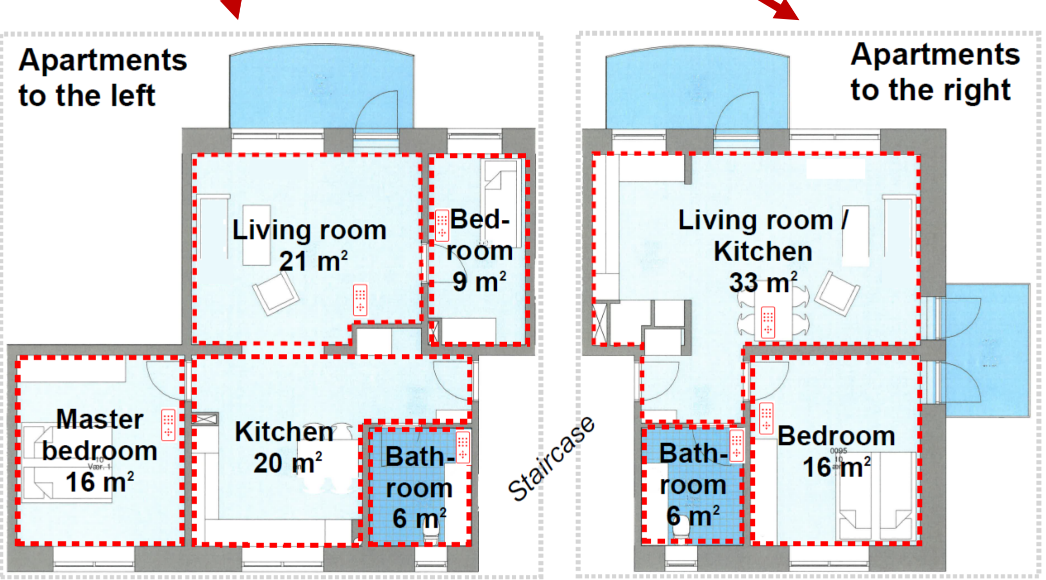
A Tool for Assessing Building Performance
Key findings

- Scalable and portable FDD solutions do not exist yet, but data visualization and KPI tools can potentially help with manual FDD
- Presented methodology can help selecting adequate KPI for specific systems based on data constraints
- Presented KPI visualization tool facilitates rapid manual system assessment
- Including context and historical data can provide input to degradation detection, fault diagnosis, and preventive maintenance

Content

Residential Building Frederikshavn





- 5 households
- 6 occupants
  - 3 occupants retired (> 65 years old)
  - 3 occupants ca. 30 years old
- 2 – 10 years length of residence

Sub-research questions
Part II: Occupant-Centric Assessments

Chapter 4, Part II: Occupant-Centric Assessments

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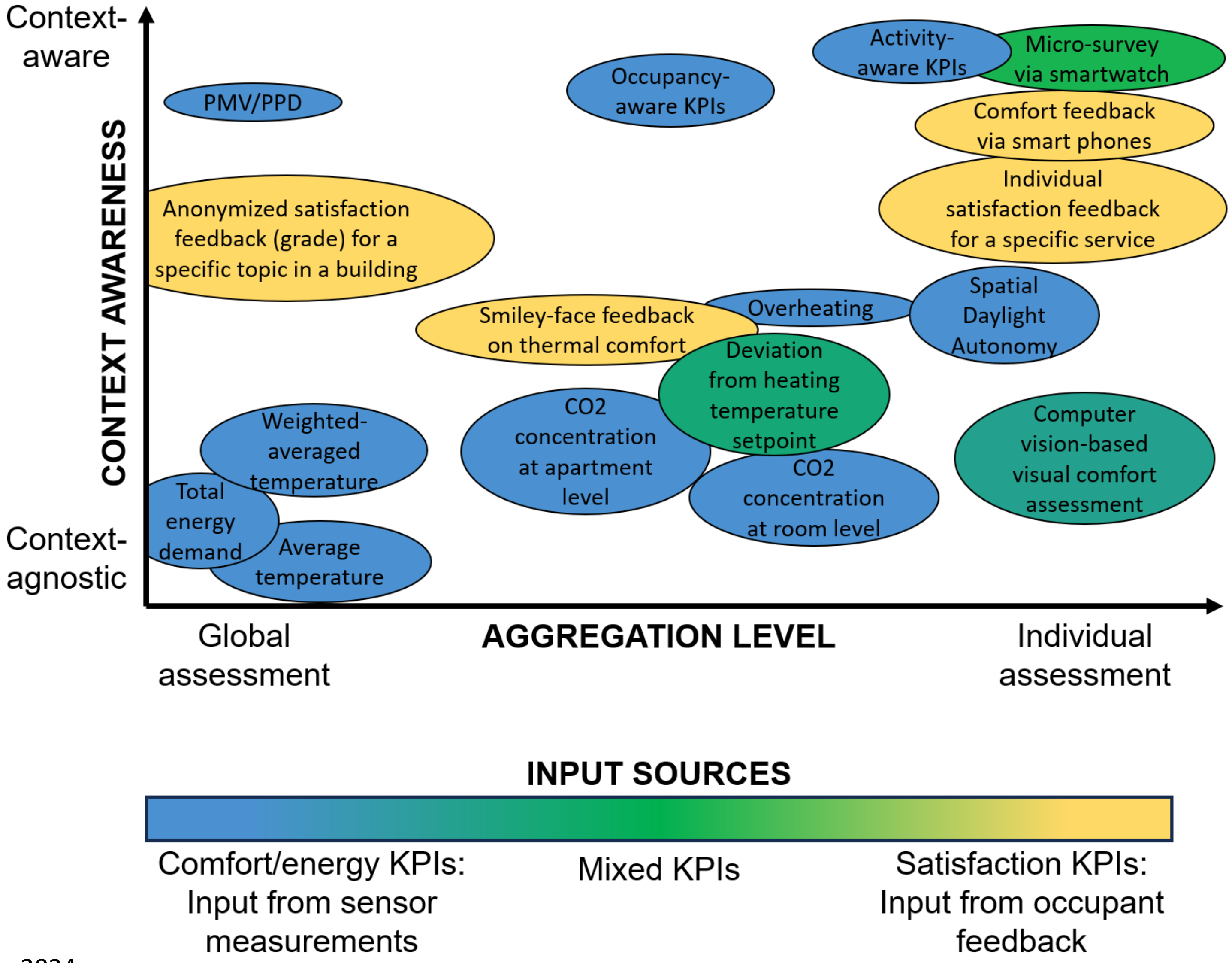
Chapter 5 & 6, Conclusions and suggestion for further work

