Project acronym	B4B
Project full name	Brains for Building's Energy Systems
Grant No	MOOI32004
Project duration	4 year (Starting date May 1, 2021)

Deliverable 1.02a

Use-cases for pre- and post-processing building data

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Work package	1
Result	1
Due data	Month 35
Lead beneficiary	TU Delft
Deliverable status	Interim

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Introduction

- The Brains for Buildings Energy Systems (B4B) project is a multi-year, multi-stakeholder project that aims to develop smart building methods to enhance buildings' operations by reducing energy consumption, increasing energy flexibility, increasing occupant comfort, and improving installation maintenance costs. This will be achieved by developing faster and more efficient Machine Learning and Artificial Intelligence models and algorithms. The project is geared to existing utility buildings, such as commercial and institutional buildings.
- Using raw data from buildings directly in smart building applications is nearly impossible. Its use requires a major pre-processing effort, depending on the quality of data and the intended application. Often, a considerable amount of human input is required. This report introduces the topics of data labelling, pre-processing, and integration for machine learning applications. It aims to support HVAC engineers who want to know more about using smart building data.

01

Data Labeling

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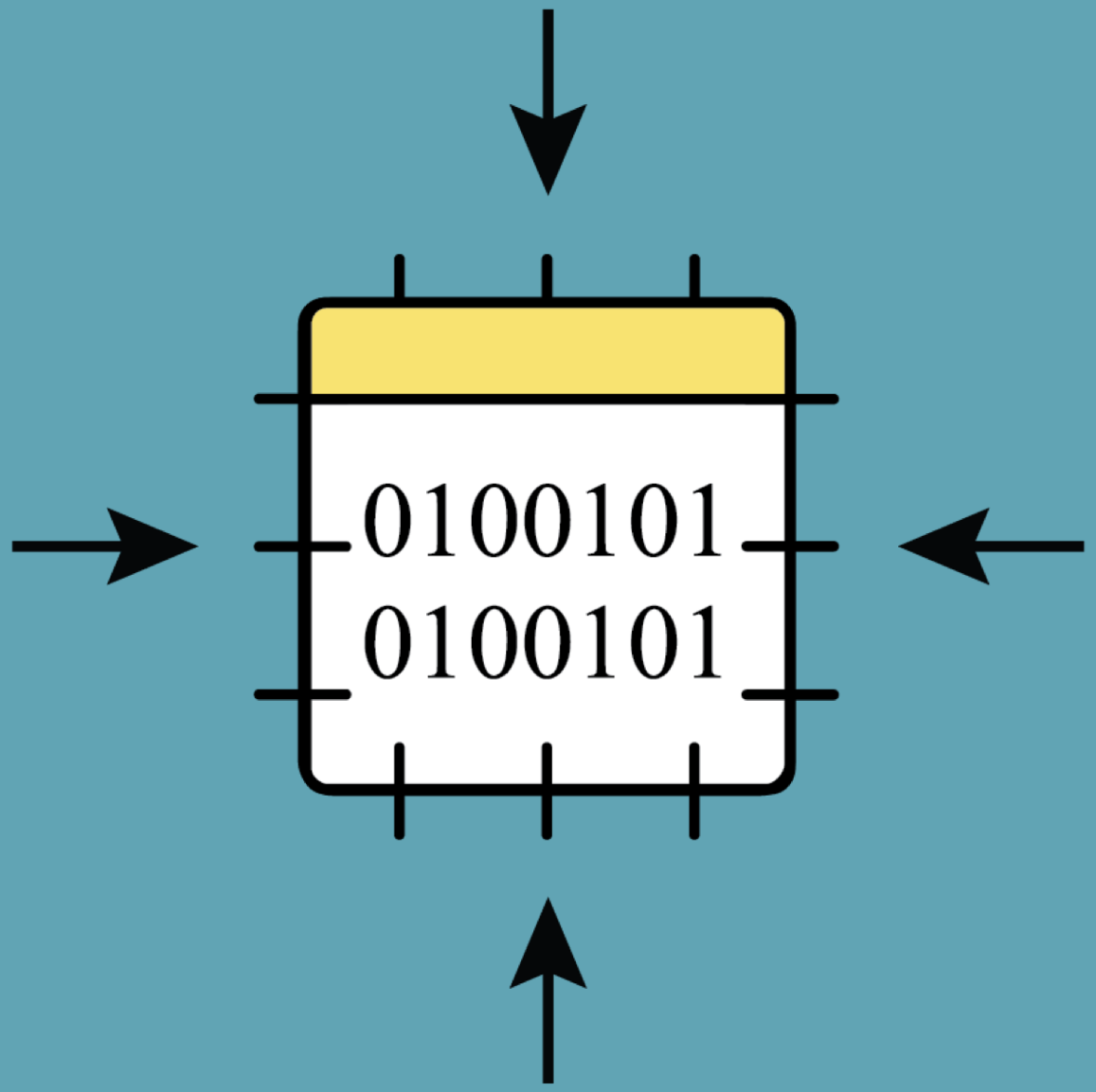
Data Labeling

- One of the most common problems in smart building applications is **inconsistent data labeling**
- Smart building applications need **knowledge across multiple systems**, e.g.: HVAC, fire, lighting, etc.
- Usually installed by **different vendors** and follow **different naming conventions**
- Different buildings and systems use diverging standards and conventions, leading to lots of **manual work to adapt procedures** from building to building
- **Unstructured naming conventions** and tagging systems to represent data syntax and semantics make it **difficult to understand and interpret** the data
- If **metadata standards** are not properly documented, it makes the **provenance, quality, and purpose** of data unclear.



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Sensor metadata

- In a sensor measurement, its **value and timestamp** are the key components
- **Metadata** (data about data) is **equally important**

Sensor metadata

- In a sensor measurement, its **value and timestamp** are the key components
- **Metadata** (data about data) is **equally important**
- If labels lack meaningfulness, **limited knowledge** can be inferred
- This hinders analytics without **expert prior knowledge** of existing systems

Timestamp	11NR008LT-059PIRTM	11NR008LT-301PIRTM	11NR008LT-302PIRTM	11NR008QT-013CO2
1/1/2021 0:02	2	2	2	437
1/1/2021 1:02	2	2	2	440
1/1/2021 2:02	2	2	2	439
1/1/2021 3:02	2	2	2	433
1/1/2021 4:02	2	2	2	439
1/1/2021 5:02	2	2	2	435
1/1/2021 6:02	3	3	3	449
1/1/2021 7:02	3	3	3	436
1/1/2021 8:02	3	3	3	442
1/1/2021 9:02	3	3	3	434
1/1/2021 10:02	3	3	3	433
1/1/2021 11:02	3	3	3	446
1/1/2021 12:02	3	3	3	448
1/1/2021 13:02	3	3	3	443
1/1/2021 14:02	3	3	3	449
1/1/2021 15:02	3	3	3	448
1/1/2021 16:02	3	3	3	443
1/1/2021 17:02	3	3	3	446
1/1/2021 18:02	3	3	3	444
1/1/2021 19:02	3	3	3	444
1/1/2021 20:02	3	3	3	446
1/1/2021 21:02	3	3	3	445
1/1/2021 22:02	3	3	3	447
1/1/2021 23:02	3	2	3	448
1/2/2021 0:02	2	2	2	447
1/2/2021 1:02	2	2	2	439
1/2/2021 2:02	2	2	2	443
1/2/2021 3:02	2	2	2	445
1/2/2021 4:02	2	2	2	438
1/2/2021 5:02	2	2	2	438

Example BMS data from the Atlas Living Lab at TU Eindhoven
(Brains4Buildings Deliverable 4.3)

Sensor metadata

- **Properties** of equipment, sensors and controls used, e.g.:
  - **device id**, **function**, **location**, **type**, **units**, **manufacturer**, **relationship** with other systems, and any **description** of the measurement
- Available metadata is **ambiguous, building- and vendor-specific** and often **not machine-readable**
- **Difficult to maintain uniformity**

Timestamp	11NR008LT-059PIRTM	11NR008LT-301PIRTM	11NR008LT-302PIRTM	11NR008QT-013CO2
1/1/2021 0:02	2	2	2	437
1/1/2021 1:02	2	2	2	440
1/1/2021 2:02	2	2	2	439
1/1/2021 3:02	2	2	2	433
1/1/2021 4:02	2	2	2	439
1/1/2021 5:02	2	2	2	435
1/1/2021 6:02	3	3	3	449
1/1/2021 7:02	3	3	3	436
1/1/2021 8:02	3	3	3	442
1/1/2021 9:02	3	3	3	434
1/1/2021 10:02	3	3	3	433
1/1/2021 11:02	3	3	3	446
1/1/2021 12:02	3	3	3	448
1/1/2021 13:02	3	3	3	443
1/1/2021 14:02	3	3	3	449
1/1/2021 15:02	3	3	3	448
1/1/2021 16:02	3	3	3	443
1/1/2021 17:02	3	3	3	446
1/1/2021 18:02	3	3	3	444
1/1/2021 19:02	3	3	3	444
1/1/2021 20:02	3	3	3	446
1/1/2021 21:02	3	3	3	445
1/1/2021 22:02	3	3	3	447
1/1/2021 23:02	3	2	3	448
1/2/2021 0:02	2	2	2	447
1/2/2021 1:02	2	2	2	439
1/2/2021 2:02	2	2	2	443
1/2/2021 3:02	2	2	2	445
1/2/2021 4:02	2	2	2	438
1/2/2021 5:02	2	2	2	438

Example BMS data from the Atlas Living Lab at TU Eindhoven
(Brains4Buildings Deliverable 4.3)

Sensor metadata

- Data must be associated with its **human- and machine-readable metadata**, tags must follow a **naming convention**
- Some naming conventions are documented in a **mapping table**, but others are not

11NR008TE-001TRL

8th floor

Temperature sensor

ItemName	ItemDescriptionDutch	ItemDescriptionEnglish
11NR009LT-030PIRTM	AANWEZIGHEID 9_Z01	PRESENCE 9_Z01
11NR009TE-033CPA	CPA VIA WANDMODULE RUIMTE 9_Z01	CPA VIA WALL MODULE ROOM 9_Z01
11NR009LT-033PIRTM	AANWEZIGHEID 9_Z01	PRESENCE 9_Z01
11NR009TE-030CPA	CPA VIA WANDMODULE RUIMTE 9_Z01	CPA VIA WALL MODULE ROOM 9_Z01
11NR009LT-104PIRTM	AANWEZIGHEID 9_V04	PRESENCE 9_V04
11NR009QT-104CO2	*CO2 METING 9_V04	*CO2 MEASUREMENT 9_V04
11NR009TE-104CPA	CPA VIA WANDMODULE RUIMTE 9_V04	CPA VIA WALL MODULE ROOM 9_V04
11NR009FT-104FLW	FLOW TOEVOER VAV 9_V04	FLOW SUPPLY VAV 9_V04
11NR009LT-102PIRTM	AANWEZIGHEID 9_V01	PRESENCE 9_V01
11NR009QT-102CO2	*CO2 METING 9_V01	*CO2 MEASUREMENT 9_V01
11NR009TE-102CPA	CPA VIA WANDMODULE RUIMTE 9_V01	CPA VIA WALL MODULE ROOM 9_V01
11NR009FT-102FLW	FLOW TOEVOER VAV 9_V01	FLOW SUPPLY VAV 9_V01
11NR009QT-305CO2	*CO2 METING 9_445	*CO2 MEASUREMENT 9_445
11NR009TE-305CPA	CPA VIA WANDMODULE RUIMTE 9_445	CPA VIA WALL MODULE ROOM 9_445
11NR009LT-305PIRTM	AANWEZIGHEID 9_445	PRESENCE 9_445
11NR009FT-305FLW	FLOW TOEVOER VAV 9_445	FLOW SUPPLY VAV 9_445
11NR009FT-304FLW	FLOW TOEVOER VAV 9_442	FLOW SUPPLY VAV 9_442
11NR009LT-304PIRTM	AANWEZIGHEID 9_442	PRESENCE 9_442
11NR009QT-304CO2	*CO2 METING 9_442	*CO2 MEASUREMENT 9_442
11NR009TE-304CPA	CPA VIA WANDMODULE RUIMTE 9_442	CPA VIA WALL MODULE ROOM 9_442
11NR009TE-059CPA	CPA VIA WANDMODULE RUIMTE 9_421	CPA VIA WALL MODULE ROOM 9_421

BMS Sensor Mapping Table from the Atlas Living Lab at TU Eindhoven
(Brains4Buildings Deliverable 4.3)

TU Delft

Structuring the data

- Using a **self-descriptive naming** convention
- **Semantically annotate data** using a well-established standard to avoid inconsistencies

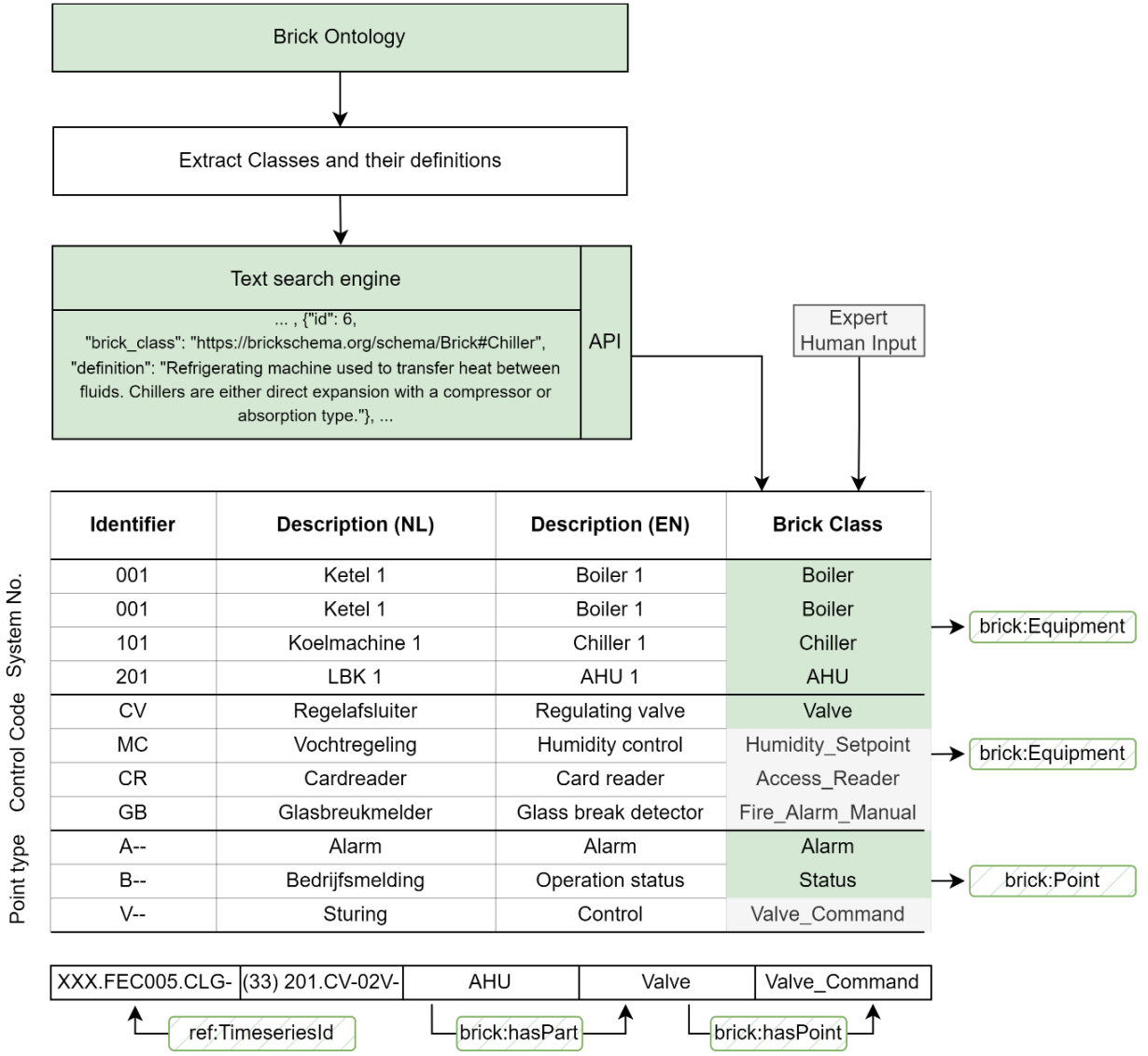
ItemName	ItemDescriptionDutch	ItemDescriptionEnglish
11NR009LT-030PIRTM	AANWEZIGHEID 9_Z01	PRESENCE 9_Z01
11NR009TE-033CPA	CPA VIA WANDMODULE RUIMTE 9_Z01	CPA VIA WALL MODULE ROOM 9_Z01
11NR009LT-033PIRTM	AANWEZIGHEID 9_Z01	PRESENCE 9_Z01
11NR009TE-030CPA	CPA VIA WANDMODULE RUIMTE 9_Z01	CPA VIA WALL MODULE ROOM 9_Z01
11NR009LT-104PIRTM	AANWEZIGHEID 9_V04	PRESENCE 9_V04
11NR009QT-104CO2	*CO2 METING 9_V04	*CO2 MEASUREMENT 9_V04
11NR009TE-104CPA	CPA VIA WANDMODULE RUIMTE 9_V04	CPA VIA WALL MODULE ROOM 9_V04
11NR009FT-104FLW	FLOW TOEVOER VAV 9_V04	FLOW SUPPLY VAV 9_V04
11NR009LT-102PIRTM	AANWEZIGHEID 9_V01	PRESENCE 9_V01
11NR009QT-102CO2	*CO2 METING 9_V01	*CO2 MEASUREMENT 9_V01
11NR009TE-102CPA	CPA VIA WANDMODULE RUIMTE 9_V01	CPA VIA WALL MODULE ROOM 9_V01
11NR009FT-102FLW	FLOW TOEVOER VAV 9_V01	FLOW SUPPLY VAV 9_V01
11NR009QT-305CO2	*CO2 METING 9_445	*CO2 MEASUREMENT 9_445
11NR009TE-305CPA	CPA VIA WANDMODULE RUIMTE 9_445	CPA VIA WALL MODULE ROOM 9_445
11NR009LT-305PIRTM	AANWEZIGHEID 9_445	PRESENCE 9_445
11NR009FT-305FLW	FLOW TOEVOER VAV 9_445	FLOW SUPPLY VAV 9_445
11NR009FT-304FLW	FLOW TOEVOER VAV 9_442	FLOW SUPPLY VAV 9_442
11NR009LT-304PIRTM	AANWEZIGHEID 9_442	PRESENCE 9_442
11NR009QT-304CO2	*CO2 METING 9_442	*CO2 MEASUREMENT 9_442
11NR009TE-304CPA	CPA VIA WANDMODULE RUIMTE 9_442	CPA VIA WALL MODULE ROOM 9_442
11NR009TE-059CPA	CPA VIA WANDMODULE RUIMTE 9_421	CPA VIA WALL MODULE ROOM 9_421

BMS Sensor Mapping Table from the Atlas Living Lab at TU Eindhoven
(Brains4Buildings Deliverable 4.3)

TU Delft

Structuring the data

- Using a **self-descriptive naming** convention
- **Semantically annotate data** using a well-established standard to avoid inconsistencies
- Using **widely accepted standards** to express syntax and semantics of data to make them understandable and easier to integrate
  - e.g., Brick, Haystack, SSN, SOSA, iotschema



Procedure for mapping to a Brick ontology
(Chamari, L. et al. (2020), CEUR Workshop Proceedings CEUR-WS)

Example 1

- TU Delft sensor naming convention
  (##) ###.XX-##XX-

Name	Description
(##) 201.TA-01A--	Vorstgevaar
(##) 302.VA-01A--	Afzuigventilator storing
(##) 201.VT-01A--	Toevoerventilator storing
(##) 201.CP-01A--	Circulatiepomp verwarmer storing
(##) 201.WW-01A--	Warmtewiel storing
(##) 201.VA-01A--	Afvoerventilator storing
(##) 201.CV-02V--	Regelafsluiter koeler
(##) 201.CV-01V--	Regelafsluiter verwarmer
(##) 201.VT-01B--	Toevoerventilator bedrijf
(##) 302.FT-01M--	Flowmeting LBK2
(##) 302.PT-01M--	Afzuigdrukopnemer
(##) 201.TT-02M--	Retourtemperatuur
(##) 201.PT-01M--	Inblaasdrukopnemer
(##) 201.TT-01M--	Inblaastemperatuur
(##) 201.PT-01M--	Afzuigdrukopnemer
(##) 201.MT-01M--	Inblaasvocht
(##) 302.VA-01B--	Afzuigventilator bedrijf
(##) 201.CD-02SW-	Afblaasluchtklep west vrijg.
(##) 201.CD-02SO-	Afblaasluchtklep oost vrijg.
(##) 302.VA-01S--	Afzuigventilato vrijgave
(##) 201.VT-01S--	Toevoerventilator vrijgave
(##) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(##) 201.WW-01S--	Warmtewiel vrijgave
(##) 201.VA-01S--	Afvoerventilator vrijgave
(##) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(##) 201.WW-01B--	Warmtewiel bedrijf
(##) 201.VA-01B--	Afvoerventilator bedrijf
(##) 201.WW-01V--	Warmtewiel sturing
(##) 302.VA-01V--	Afzuigventilator sturing
(##) 201.VT-01V--	Toevoervent. sturing
(##) 201.VA-01V--	Afvoervent. sturing
(##) 201.SC-03M--	Signaal toerenreg. VA
(##) 201.SC-02M--	Signaal toerenreg. VA
(##) 201.SC-01M--	Signaal toerenreg. VT
(##) 201.TT-03M--	Aanzuigtemperatuur
(##) 201.TT-07M--	Retourtemp. verwarmer
(##) 201.TT-05M--	Inblaastemp. na ww
(##) 201.TT-04M--	Afblaastemp. na ww
(##) 201.PDT03M--	Drukverschil 1e filter
(##) 201.PDT04M--	Drukverschil 2e filter
(##) 302.CD-01V--	Luchtklep sturing

Example 1

- TU Delft sensor naming convention
  (##) ###.XX-##XX-
  - *(##)* – Building number

Name	Description
(##) 201.TA-01A--	Vorstgevaar
(##) 302.VA-01A--	Afzuigventilator storing
(##) 201.VT-01A--	Toevoerventilator storing
(##) 201.CP-01A--	Circulatiepomp verwarmer storing
(##) 201.WW-01A--	Warmtewiel storing
(##) 201.VA-01A--	Afvoerventilator storing
(##) 201.CV-02V--	Regelafsluiter koeler
(##) 201.CV-01V--	Regelafsluiter verwarmer
(##) 201.VT-01B--	Toevoerventilator bedrijf
(##) 302.FT-01M--	Flowmeting LBK2
(##) 302.PT-01M--	Afzuigdrukopnemer
(##) 201.TT-02M--	Retourtemperatuur
(##) 201.PT-01M--	Inblaasdrukopnemer
(##) 201.TT-01M--	Inblaastemperatuur
(##) 201.PT-01M--	Afzuigdrukopnemer
(##) 201.MT-01M--	Inblaasvocht
(##) 302.VA-01B--	Afzuigventilator bedrijf
(##) 201.CD-02SW-	Afblaasluchtklep west vrijg.
(##) 201.CD-02SO-	Afblaasluchtklep oost vrijg.
(##) 302.VA-01S--	Afzuigventilato vrijgave
(##) 201.VT-01S--	Toevoerventilator vrijgave
(##) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(##) 201.WW-01S--	Warmtewiel vrijgave
(##) 201.VA-01S--	Afvoerventilator vrijgave
(##) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(##) 201.WW-01B--	Warmtewiel bedrijf
(##) 201.VA-01B--	Afvoerventilator bedrijf
(##) 201.WW-01V--	Warmtewiel sturing
(##) 302.VA-01V--	Afzuigventilator sturing
(##) 201.VT-01V--	Toevoervent. sturing
(##) 201.VA-01V--	Afvoervent. sturing
(##) 201.SC-03M--	Signaal toerenreg. VA
(##) 201.SC-02M--	Signaal toerenreg. VA
(##) 201.SC-01M--	Signaal toerenreg. VT
(##) 201.TT-03M--	Aanzuigtemperatuur
(##) 201.TT-07M--	Retourtemp. verwarmer
(##) 201.TT-05M--	Inblaastemp. na ww
(##) 201.TT-04M--	Afblaastemp. na ww
(##) 201.PDT03M--	Drukverschil 1e filter
(##) 201.PDT04M--	Drukverschil 2e filter
(##) 302.CD-01V--	Luchtklep sturing

Building number

Example 1

- TU Delft sensor naming convention
  (##) ###.XX-##XX-
  - *(##)* – Building number
  - *###* – System number

Name	Description
(##) 201.TA-01A--	Vorstgevaar
(##) 302.VA-01A--	Afzuigventilator storing
(##) 201.VT-01A--	Toevoerventilator storing
(##) 201.CP-01A--	Circulatiepomp verwarmer storing
(##) 201.WW-01A--	Warmtewiel storing
(##) 201.VA-01A--	Afvoerventilator storing
(##) 201.CV-02V--	Regelafsluiter koeler
(##) 201.CV-01V--	Regelafsluiter verwarmer
(##) 201.VT-01B--	Toevoerventilator bedrijf
(##) 302.FT-01M--	Flowmeting LBK2
(##) 302.PT-01M--	Afzuigdrukopnemer
(##) 201.TT-02M--	Retourtemperatuur
(##) 201.PT-01M--	Inblaasdrukopnemer
(##) 201.TT-01M--	Inblaastemperatuur
(##) 201.PT-01M--	Afzuigdrukopnemer
(##) 201.MT-01M--	Inblaasvocht
(##) 302.VA-01B--	Afzuigventilator bedrijf
(##) 201.CD-02SW-	Afblaasluchtklep west vrijg.
(##) 201.CD-02SO-	Afblaasluchtklep oost vrijg.
(##) 302.VA-01S--	Afzuigventilato vrijgave
(##) 201.VT-01S--	Toevoerventilator vrijgave
(##) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(##) 201.WW-01S--	Warmtewiel vrijgave
(##) 201.VA-01S--	Afvoerventilator vrijgave
(##) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(##) 201.WW-01B--	Warmtewiel bedrijf
(##) 201.VA-01B--	Afvoerventilator bedrijf
(##) 201.WW-01V--	Warmtewiel sturing
(##) 302.VA-01V--	Afzuigventilator sturing
(##) 201.VT-01V--	Toevoervent. sturing
(##) 201.VA-01V--	Afvoervent. sturing
(##) 201.SC-03M--	Signaal toerenreg. VA
(##) 201.SC-02M--	Signaal toerenreg. VA
(##) 201.SC-01M--	Signaal toerenreg. VT
(##) 201.TT-03M--	Aanzuigtemperatuur
(##) 201.TT-07M--	Retourtemp. verwarmer
(##) 201.TT-05M--	Inblaastemp. na ww
(##) 201.TT-04M--	Afblaastemp. na ww
(##) 201.PDT03M--	Drukverschil 1e filter
(##) 201.PDT04M--	Drukverschil 2e filter
(##) 302.CD-01V--	Luchtklep sturing

Building number

System number:
201 = AHU

Systeem nr.	Omschrijving	Voorbeeld
001 t/m 009	Ketels	001 = Ketel 1 002 = Ketel 2
011 t/m 019	Transportsysteem Warmwater	011 = Transportsysteem ketel 1 012 = Transportsysteem ketel 2
021 t/m 099	Warmwater groepen	021 = Warm water groep 1 022 = Warm water groep 2
101 t/m 109	Koelmachines	101 = Koelmachine 1 102 = Koelmachine 2
111 t/m 119	Transportsysteem Gek. water	111 = Transportsysteem GKW 1 112 = Transportsysteem GKW 2
121 t/m 159	Gekoeld water groepen	121 = Gekoeld water groep 1 122 = Gekoeld water groep 2
161 t/m 179	Transportsysteem Koelwater	161 = Transportsysteem KW 1 162 = Transportsysteem KW 2
181 t/m 199	Koeltorens & Drykoelers	181 = Koeltoren 1 182 = Koeltoren 2
201 t/m 299	Luchtbehandeling installaties	201 = LBK 1 202 = LBK 2
301 t/m 399	Diverse ventilatie installaties	301 = Afzuig liftmachinekamer 302 = Afzuig toiletten
401 t/m 449	Bronnen / Warmtepompen	401 = Warmebron 402 = Koudebron
451 t/m 499	Stoom / Heetwater	451 = Stoom 452 = Stoom
501 t/m 599	Verlichting	601 = Verlichting verdieping 1 602 = Verlichting verdieping 2
601 t/m 699	Zonwering	651 = Zonwering verdieping 1 652 = Zonwering verdieping 2
701 t/m 799	Naregelingen	701 = Naregelingen volgnr 1 710 = Naregelingen verdieping 10
801 t/m 899	Schakelkasten	801 = Schakelkast RK-01 802 = Schakelkast RK-02
901 t/m 999	Overige installaties	901 = Wateroverlast 902 = Vuilwaterputten 903= Hydrofoor installatie 904 = Perslucht installatie 905 = SER/MER meldingen 906 = ... 907 = ... 999 = Weerstation