Landscape of including occupants' characteristics into BPAs



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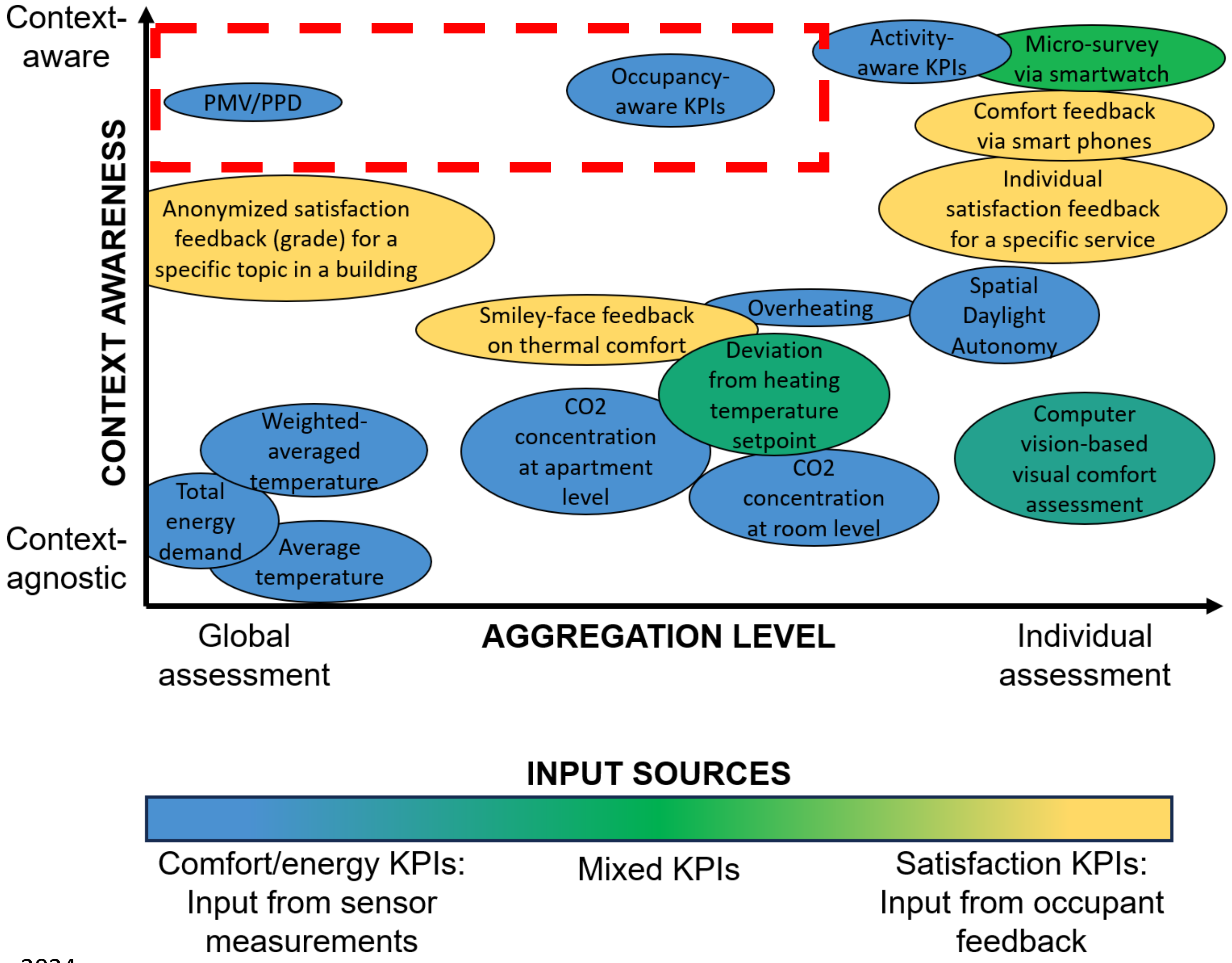
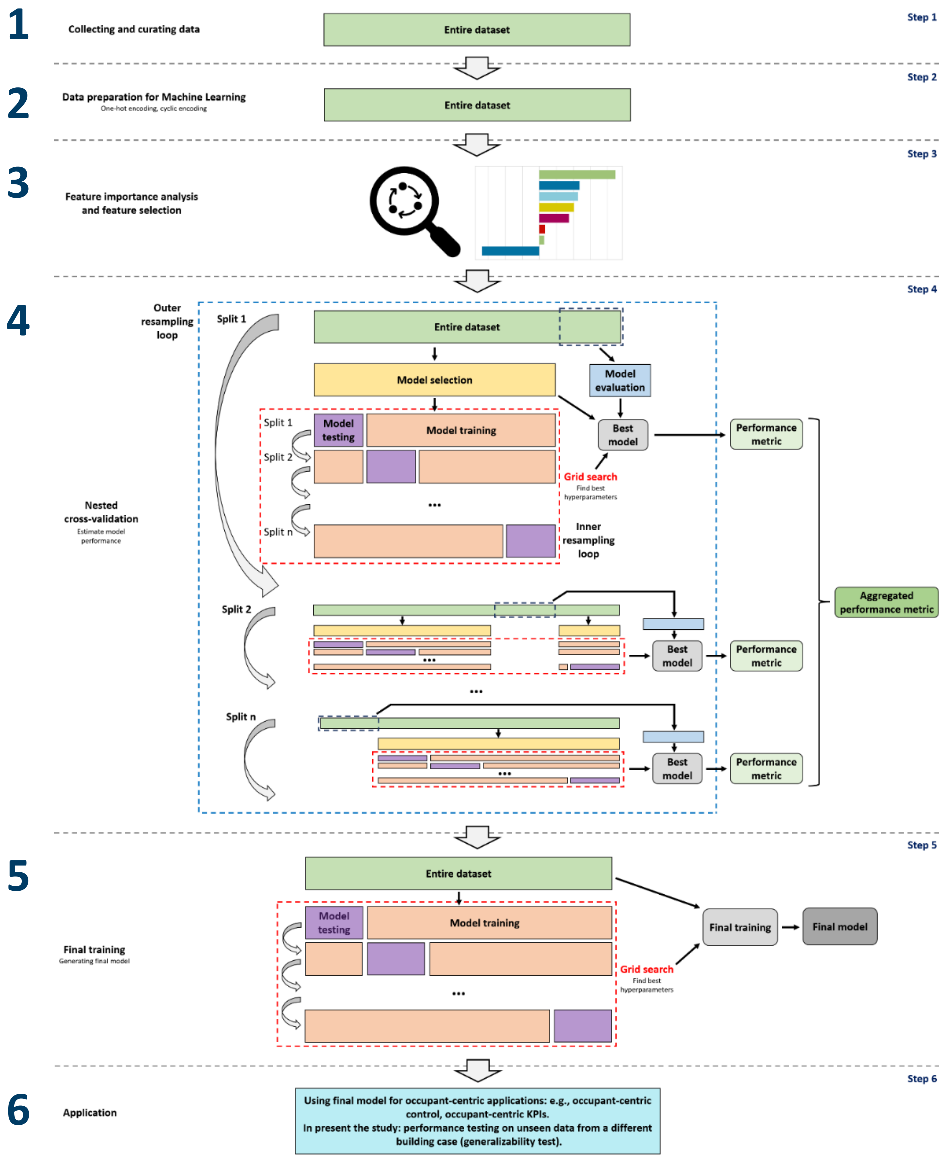