Example 1

- TU Delft sensor naming convention
  (##) ###.XX-##XX-
  - *(##)* – Building number
  - *###* – System number
  - *XX* – Control engineering code

Name	Description
(##) 201.TA-01A--	Vorstgevaar
(##) 302.VA-01A--	Afzuigventilator storing
(##) 201.VT-01A--	Toevoerventilator storing
(##) 201.CP-01A--	Circulatiepomp verwarmer storing
(##) 201.WW-01A--	Warmtewiel storing
(##) 201.VA-01A--	Afvoerventilator storing
(##) 201.CV-02V--	Regelafsluiter koeler
(##) 201.CV-01V--	Regelafsluiter verwarmer
(##) 201.VT-01B--	Toevoerventilator bedrijf
(##) 302.FT-01M--	Flowmeting LBK2
(##) 302.PT-01M--	Afzuigdrukopnemer
(##) 201.TT-02M--	Retourtemperatuur
(##) 201.PT-01M--	Inblaasdrukopnemer
(##) 201.TT-01M--	Inblaastemperatuur
(##) 201.PT-01M--	Afzuigdrukopnemer
(##) 201.MT-01M--	Inblaasvocht
(##) 302.VA-01B--	Afzuigventilator bedrijf
(##) 201.CD-02SW-	Afblaasluchtklep west vrijg.
(##) 201.CD-02SO-	Afblaasluchtklep oost vrijg.
(##) 302.VA-01S--	Afzuigventilato vrijgave
(##) 201.VT-01S--	Toevoerventilator vrijgave
(##) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(##) 201.WW-01S--	Warmtewiel vrijgave
(##) 201.VA-01S--	Afvoerventilator vrijgave
(##) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(##) 201.WW-01B--	Warmtewiel bedrijf
(##) 201.VA-01B--	Afvoerventilator bedrijf
(##) 201.WW-01V--	Warmtewiel sturing
(##) 302.VA-01V--	Afzuigventilator sturing
(##) 201.VT-01V--	Toevoervent. sturing
(##) 201.VA-01V--	Afvoervent. sturing
(##) 201.SC-03M--	Signaal toerenreg. VA
(##) 201.SC-02M--	Signaal toerenreg. VA
(##) 201.SC-01M--	Signaal toerenreg. VT
(##) 201.TT-03M--	Aanzuigtemperatuur
(##) 201.TT-07M--	Retourtemp. verwarmer
(##) 201.TT-05M--	Inblaastemp. na ww
(##) 201.TT-04M--	Afblaastemp. na ww
(##) 201.PDT03M--	Drukverschil 1e filter
(##) 201.PDT04M--	Drukverschil 2e filter
(##) 302.CD-01V--	Luchtklep sturing

Building number

System number:
201 = AHU

Control engineering code:
CV = Control valve

AKM	Absorptiekoelmachine	MC-	Vochtregeling
BA-	Brandmelding	MT-	Vocht transmitter
BG-	Breekglaasje	NB-	No brak
BKA	Brandklep afvoer	ND-	Nooddrukker
BKT	Brandklep toevoer	O--	Optimalisering
BL-	Blusgasinstallatie	OK-	Overvalknop
BMC	Brandmeldcentrale	PA-	Systeemdruk alarm
BP-	Bronpomp	PC-	Drukregeling
BR-	Brandpomp	PdA	Drukverschil alarm
BSA	Brandschakelaar afvoer	PdT	Drukverschil meting
BST	Brandschakelaar toevoer	PIR	Passief infrarood
BV-	Bakverwarming	PL-	Perslucht
CA-	Camera	QT-	Lucht kwaliteit
CBP	Codebedienpaneel	QTG	Geleidbaarheid meting
CD-	Luchtklep	QW-	Water kwaliteit
CM-	Compressor	QZA	Rook melding
CP-	Circulatie pomp	RK-	Regelkast
CR-	Cardreader	RT--	Regen meting
CV-	Regelafsluiter	SB-	Stoom bevochtiger
DK-	Doseer klep	SC-	Toerenregeling
DP-	Doseer pomp	SK-	Sleutelkluis
DR-	Deur	SL-	Sloten
EH-	Elektrische heater	SP-	Shunt pomp
EqT	Energie meting	SPR	Sprinklermelding
FA-	Flowalarm	ST-	Storingsmelding
FQ-	Waterkwaliteit	SV-	Stoomvraag
FS-	Flowswitch	TA-	Temperatuur alarm
FT-	Flow transmitter	TC-	Temperatuurregeling
FU-	Fancoil unit	TGC	Toegangscontrole
GB-	Glasbreukmelder	TP-	Transportpomp
GU-	Galaxy Unit	TQ-	Tourniquet
HT-	Enthalpie Transmitter	TS-	Thermostaat
HYD	Hydrofoor installatie	TT-	Temperatuur transmitter
IB-	Inbraakdetectie	VA-	Afzuig ventilator
IBC	Inbraakcentrale	VB-	Booster ventilator
IC-	Intercom	VD-	Drykoeler ventilator
ICC	Intercomcentrale	VK-	Koeltoren ventilator
KE-	Ketelinstallatie	VL-	Ventilator luchtverhitter
KF-	Kleefmagneet	VP-	Vuilwaterpomp installatie
KL-	Klok	VR-	Recirculatie ventilator
KM-	Koelmachine	VT-	Ventilator toevoer
KS-	Overwerk	VV-	Vochtaanvraag
KT-	Koeltoren	WKK	Warmtekracht koppeling
KU-	Koelunit	WP-	Warmtepomp
LA-	Niveau alarm	WR-	Windrichting
LC-	Niveau regelaar	WS-	Windsnelheid
LD-	Leidingverwarming/tracing	WV-	Warmtevraag
LI-	Lichtinstallatie	WW-	Warmtewiel
LIF	Invalidenlift	XA-	Storing algemeen
LS-	Niveau schakelend	XB-	Bedrijf algemeen
LT-	Nivo meting	XS-	Status algemeen
NSA	Nood stroomaggregaat	ZO-	Zonnewarmte
MA-	Vocht alarm	ZW-	Zonwering

Example 1

- TU Delft sensor naming convention
  (##) ###.XX-##XX-
  - *(##)* – Building number
  - *###* – System number
  - *XX* – Control engineering code
  - *##* – Process number

Name	Description
(##) 201.TA-01A--	Vorstgevaar
(##) 302.VA-01A--	Afzuigventilator storing
(##) 201.VT-01A--	Toevoerventilator storing
(##) 201.CP-01A--	Circulatiepomp verwarmer storing
(##) 201.WW-01A--	Warmtewiel storing
(##) 201.VA-01A--	Afvoerventilator storing
(##) 201.CV-02V--	Regelafsluiter koeler
(##) 201.CV-01V--	Regelafsluiter verwarmer
(##) 201.VT-01B--	Toevoerventilator bedrijf
(##) 302.FT-01M--	Flowmeting LBK2
(##) 302.PT-01M--	Afzuigdrukopnemer
(##) 201.TT-02M--	Retourtemperatuur
(##) 201.PT-01M--	Inblaasdrukopnemer
(##) 201.TT-01M--	Inblaastemperatuur
(##) 201.PT-01M--	Afzuigdrukopnemer
(##) 201.MT-01M--	Inblaasvocht
(##) 302.VA-01B--	Afzuigventilator bedrijf
(##) 201.CD-02SW-	Afblaasluchtklep west vrijg.
(##) 201.CD-02SO-	Afblaasluchtklep oost vrijg.
(##) 302.VA-01S--	Afzuigventilato vrijgave
(##) 201.VT-01S--	Toevoerventilator vrijgave
(##) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(##) 201.WW-01S--	Warmtewiel vrijgave
(##) 201.VA-01S--	Afvoerventilator vrijgave
(##) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(##) 201.WW-01B--	Warmtewiel bedrijf
(##) 201.VA-01B--	Afvoerventilator bedrijf
(##) 201.WW-01V--	Warmtewiel sturing
(##) 302.VA-01V--	Afzuigventilator sturing
(##) 201.VT-01V--	Toevoervent. sturing
(##) 201.VA-01V--	Afvoervent. sturing
(##) 201.SC-03M--	Signaal toerenreg. VA
(##) 201.SC-02M--	Signaal toerenreg. VA
(##) 201.SC-01M--	Signaal toerenreg. VT
(##) 201.TT-03M--	Aanzuigtemperatuur
(##) 201.TT-07M--	Retourtemp. verwarmer
(##) 201.TT-05M--	Inblaastemp. na ww
(##) 201.TT-04M--	Afblaastemp. na ww
(##) 201.PDT03M--	Drukverschil 1e filter
(##) 201.PDT04M--	Drukverschil 2e filter
(##) 302.CD-01V--	Luchtklep sturing

Building number

System number:
201 = AHU

Control engineering code:
CV = Control valve

Process number

Example 1

- TU Delft sensor naming convention *(##) ###.XX-##XX-*
  - *(##)* – Building number
  - *###* – System number
  - *XX* – Control engineering code
  - *##* – Process number
  - *XX-* – Reporting, measuring and control code

Name	Description
(##) 201.TA-01A--	Vorstgevaar
(##) 302.VA-01A--	Afzuigventilator storing
(##) 201.VT-01A--	Toevoerventilator storing
(##) 201.CP-01A--	Circulatiepomp verwarmer storing
(##) 201.WW-01A--	Warmtewiel storing
(##) 201.VA-01A--	Afvoerventilator storing
(##) 201.CV-02V--	Regelafsluiter koeler
(##) 201.CV-01V--	Regelafsluiter verwarmer
(##) 201.VT-01B--	Toevoerventilator bedrijf
(##) 302.FT-01M--	Flowmeting LBK2
(##) 302.PT-01M--	Afzuigdrukopnemer
(##) 201.TT-02M--	Retourtemperatuur
(##) 201.PT-01M--	Inblaasdrukopnemer
(##) 201.TT-01M--	Inblaastemperatuur
(##) 201.PT-01M--	Afzuigdrukopnemer
(##) 201.MT-01M--	Inblaasvocht
(##) 302.VA-01B--	Afzuigventilator bedrijf
(##) 201.CD-02SW-	Afblaasluchtklep west vrijg.
(##) 201.CD-02SO-	Afblaasluchtklep oost vrijg.
(##) 302.VA-01S--	Afzuigventilato vrijgave
(##) 201.VT-01S--	Toevoerventilator vrijgave
(##) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(##) 201.WW-01S--	Warmtewiel vrijgave
(##) 201.VA-01S--	Afvoerventilator vrijgave
(##) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(##) 201.WW-01B--	Warmtewiel bedrijf
(##) 201.VA-01B--	Afvoerventilator bedrijf
(##) 201.WW-01V--	Warmtewiel sturing
(##) 302.VA-01V--	Afzuigventilator sturing
(##) 201.VT-01V--	Toevoervent. sturing
(##) 201.VA-01V--	Afvoervent. sturing
(##) 201.SC-03M--	Signaal toerenreg. VA
(##) 201.SC-02M--	Signaal toerenreg. VA
(##) 201.SC-01M--	Signaal toerenreg. VT
(##) 201.TT-03M--	Aanzuigtemperatuur
(##) 201.TT-07M--	Retourtemp. verwarmer
(##) 201.TT-05M--	Inblaastemp. na ww
(##) 201.TT-04M--	Afblaastemp. na ww
(##) 201.PDT03M--	Drukverschil 1e filter
(##) 201.PDT04M--	Drukverschil 2e filter
(##) 302.CD-01V--	Luchtklep sturing

Building number

System number:
201 = AHU

Control engineering code:
CV = Control valve

Process number

Reporting, measuring and control code:
M--: measurement

A--	Alarm
B--	Bedrijfsmelding
D--	Dicht
HS--	Hoofdschakelaar
L--	Lokaal bediend
LG--	Lichtgroep
M--	Meting
O--	Open
S--	Schakelen
T--	Telling(er)
V--	Sturing
WS-	Werkschakelaar
W--	Werksetpunt
X--	Instelling (X-as)
XS-	Setpunt verstelling
Y--	Instelling (Y-as)

	sturingen
SU-	urgente storing
SN-	niet urgente storingsmelding
SR-	reset op afstand (GBS)
SB-	brandsturing
SI-	brandschakelaar ventilatie in
SU-	brandschakelaar ventilatie uit
SS-	staffel relais
SRP	resetplus
	meldingen
BR-	reset storing
BI-	herinschakelen ventilatie na brand
BU-	heruitschakelen ventilatie na brand
BV-	voeding aanwezig
L--	regelkast lokaal bediend
BS-	spanningsbewaking stuurstroom (NC)
	alarmen
AB-	brandmelding RK-01 BMC
AN-	netwachter
AS-	sabotage
AI-	installatie automaten

TU Delft

Example 1

- TU Delft sensor naming convention
  (##) ###.XX-##XX-
  - *(##)* – Building number
  - *###* – System number
  - *XX* – Control engineering code
  - *##* – Process number
  - *XX-* – Reporting, measuring and control code

Name	Description
(##) 201.TA-01A--	Vorstgevaar
(##) 302.VA-01A--	Afzuigventilator storing
(##) 201.VT-01A--	Toevoerventilator storing
(##) 201.CP-01A--	Circulatiepomp verwarmer storing
(##) 201.WW-01A--	Warmtewiel storing
(##) 201.VA-01A--	Afvoerventilator storing
(##) 201.CV-02V--	Regelafsluiter koeler
(##) 201.CV-01V--	Regelafsluiter verwarmer
(##) 201.VT-01B--	Toevoerventilator bedrijf
(##) 302.FT-01M--	Flowmeting LBK2
(##) 302.PT-01M--	Afzuigdrukopnemer
(##) 201.TT-02M--	Retourtemperatuur
(##) 201.PT-01M--	Inblaasdrukopnemer
(##) 201.TT-01M--	Inblaastemperatuur
(##) 201.PT-01M--	Afzuigdrukopnemer
(##) 201.MT-01M--	Inblaasvocht
(##) 302.VA-01B--	Afzuigventilator bedrijf
(##) 201.CD-02SW-	Afblaasluchtklep west vrijg.
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(##) 302.VA-01S--	Afzuigventilato vrijgave
(##) 201.VT-01S--	Toevoerventilator vrijgave
(##) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(##) 201.WW-01S--	Warmtewiel vrijgave
(##) 201.VA-01S--	Afvoerventilator vrijgave
(##) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(##) 201.WW-01B--	Warmtewiel bedrijf
(##) 201.VA-01B--	Afvoerventilator bedrijf
(##) 201.WW-01V--	Warmtewiel sturing
(##) 302.VA-01V--	Afzuigventilator sturing
(##) 201.VT-01V--	Toevoervent. sturing
(##) 201.VA-01V--	Afvoervent. sturing
(##) 201.SC-03M--	Signaal toerenreg. VA
(##) 201.SC-02M--	Signaal toerenreg. VA
(##) 201.SC-01M--	Signaal toerenreg. VT
(##) 201.TT-03M--	Aanzuigtemperatuur
(##) 201.TT-07M--	Retourtemp. verwarmer
(##) 201.TT-05M--	Inblaastemp. na ww
(##) 201.TT-04M--	Afblaastemp. na ww
(##) 201.PDT03M--	Drukverschil 1e filter
(##) 201.PDT04M--	Drukverschil 2e filter
(##) 302.CD-01V--	Luchtklep sturing

AHU 1 Temperature Supply Measurement 1

Example 2

- Sensor labels for an **air handling unit** (Brains4Buildings project)
- Can you identify any patterns?

Label	Code	Description
1-5XV1	9.1.2244	Supply air damper control
1-5XV2	9.1.2250	Exhausted air damper control
1-5PdT1	9.1.1585	Pressure difference between supply air filter
1-5PdT2	9.1.1586	Pressure difference between exhausted air filter
1-5PdT3	9.1.1547	Pressure difference between supply fan
1-5PT1	9.1.1582	Static pressure at supply pipeline
1-5XT1	9.1.1587	Supply air temperature
1-5XT1	9.1.1588	Supply air related humidity
1-5XT2	9.1.1549	Outdoor air temperature
1-5XT2	9.1.1550	Outdoor air related humidity
1-5XT2	9.1.2179	Outdoor air absolute humidity
1-5XT3	9.1.1554	Preheated air temperature/related humidity
1-5XT3	9.1.1551	Preheated air related humidity
1-5XT3	9.1.2180	Preheated air absolute humidity
1-5XT4	9.1.1552	Preheated air temperature
1-5XT4	9.1.1555	Preheated air related humidity
1-5XT4	9.1.2181	Preheated air absolute humidity
1-5XT5	9.1.1556	Preheated air temperature
1-5XT5	9.1.1553	Preheated air related humidity
1-5XT5	9.1.2182	Preheated air absolute humidity
1-5XT6	9.1.1558	Return air temperature
1-5XT6	9.1.1546	Return air related humidity
1-5XT6	9.1.2183	Return air absolute humidity
1-5XT7	9.1.1557	Exhausted air temperature/related humidity
1-5XT7	9.1.1545	Exhausted air temperature/related humidity
1-5XT7	9.1.2184	Exhausted air temperature/related humidity
1-5TT1	9.1.1577	Supply water temperature at heating coil

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02

Data Preprocessing

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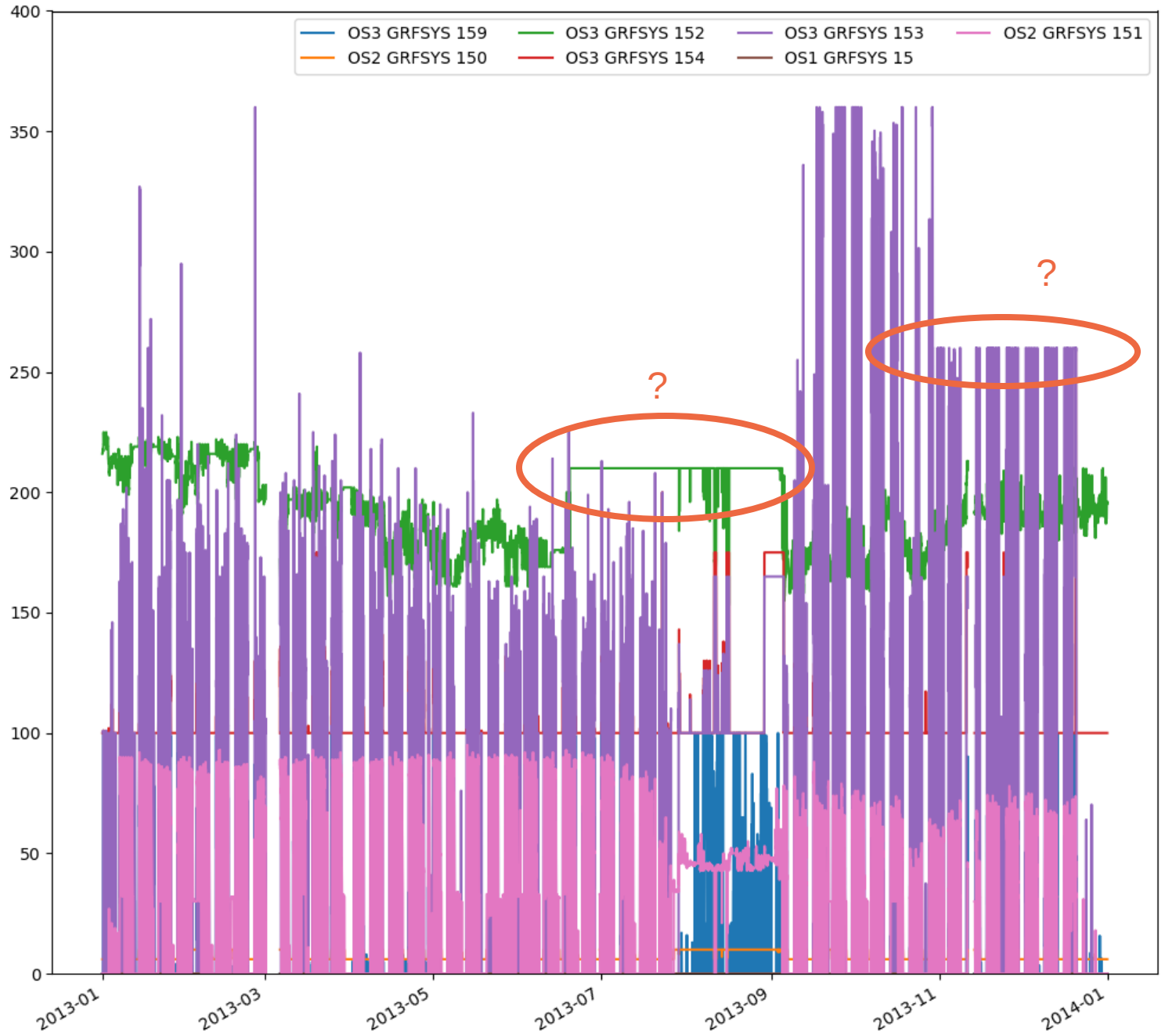
Data Preprocessing

- Using data from buildings requires a major effort of pre-processing, depending on the quality of data and the intended application:
  - Handling missing or erroneous values
  - Choosing summarisation and aggregation techniques
  - Filtering or down sampling data if gathering frequency does not match the application
  - Removing outliers



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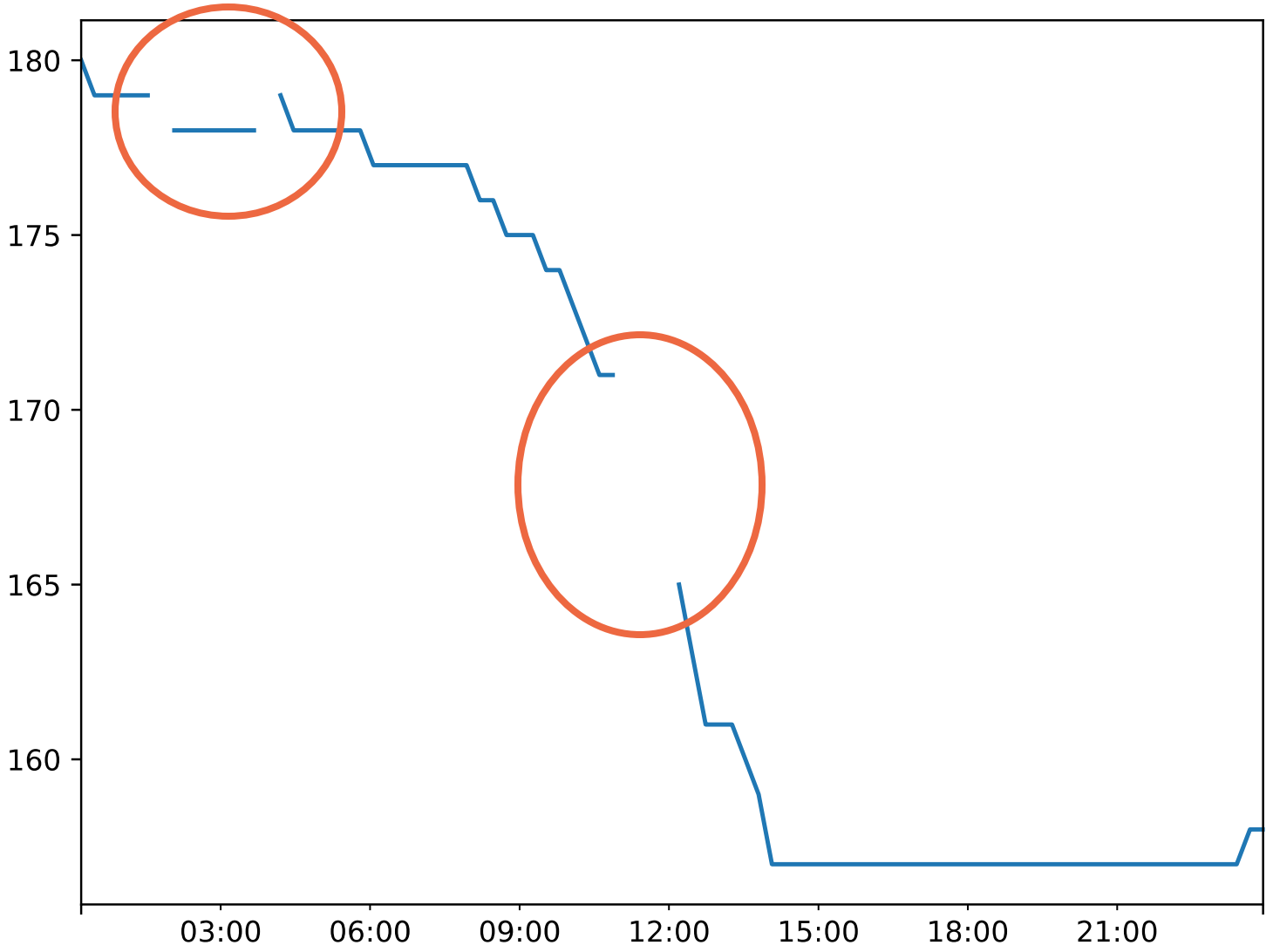
Handling missing data

- Techniques used for **treating erroneous and missing values** vary from one application to another

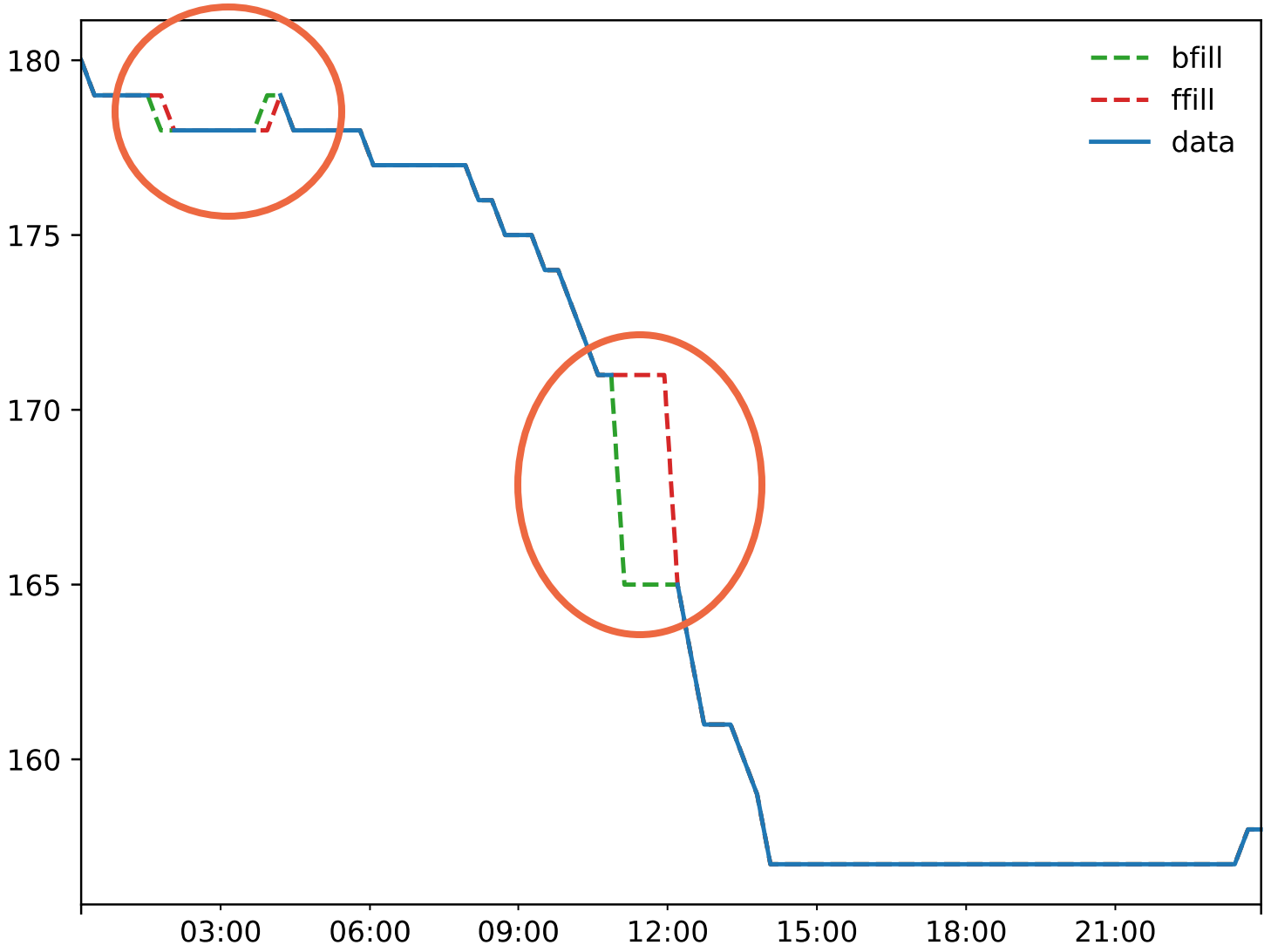


Handling missing data

- Techniques used for **treating erroneous and missing values** vary from one application to another