Building Performance Insights When Including Occupants in the Loop

Methodology

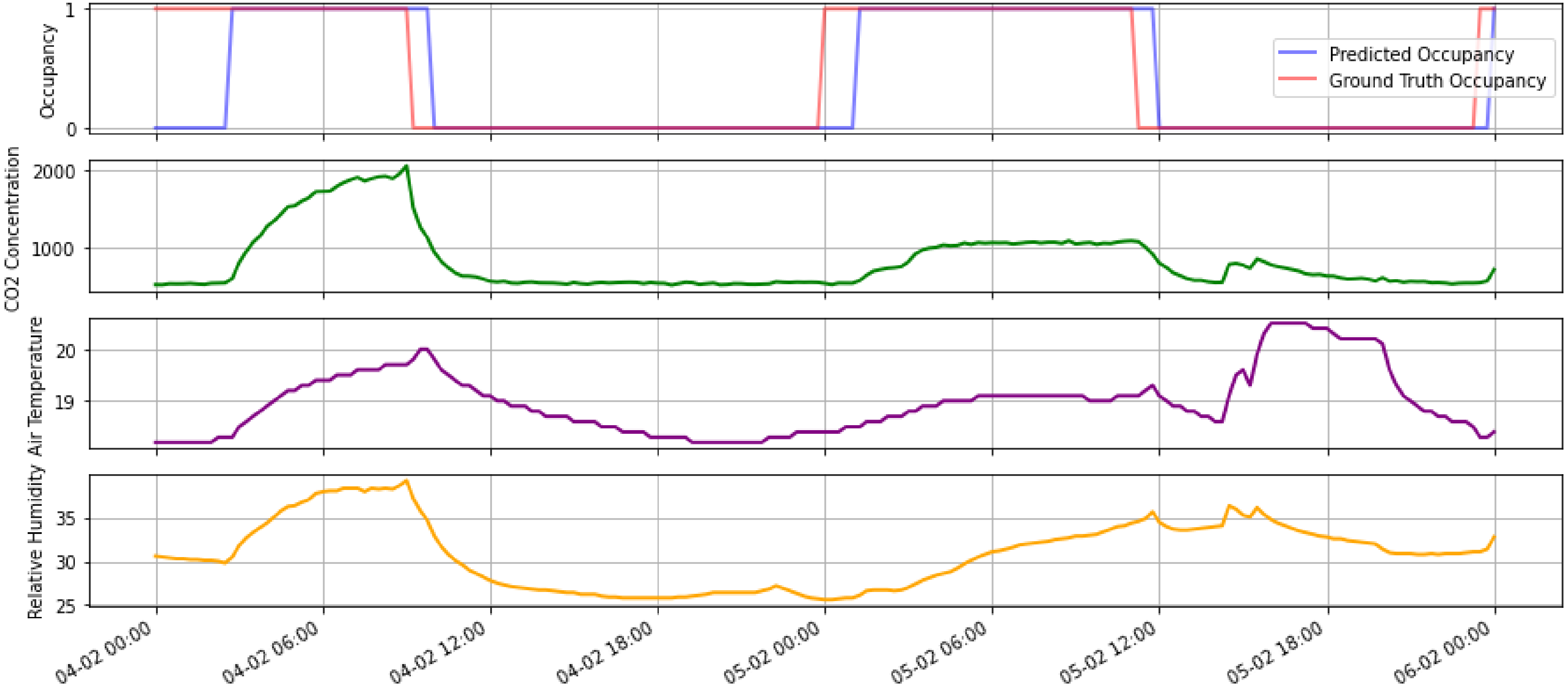
Machine learning pipeline

1. Collecting and curating dataset
2. Data preparation of dataset
3. Feature importance analysis and feature selection
4. Model training
5. Final training
6. Application



Building Performance Insights When Including Occupants in the Loop
Results and key findings

	Average performance of the 10-folds	Standard deviation of the 10-folds
Balanced accuracy	86 %	1.8 %
Accuracy	90 %	0.8 %
Precision	82 %	3.2 %
Recall	[illegible]	[illegible]
Confusion matrix	[illegible]	[illegible]
F1-score	[illegible]	[illegible]
MCC	[illegible]	[illegible]
AUROC	[illegible]	[illegible]
Briar-score loss	[illegible]	[illegible]