  1. replacing with next or previous value

  ➢ When using these techniques, we are assuming that the measurements before and after the gap in the data are similar. However, the difference can be considerable (e.g., see the values in the middle)



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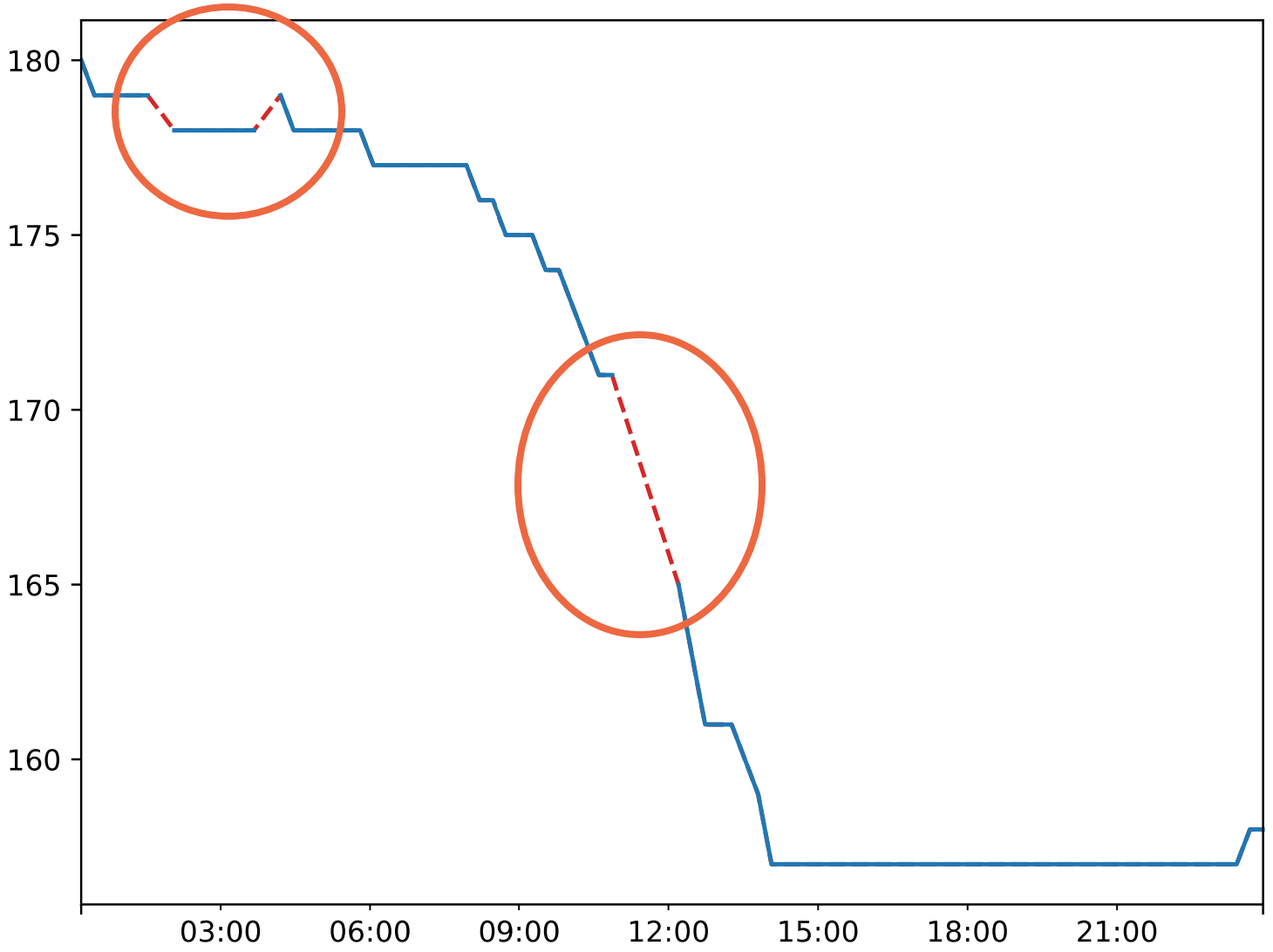
Handling missing data

- Techniques used for **treating erroneous and missing values** vary from one application to another:
  1. replacing with **next** or **previous** value
  2. using **interpolation**



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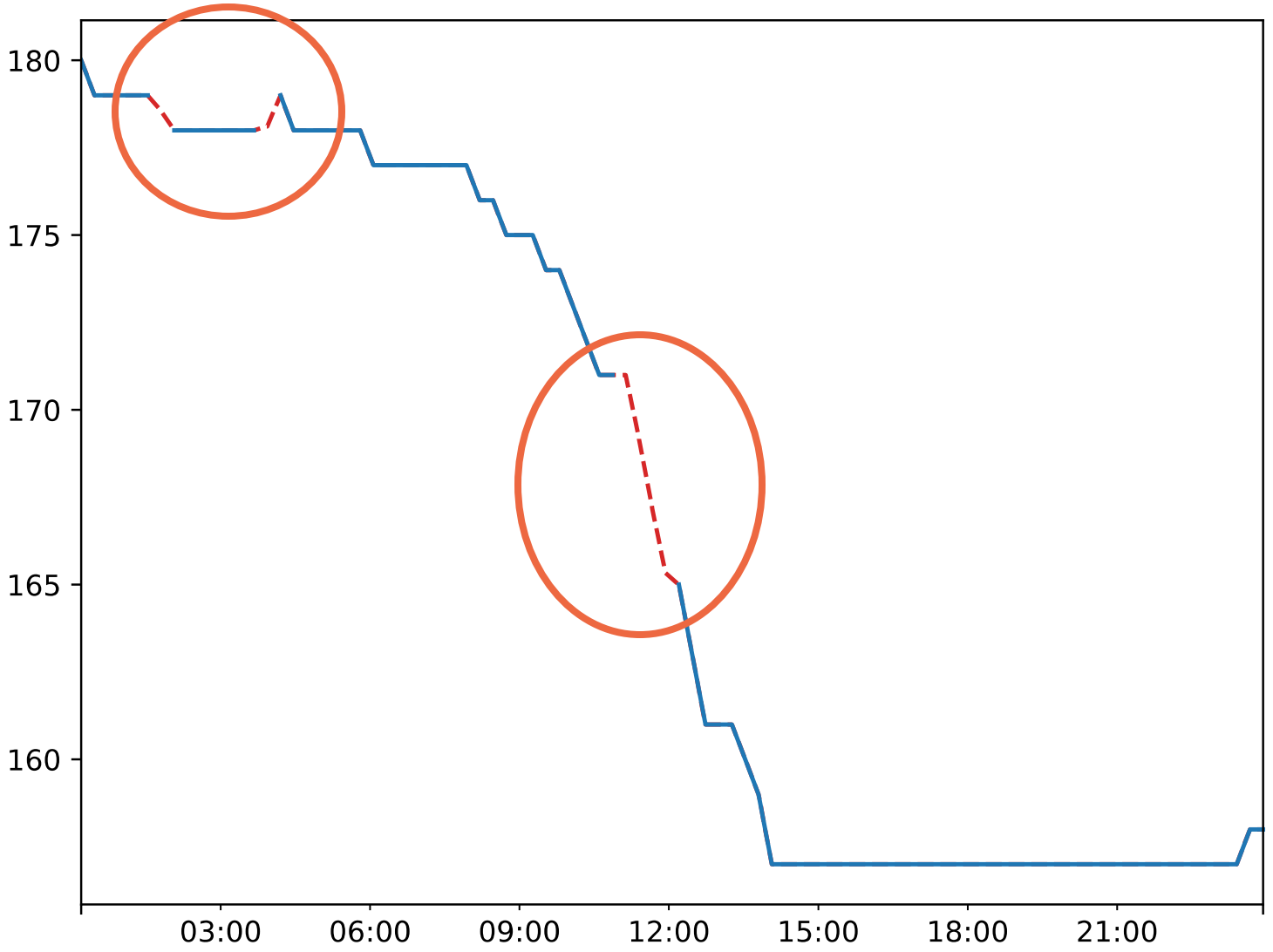
Handling missing data

- Techniques used for **treating erroneous and missing values** vary from one application to another:
  1. replacing with **next** or **previous** value
  2. using **interpolation**
  3. using a **rolling average**



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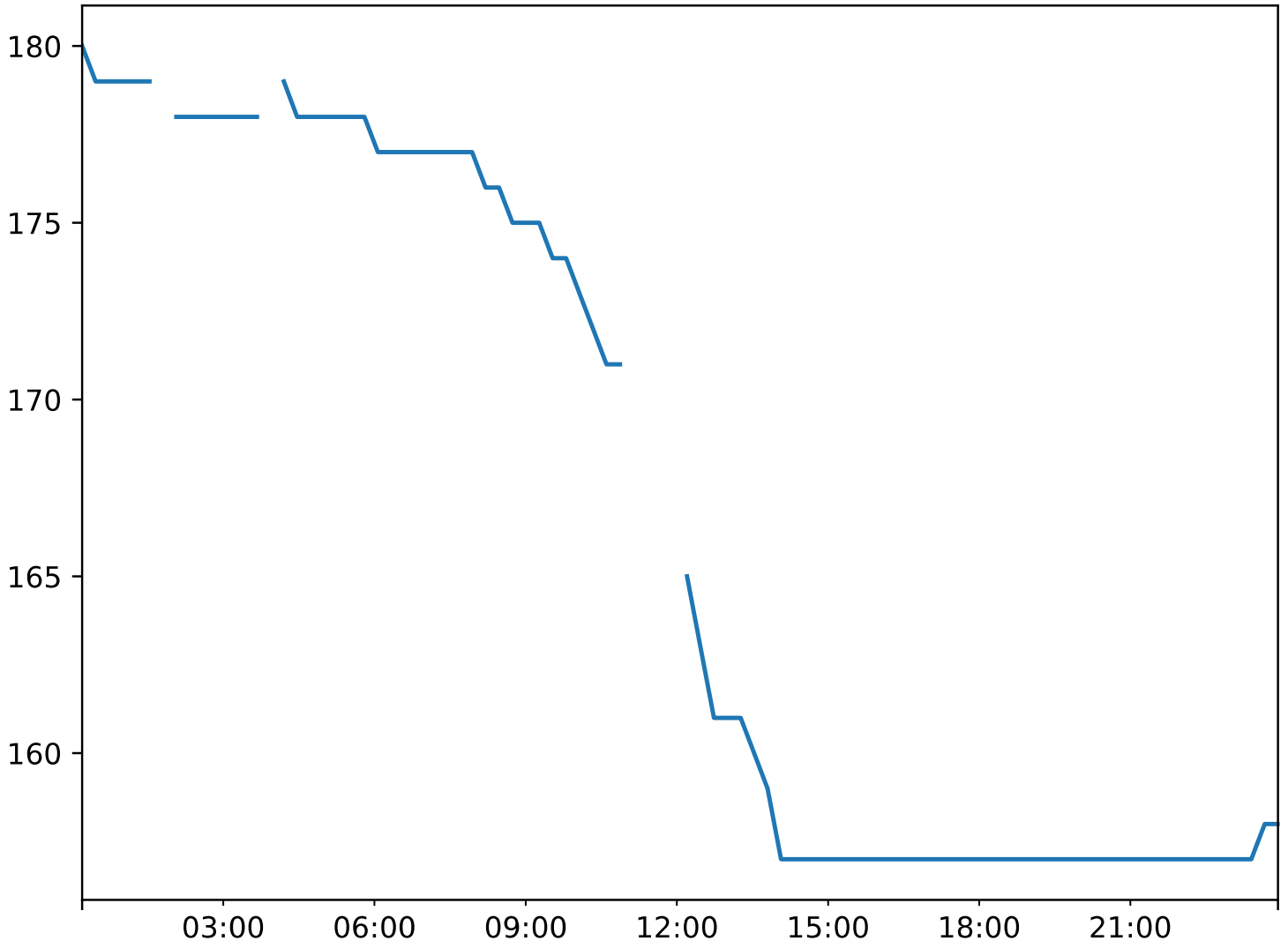
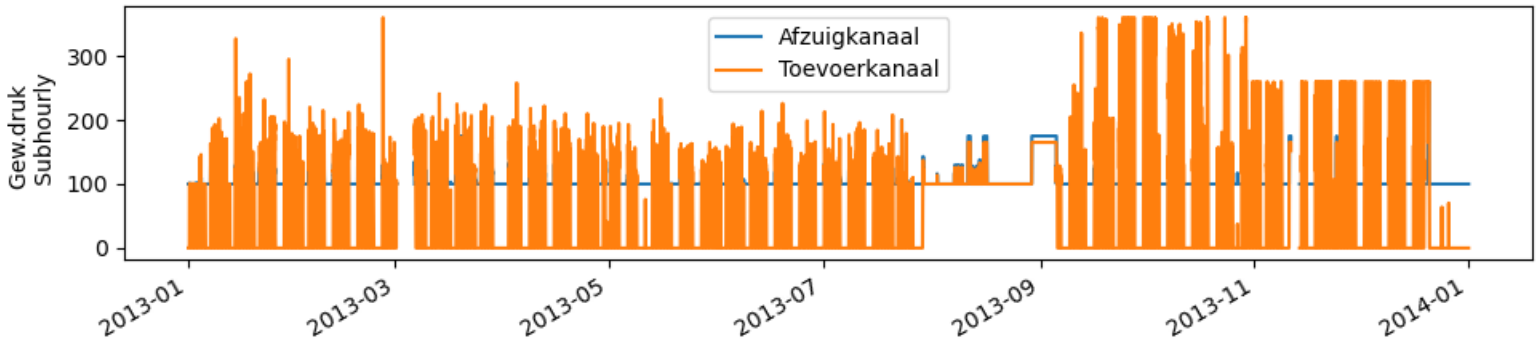
Handling long missing periods

- The previous examples assume the **gaps** in the data are relatively **short**
- However, how do we deal with **long gaps** in the measurements (e.g., an entire day missing)?
- Filling in a single value (e.g. back/forward fill) or merely interpolating would lead to an **oversimplification**.
- **Data imputation for longer time periods and accounting for seasonality** require more complex techniques, as in these simple examples (online).