Building Performance Insights When Including Occupants in the Loop

Methodology

Building Performance Insights When Including Occupants in the Loop

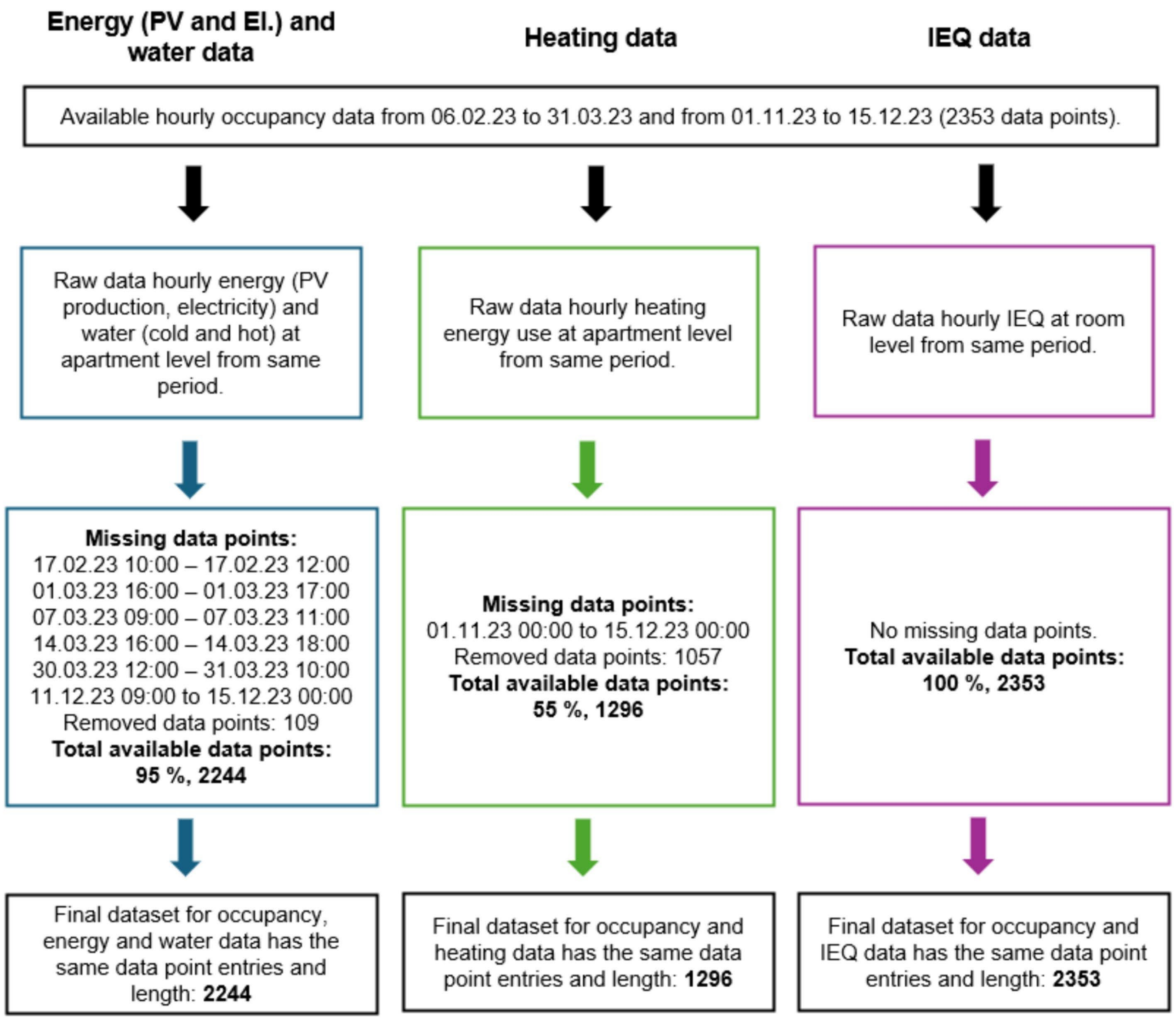
Methodology

Energy (PV and El.) and water data **Heating data** **IEQ data**

Available hourly occupancy data from 06.02.23 to 31.03.23 and from 01.11.23 to 15.12.23 (2353 data points).

Building Performance Insights When Including Occupants in the Loop

Methodology



Building Performance Insights When Including Occupants in the Loop

Results and key findings

	Average occupancy	KPI $_{cold\ water}$ 1 Monthly cold water use	OC KPI $_{cold\ water}$ 2b Monthly cold water use during non-occupancy	OC KPI $_{cold\ water}$ 3b Monthly cold water use during non-occupancy per m^2	OC KPI $_{cold\ water}$ 4a Share cold water use during occupancy	OC KPI $_{cold\ water}$ 4b Share cold water use during non-occupancy
	%	liter/month	liter/hour_no_occ per month	liter/hour_no_occ per m^2 per month	%	%
Apartment 5	88%	2769	272,4	3,8	90%	10%
Apartment 2	86%	2316	337,6	4,7	85%	15%
Apartment 4	62%	2254	300,1	4,2	87%	13%
Apartment 1	98%	1791	22,8	0,4	99%	1%
Apartment 3	98%	1292	35,9	0,7	97%	3%

	Average occupancy	KPI $_{electricity}$ 1 Monthly electricity use	KPI $_{electricity}$ 2 Monthly electricity use per m^2	KPI $_{electricity}$ 3 Load matching	OC KPI $_{electricity}$ 1 Monthly electricity use per m^2 per registered occupant	OC KPI $_{electricity}$ 2a Monthly electricity use during occupancy	OC KPI $_{electricity}$ 3a Monthly electricity use during occupancy per m^2	OC KPI $_{electricity}$ 5 Total electricity per occupied hours	OC KPI $_{electricity}$ 6 Total electricity per occupied hours per m^2
	%	kWh/month	kWh/m^2 per month	%	kWh/m^2 per month per registered occupant	kWh/hour_occ per month	kWh/hour_occ per m^2 per month	kWh/hour_occ	kWh/hour_occ per m^2
Apartment 5	88%	144	2,0	19,1%	1,0	134,0	1,9	0,22	0,0031
Apartment 3	98%	123	2,2	17,3%	2,2	121,6	2,2	0,17	0,0031
Apartment 1	98%	115	2,1	18,1%	2,1	113,6	2,1	0,16	0,0029
Apartment 4	62%	90	1,3	22,6%	1,3	70,4	1,0	0,20	0,0028
Apartment 2	86%	70	1,0	25,0%	1,0	62,5	0,9	0,11	0,0015

Sub-research questions
Part II: Occupant-Centric Assessments

Chapter 4, Part II: Occupant-Centric Assessments

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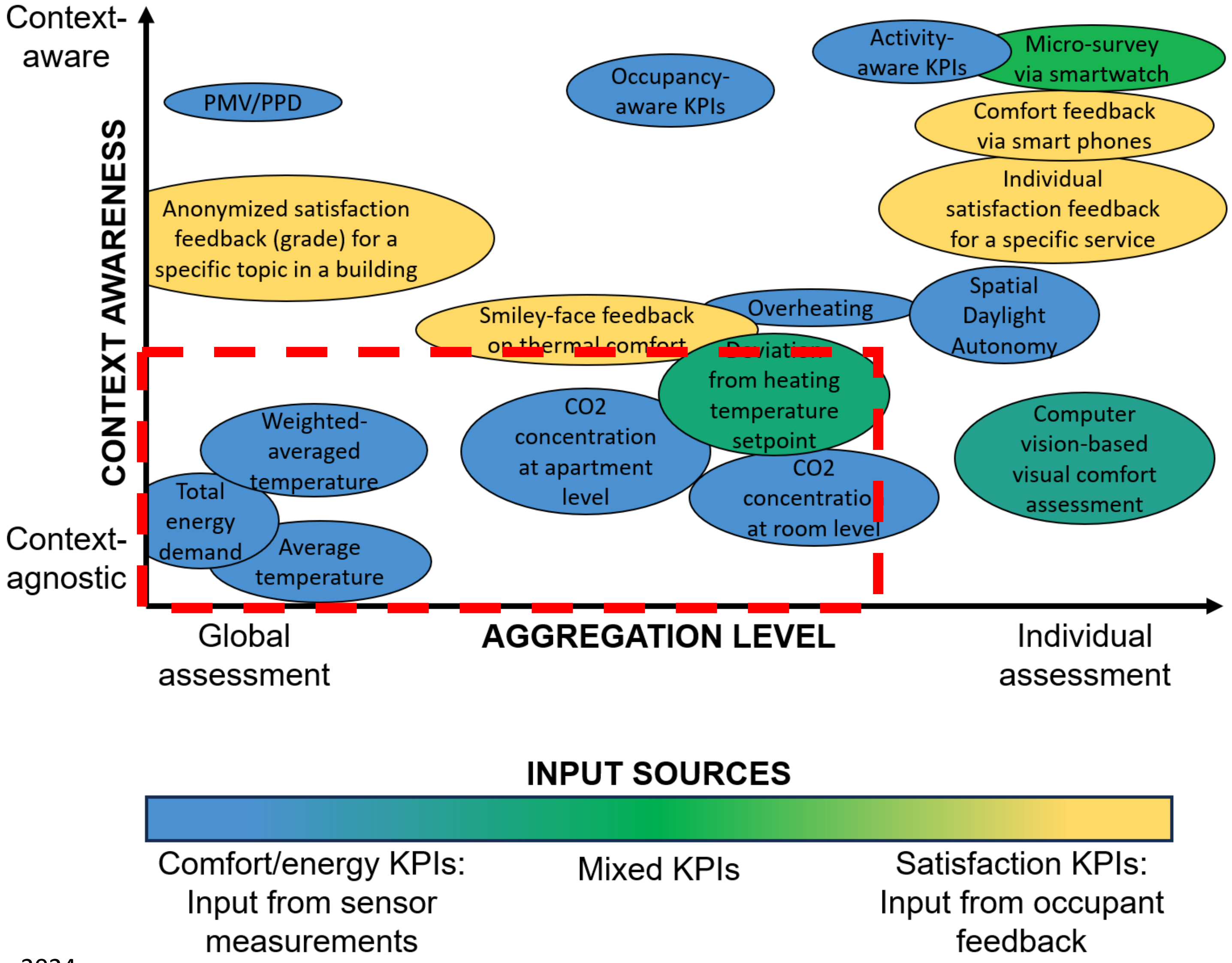