Downsampling

- When gathering **frequency** does not match the intended **application**, we might need to **resample the data**
- Again, there are some **choices** to be made



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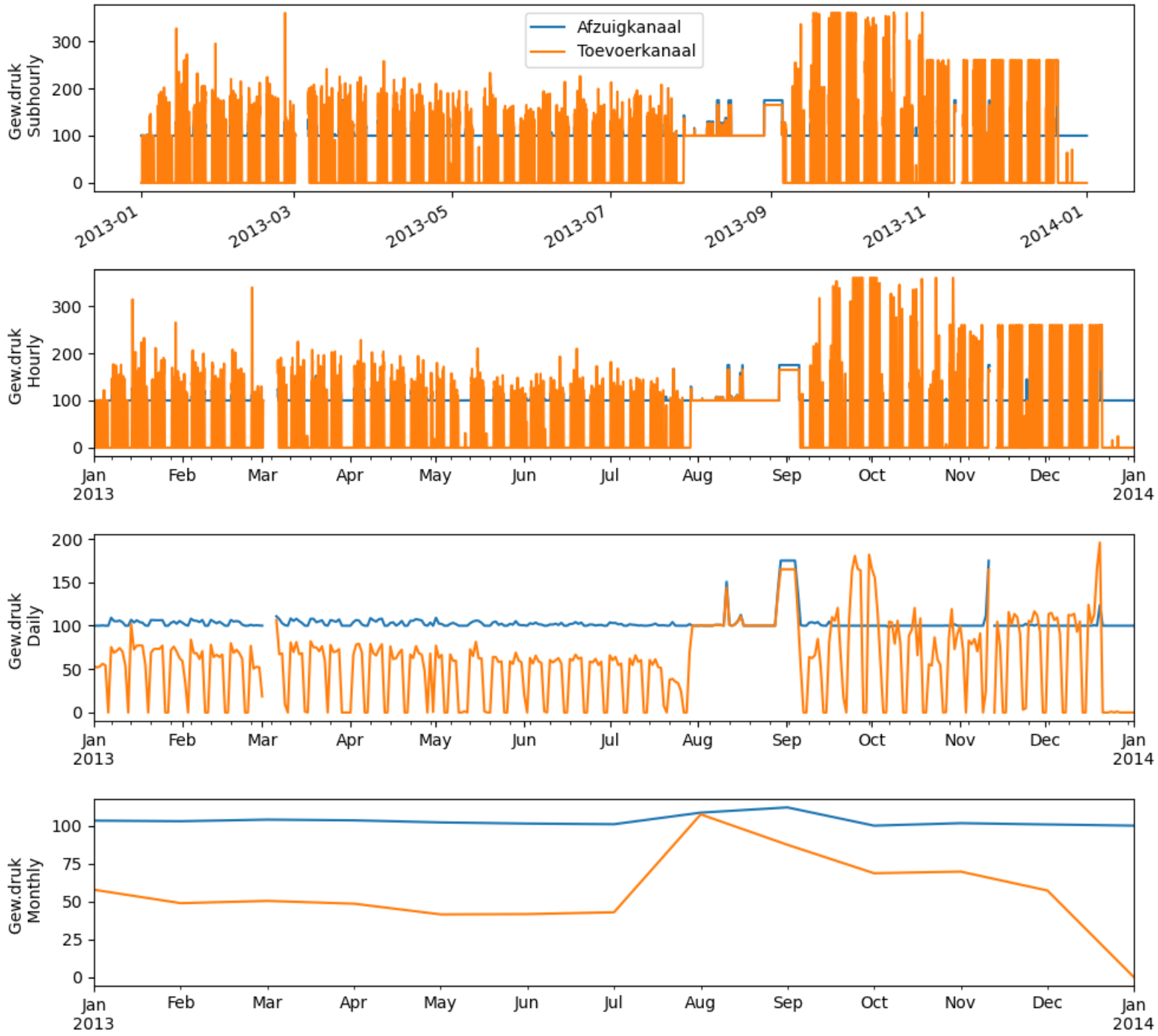
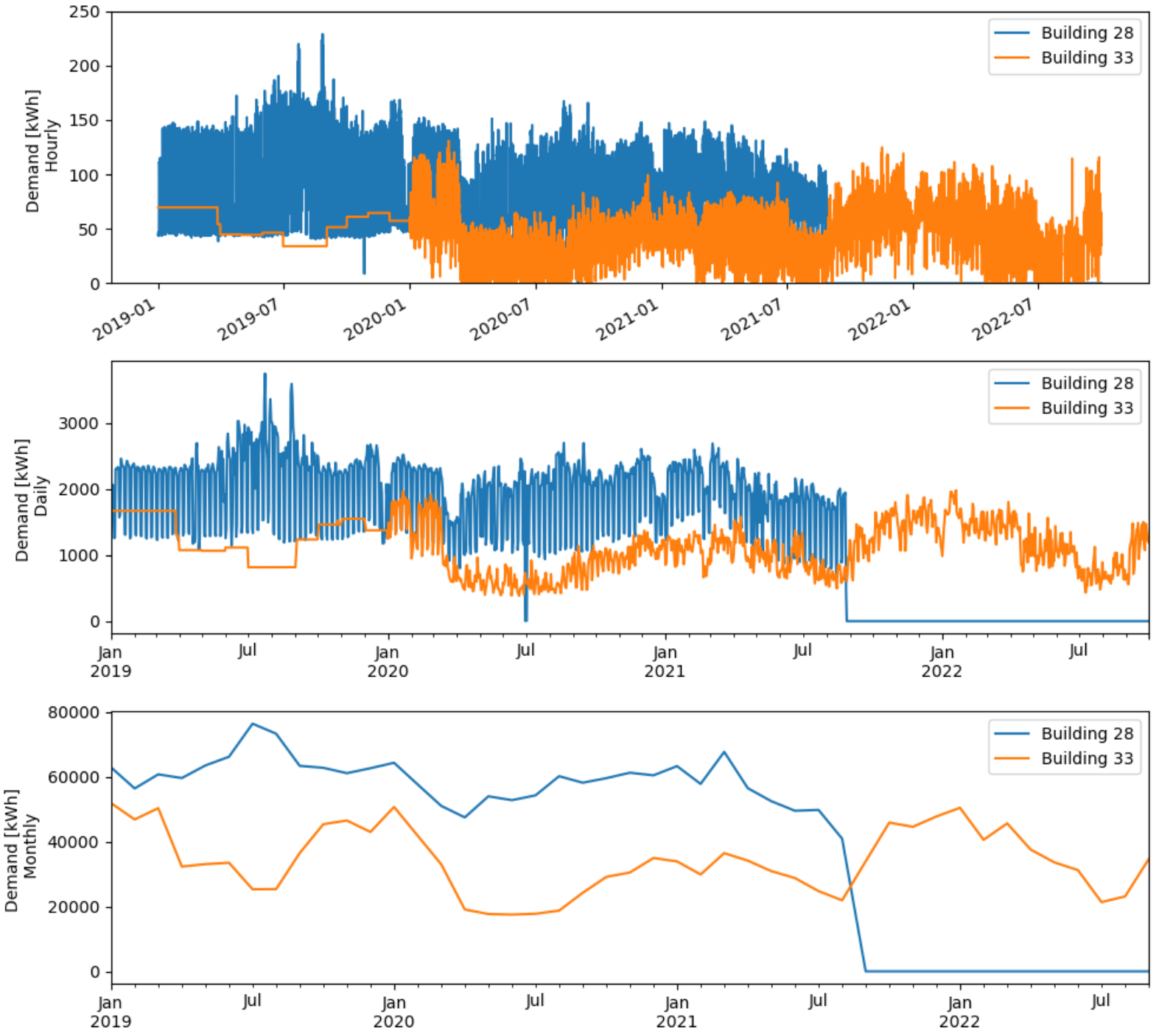
Downsampling

- When gathering **frequency** does not match the intended **application**, we might need to **resample the data**
- Again, there are some **choices** to be made:
  1. choice of **frequency** for the given application:
     - **sub-hourly** values are typically used for dynamic building system controls
     - **hourly** values are typically sufficient for building energy simulations
     - **monthly** values can be sufficient to assess seasonality
     - **yearly** values might be sufficient to analyze long-term trends (e.g., due to climate change)



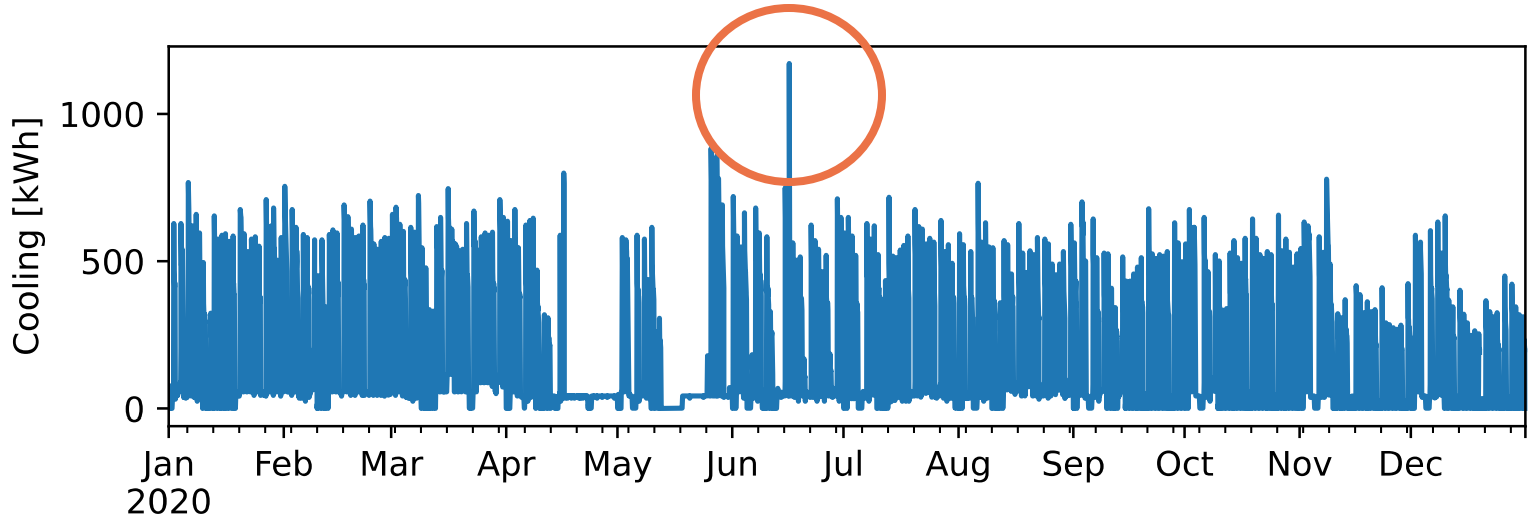
Downsampling

- When gathering **frequency** does not match the intended **application**, we might need to **resample the data**
- Again, there are some **choices** to be made:
  1. choice of **frequency** for the given application
  2. choice of **downsampling method** for the type of data used:
     - **mean:** e.g., operating temperature, pressure
     - **sum:** e.g., energy demand



Outliers

- Removing unexpected **outliers** to ensure they do not influence the **intended application**