Occupant Heating Practices and their Effects on Heating Energy Use

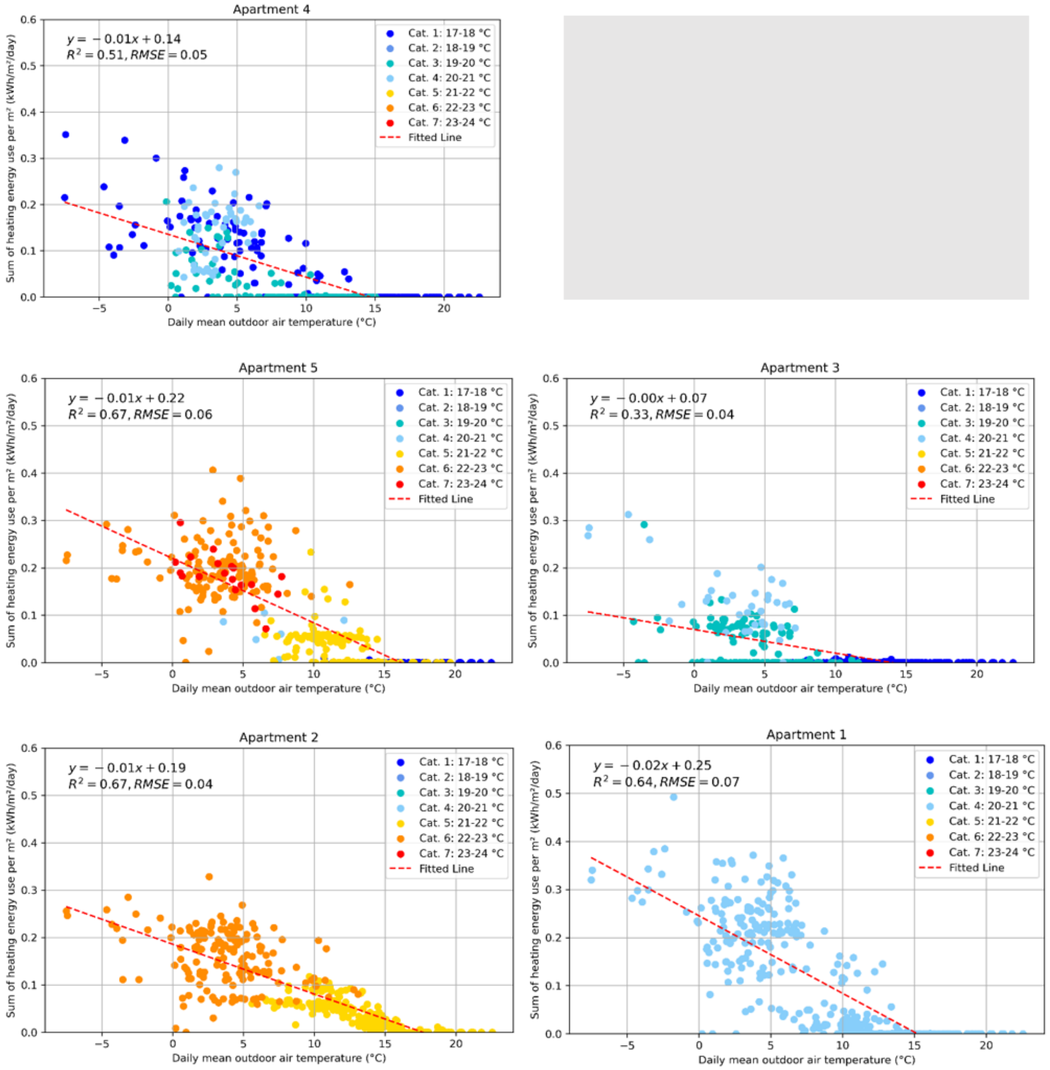
Methodology

- Explanatory sequential mixed-method
  - Quantitative method: data analyses
  - Qualitative method: semi-structured qualitative interviews with 5 households (6 occupants)

Occupant Heating Practices and their Effects on Heating Energy Use

Results

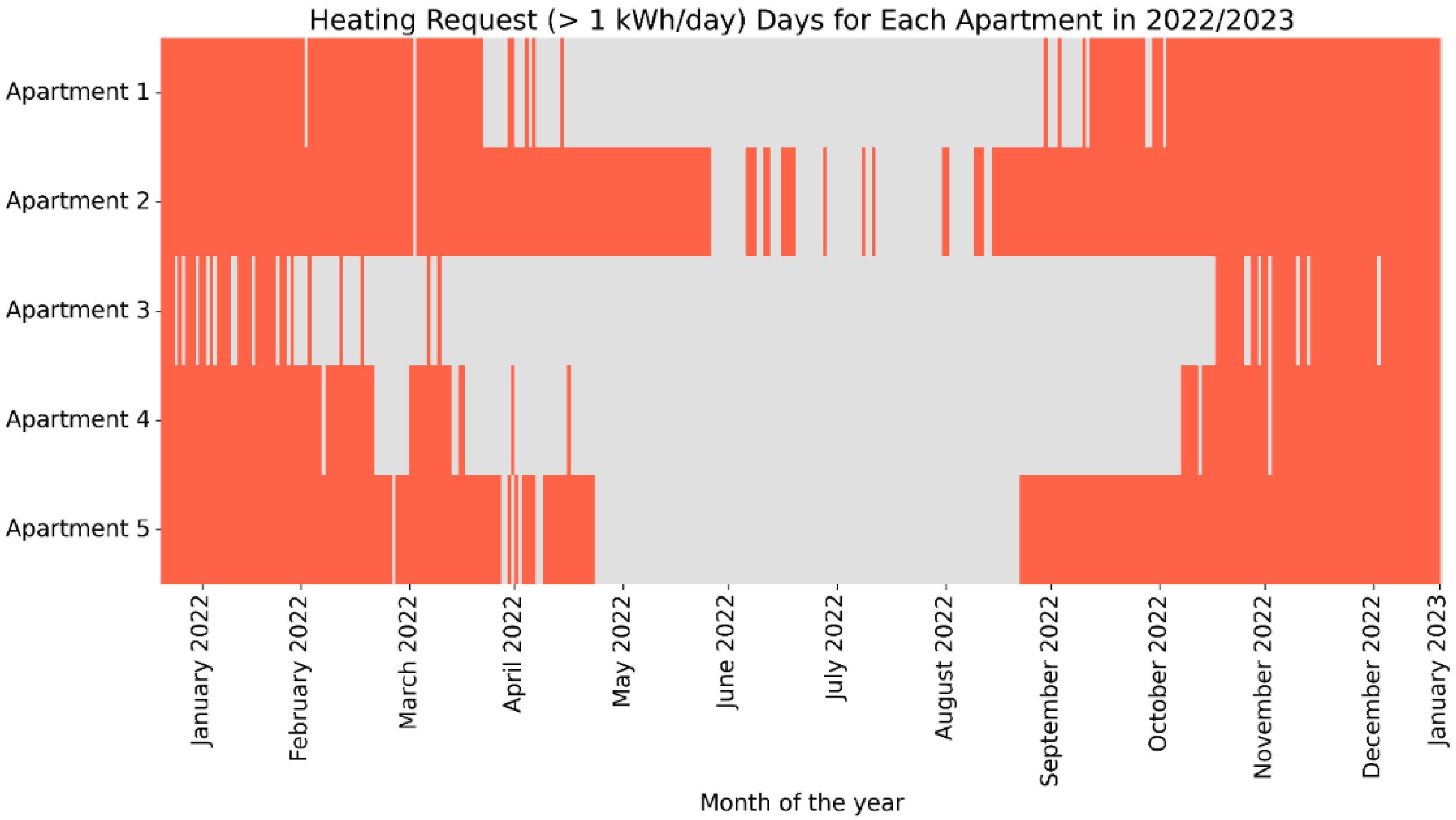
- Factor 1: Human-building interaction



Occupant Heating Practices and their Effects on Heating Energy Use

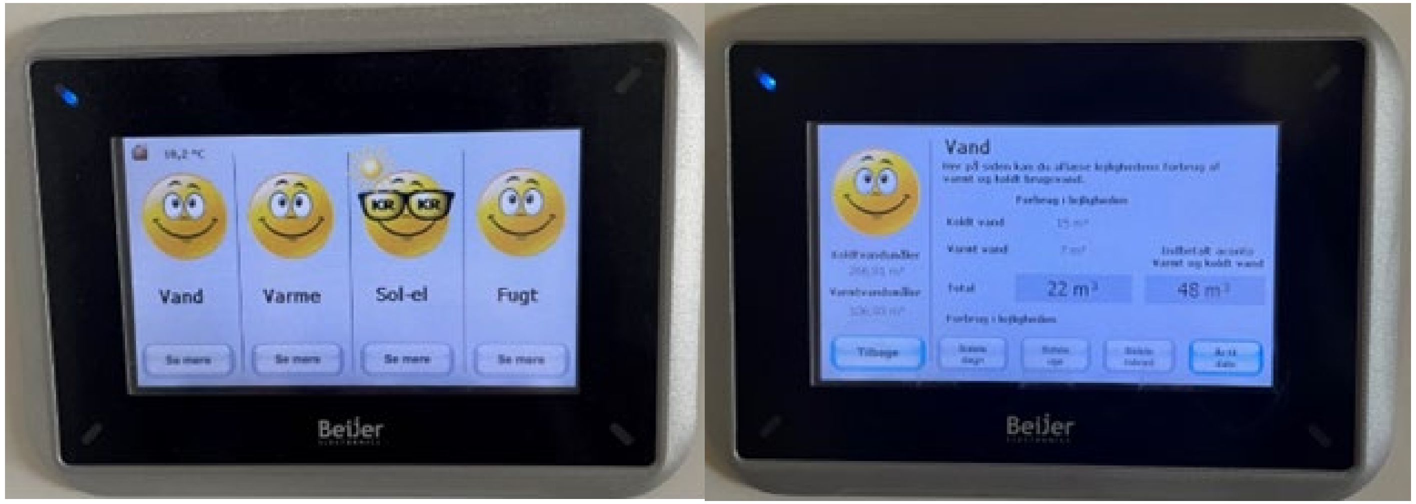
Results

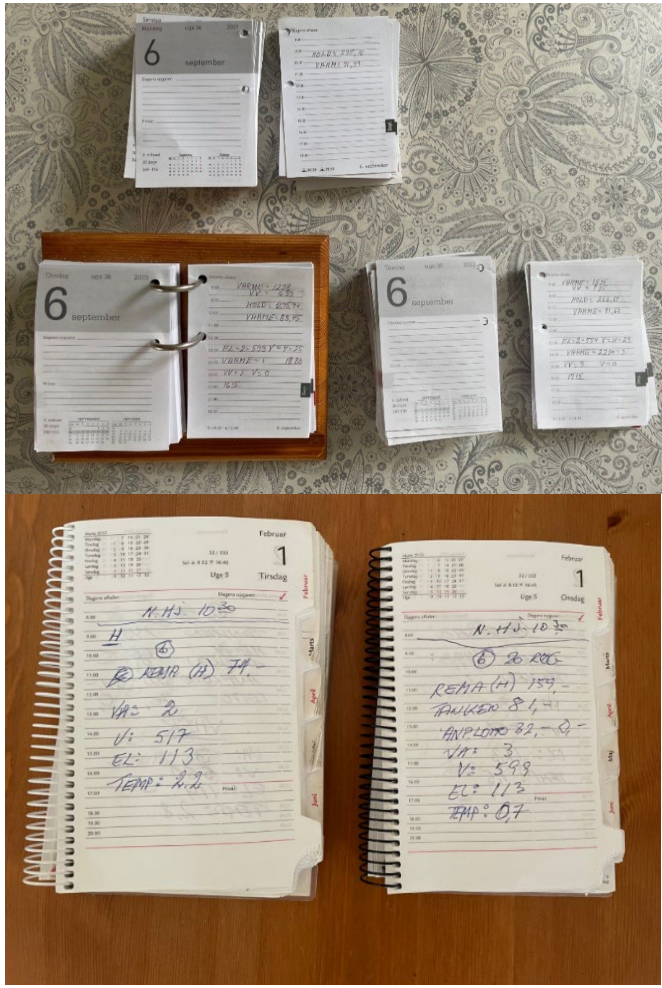
Factor 2: occupants' individual heating season over a year