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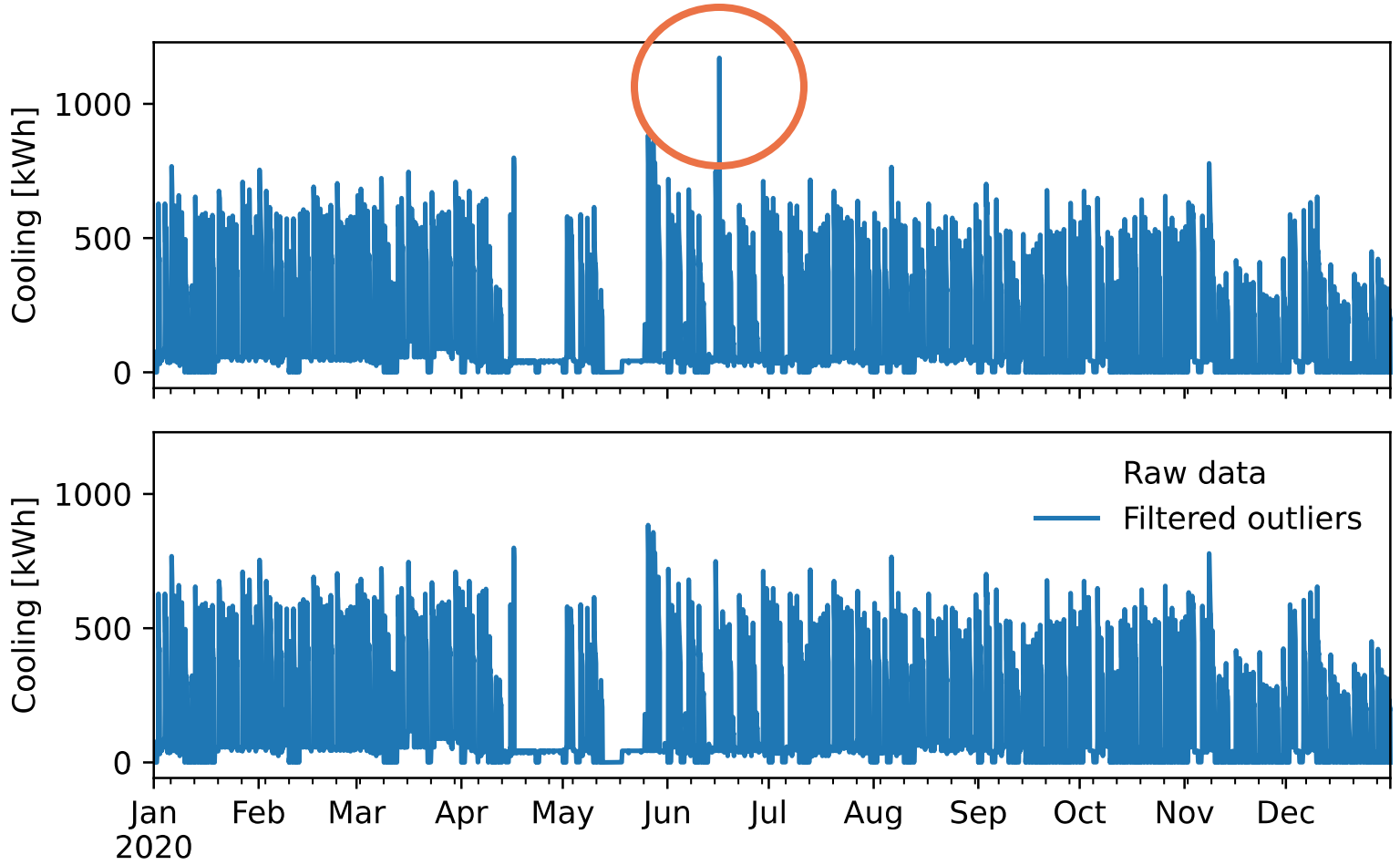
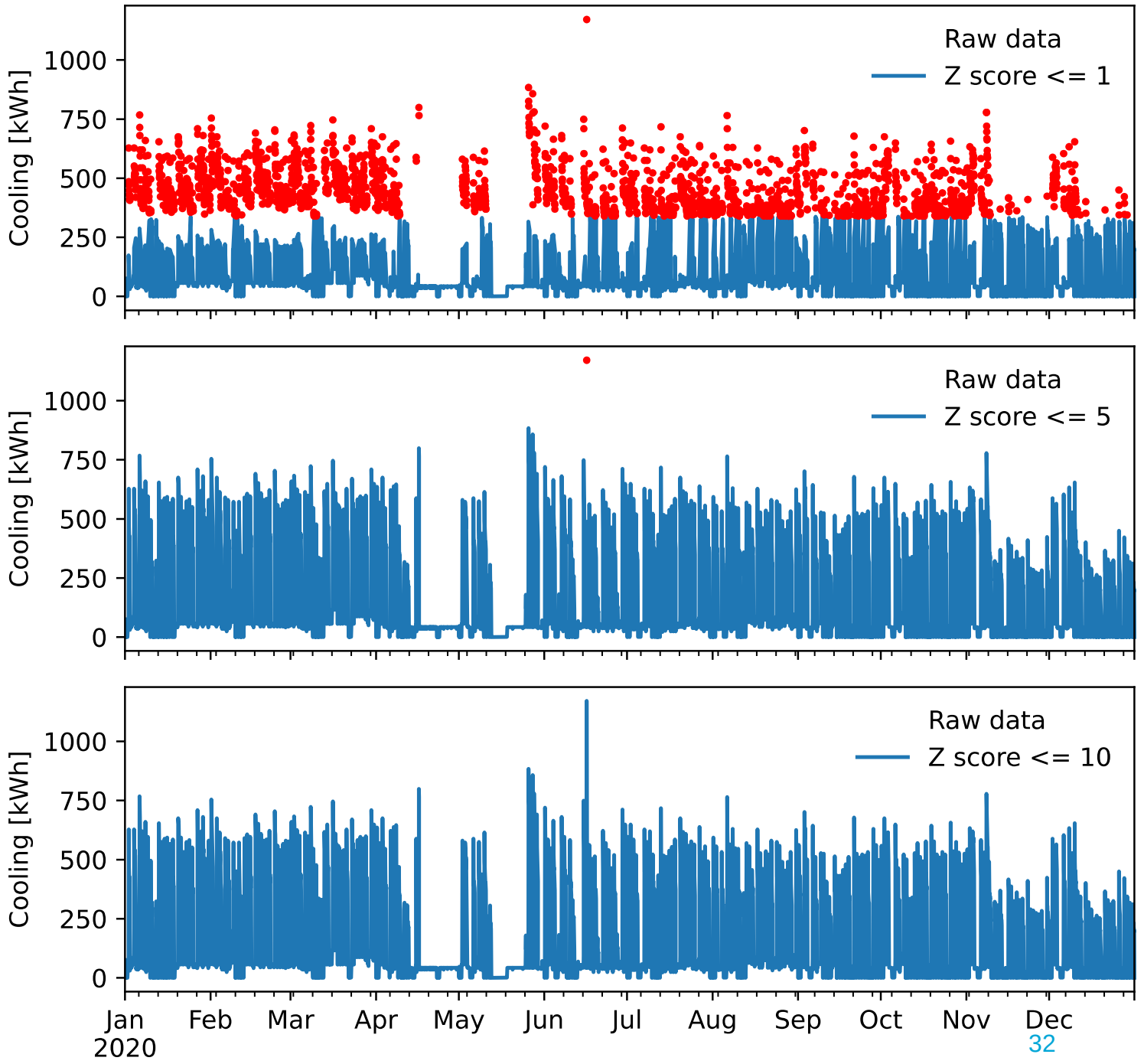
Outliers

- Removing unexpected **outliers** to ensure they do not influence the **intended application**
  - **expected range** of values (if available)
    - If there is an expected range of acceptable values for the measurement (e.g., the temperature of liquid water), any value beyond that range could be considered an outlier and filtered
    - However, selecting such a range of values might be **inadequate for most applications** where there's no clear acceptable range



Outliers

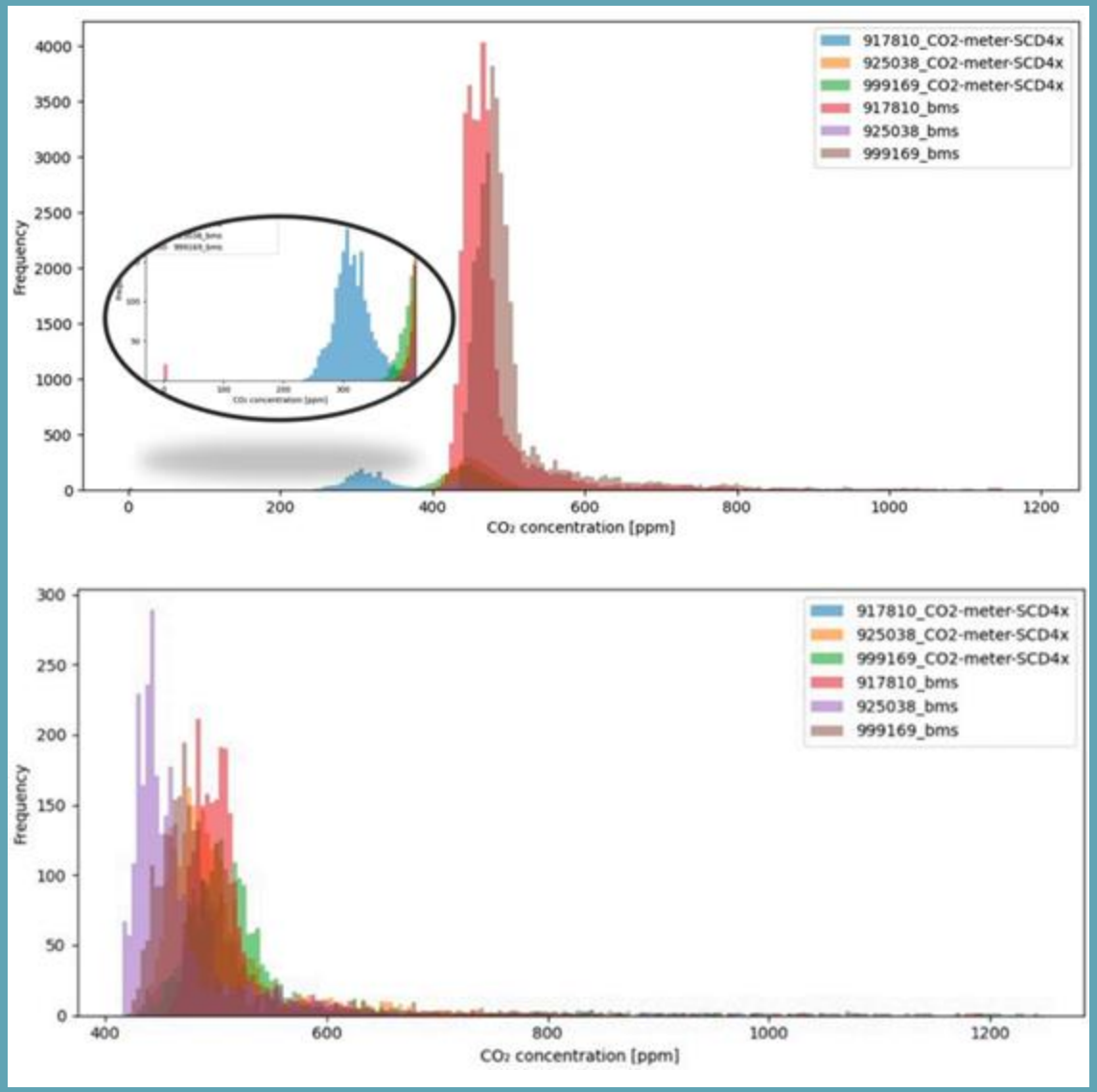
- Removing unexpected **outliers** to ensure they do not influence the **intended application**
  - **expected range** of values (if available)
  - **Z-scores**: need to pick a reasonable value
    - Z-scores can provide a simple filter for outliers
    - Again, the choice of maximum Z-score values can strongly influence which scores are selected as outliers



Data Preprocessing Example

The plots on the right show the histograms for CO_2 measurements for various rooms and sensors for a case study in the Brains4Buildings project before and after preprocessing. Data preprocessing consisted of the following steps:

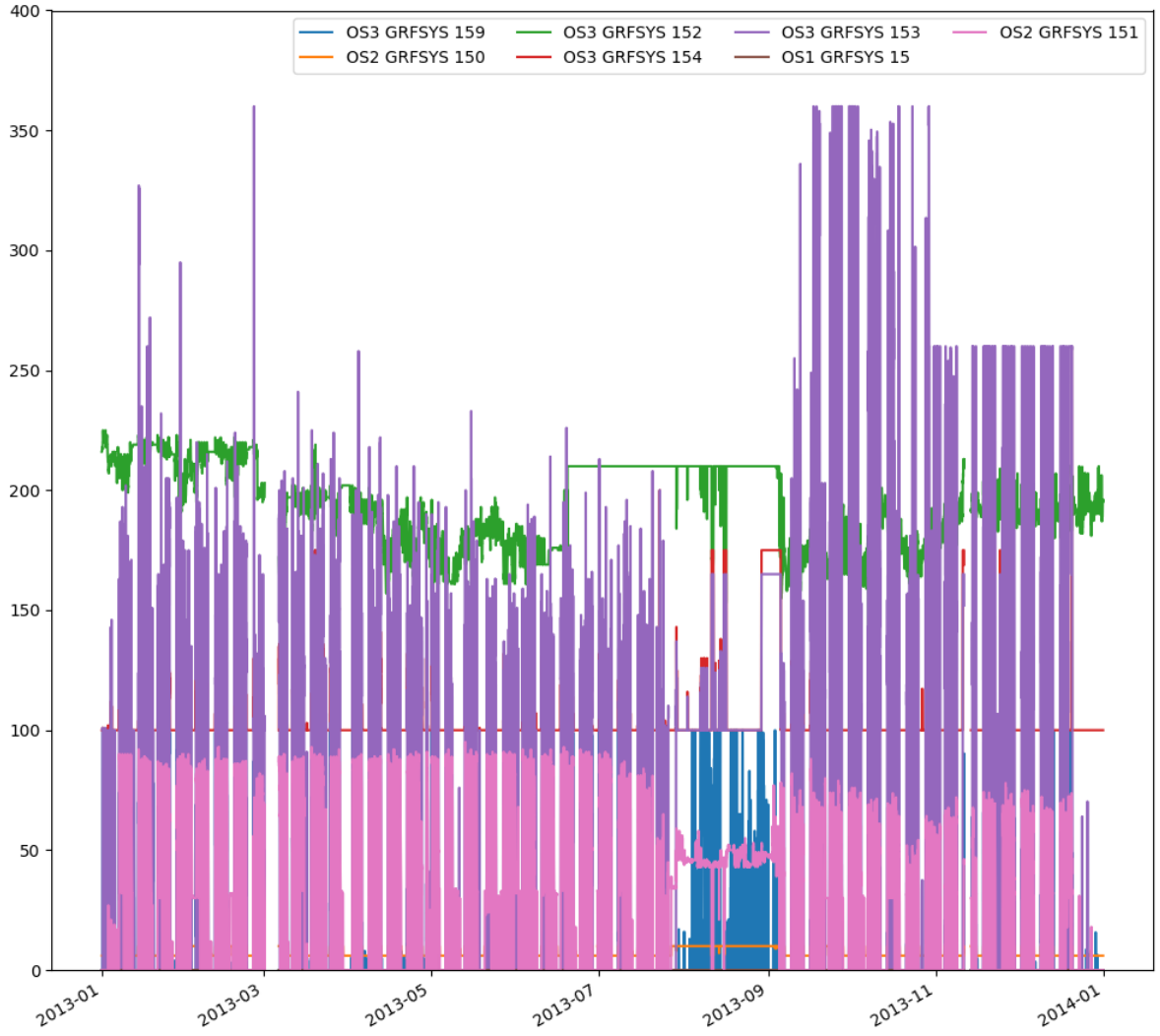
1. Removal of **duplicate measurements**
2. Removal of measurements that have no variation due to a **faulty sensor**
3. Removal of all measurements below a **minimum threshold**, assessed as clearly wrong
4. **Baseline adjustment**: minimum measurement value was determined and all measurement values were raised by the same amount to counteract the effect of long-term drift of sensors
5. **Measurement interpolation** to 15-minute intervals, except when they were 90 minutes or more apart
   - **A considerable amount of human input is required**