Occupant Heating Practices and their Effects on Heating Energy Use
Results

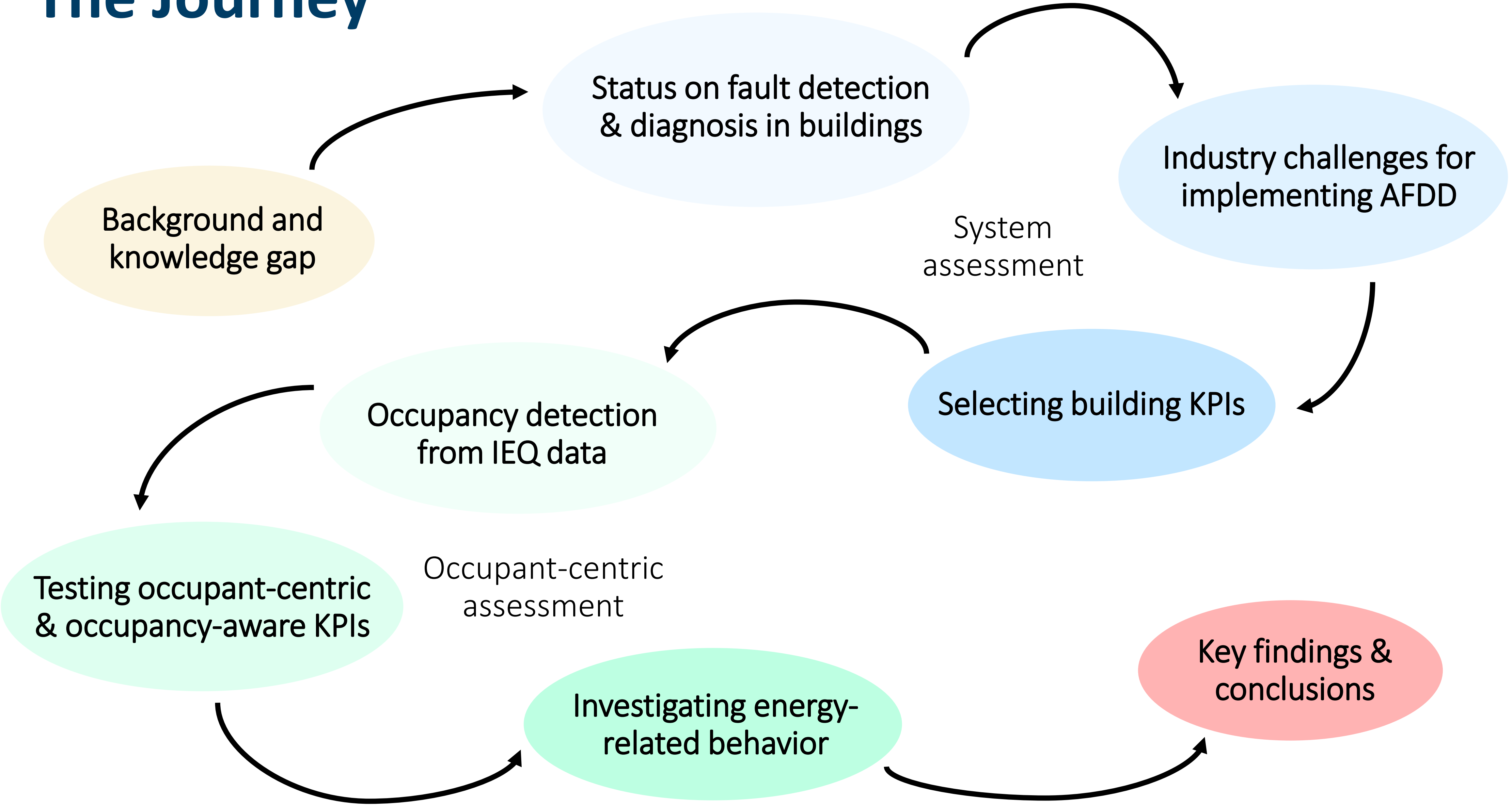
- Factor 3: social and behavioral dynamics
  - Feedback display – conversation starter
  - Shared practices – writing diaries on energy use
  - Interpersonal trust (building managers)





Content

The Journey



Background and knowledge gap
Status on fault detection & diagnosis in buildings
Industry challenges for implementing AFDD
System assessment
Selecting building KPIs
Occupancy detection from IEQ data
Testing occupant-centric & occupancy-aware KPIs
Occupant-centric assessment
Investigating energy-related behavior
Key findings & conclusions

Conclusions

*How can **system** and occupant-centric **assessments** contribute to informing decisions that enhance a building's operational efficiency and occupant well-being?*

1. Research on FDD in building systems is still in a development phase
2. More FDD-related open datasets with ground truth are needed
3. Lack of common knowledge, standardized methods, and tools for FDD in the building industry
4. General lack of understanding of what FDD is, what it can achieve, and what customers can benefit from
5. Since efficient and scalable FDD solutions do not exist yet, advanced data visualization and KPI tools can greatly help with manual FDD

Conclusions

*How can system and **occupant-centric assessments** contribute to informing decisions that enhance a building's operational efficiency and occupant well-being?*

1. Common IEQ data is sufficient to predict dynamic occupancy for occupant-centric applications
2. Some of the occupancy-aware KPIs showed promising results to assess the actual building performance
3. Occupancy-aware OC KPIs can be used to detect energy-related occupant behavior
4. Energy-related behavior and preferences are varied, even within the same building, and have a huge impact on the performance on low-energy buildings
5. Heating practices can be shared within a building, can be leveraged to improve performance

Suggestions for future research

- System assessments
  - Explore scalability and interoperability of FDD on different types of building systems
  - Improve data quality and taxonomy of fault labels
  - Create more open datasets that provide ground truth for testing and benchmarking FDD algorithms
  - Work on stronger incentives and regulatory frameworks for FDD
  - Evaluating the actual impact of FDD implementation and adoption
- Occupant-centric assessments
  - Further explore the OC BPA field and especially,
  - evaluate the OC KPIs on other study cases with varied occupancy
  - Implementation and adoption of proposed OC KPIs in management practices

Acknowledgements

- Thank you!
  - **Opponents**
    - Associate Professor Rune Korsholm Andersen (Denmark Technical University)
    - Professor Andreas Wagner (Karlsruhe Institute of Technology)
    - Associate Professor Samira Rahnama (Aalborg University)
  - **Moderator**
    - Associate Professor Olena Kalyanova Karlsen (Aalborg University)
  - The AAU team that helped me here today, with a special thanks to **Linda Vabbersgaard Andersen** (one of the most caring/helpful persons for Ph.D.s)

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Completing this Ph.D. project has been a challenging, but a rewarding journey, one that I could not have completed upon without any of the following:

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- All collaborators in the SATO project including the participants in Frederikshavn
- Brian & Michael from Frederikshavn Boligforening
- My co-authors
- AAU colleagues
- My research group at SINTEF Community, thank you for the constant encouragement and flexibility
- The Corner Office – The **best** place any Ph.D. could work at
- Friends and family
- Hicham (husband, travel buddy for life and colleague)

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Towards increased implementation and adoption of system- and occupant-centric assessments

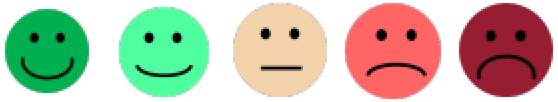
By Kamilla Heimar Andersen
Ph.D. Defense, BUILD – Department of the Built Environment, Aalborg University
14th of November 2024

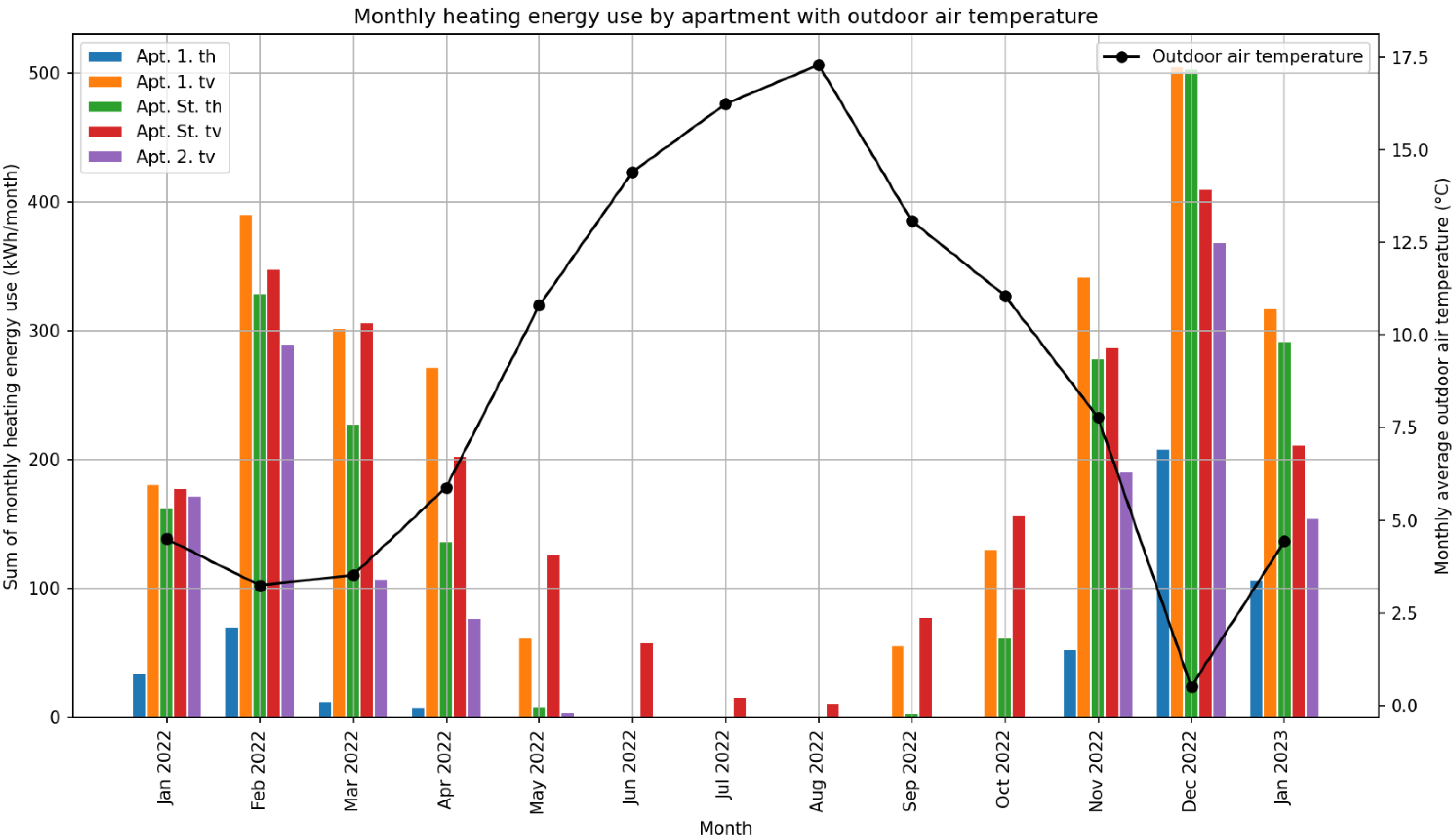
Thank you for your attention

‘RBF’: The recruited occupants’ characteristics

Apt no. and size	No. of occupants	Room no.	Room type	Gender	Occupation
Apartment 1 (55 m^2)	1	1	Bedroom	Male	Retired
		2	Kitchen/living room		
Apartment 2 (72 m^2)	1	3	Bedroom	Female	Retired
		4	Kitchen		
		5	Living room		
		6	Office		
Apartment 3 (55 m^2)	1	7	Bedroom	Male	Retired
		8	Kitchen/living room		
Apartment 4 (72 m^2)	1 + an indoor cat	9	Bedroom	Female	Librarian
		10	Kitchen		
		11	Living room		
		12	Office		
Apartment 5 (72 m^2)	2	13	Bedroom	Female and Male	Nurse and shipping manager
		14	Kitchen		
		15	Living room		
		16	Office		

Apartment: **Room:**
Date: **day** **of**

Hour of the day	I am not present	How satisfied are you with the temperature?					Do you want it warmer, no change, or colder?			Is your window open?	Remarks
		 Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied	Warmer	No change	Colder		Here you are welcome to write if there are deviations in your daily life that may affect the temperature in your home. This could, for example, be if you have visitors, you experience errors with technical installations, or your behavior or activities are different than on a normal day (for example, if you are painting or are sick)
		Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	Minutes over each hour 0 - 15 15 - 30 30 - 45 45 - 60	
00-01	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
01-02	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
02-03	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
03-04	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
04-05	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
05-06	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
06-07	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
07-08	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
08-09	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
09-10	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
10-11	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
11-12	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
12-13	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
13-14	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
14-15	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
15-16	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
16-17	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
17-18	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
18-19	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
19-20	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
20-21	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
21-22	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
22-23	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	
23-00	☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	☐☐☐☐	



Monthly heating energy use by apartment with outdoor air temperature
Apt. 1. th
Apt. 1. tv
Apt. St. th
Apt. St. tv
Apt. 2. tv
Outdoor air temperature
Sum of monthly heating energy use (kWh/month)
Monthly average outdoor air temperature (°C)
0
100
200
300
400
500
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
Jan 2022
Feb 2022
Mar 2022
Apr 2022
May 2022
Jun 2022
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Month

Feature importance (paper 4)