Histogram of CO2 measurements for various rooms and measurement devices before (top) and after (bottom) preprocessing.
(Brains4Buildings Deliverable 2.1-2.2-2.3)

Example 2:
Hands-on data labelling and preprocessing examples

- You can find hands-on examples on data labeling and preprocessing in this Colab notebook. You will:
  - Import timeseries data and give it human-readable labels using mapping tables
  - Impute missing data using different methods
  - Downsample different types of data
  - Filter outliers
  - Generate all plots shown in the previous slides
- If you are not familiar with Colab notebooks, you can first go through some simple examples in Section 5.6 of the Brains4Building learning community



03

Data Integration

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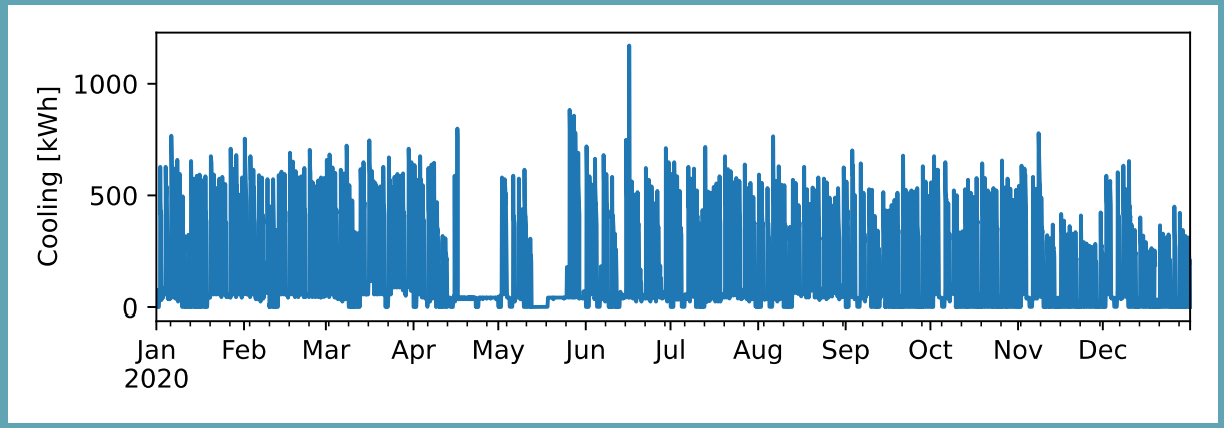
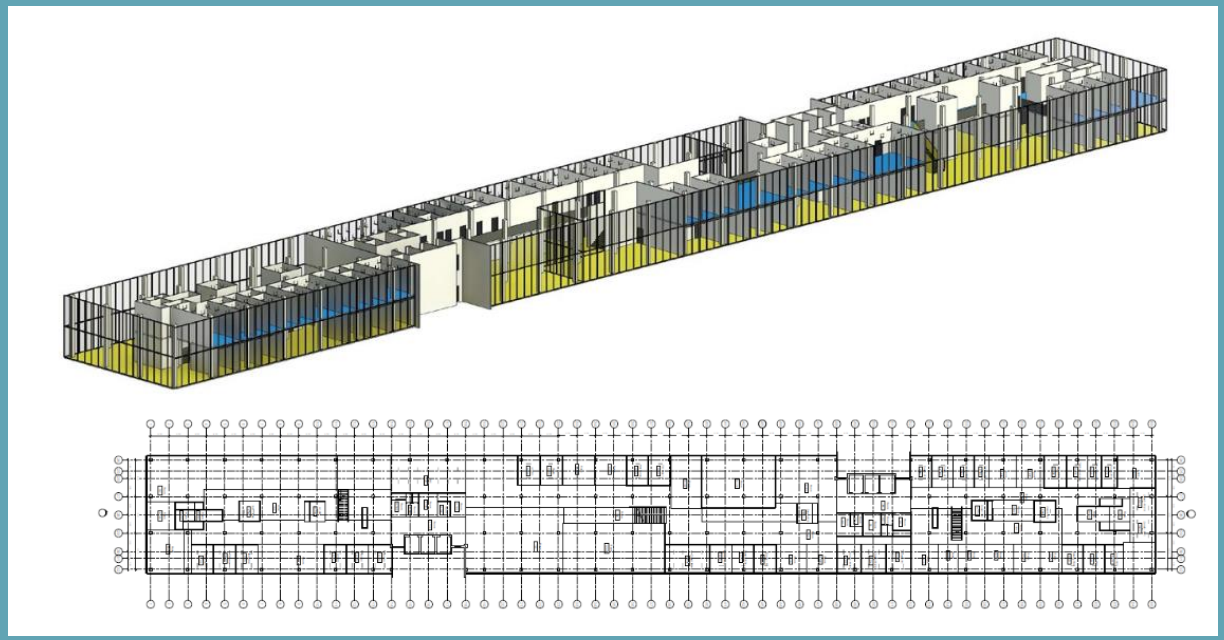
Data Integration

- Smart building applications rely on **operational and contextual data** from various sources and systems:
  - **time series data** provide operational information for HVAC systems, lighting, alarms, energy meters, weather services, smart devices, etc.
  - **contextual building data (metadata)** includes Building Information Models (BIM), technical drawings, Process and Instrumentation Diagrams (P&ID), product databases, etc., which contain information about the configurations and relationships between different systems and their components



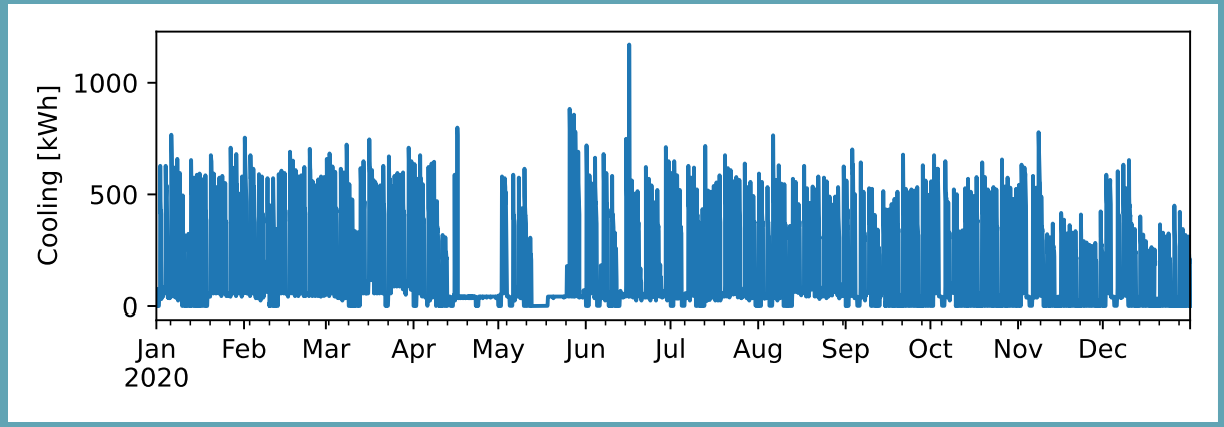
Time series data from a building in Singapore.
(Mosteiro-Romero et al., 2023)



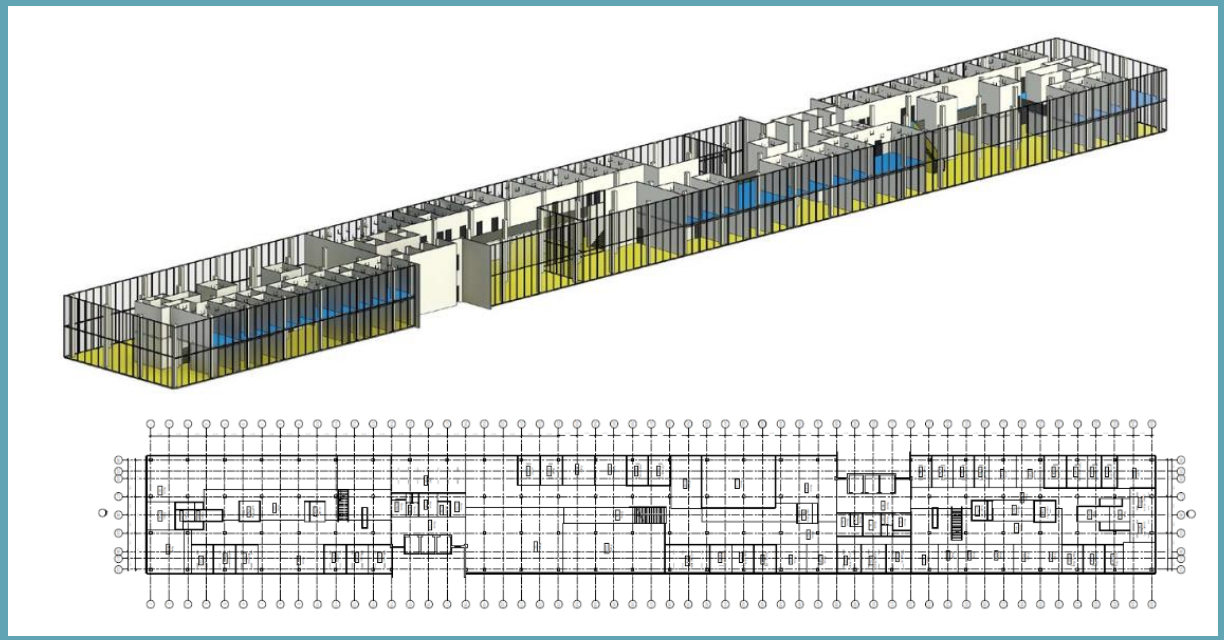
BIM model of the Atlas Building at TU Eindhoven.
(Brains4Buildings Deliverable 4.3)

Data Integration

- There is **little interaction** between these islands of data due to their **heterogeneity**
  - They rely on **different modelling approaches**, **languages** and **protocols**
  - e.g., there is **no straightforward way** to integrate a Honeywell **BMS system** with a **BIM model** created on Autodesk Revit
- **Lack of interoperability** hinders the research and development of smart building applications
- The ability to integrate systems from multiple vendors is a **major requirement** to understand the **energy usage**, **maintenance**, and overall **performance** of buildings



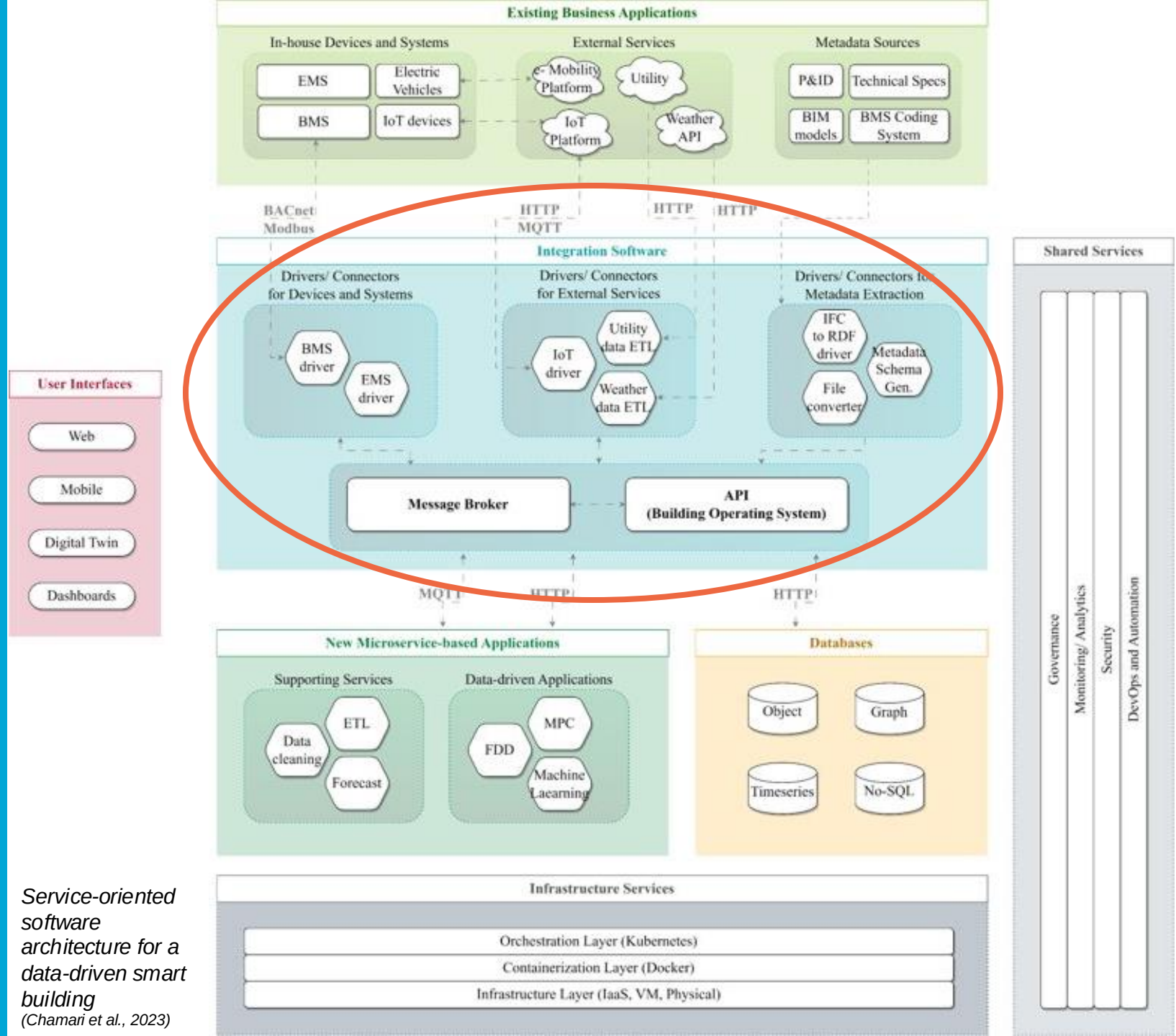
Time series data from a building in Singapore.
(Mosteiro-Romero et al., 2023)



BIM model of the Atlas Building at TU Eindhoven.
(Brains4Buildings Deliverable 4.3)

Reference Architecture

- Smart buildings need to rely on a well-defined **system architecture** and Application Programming Interfaces (APIs) that enable both the integration of diverse systems and datasets and the orchestration of various services
- Each individual building is unique, so **developing a system architecture for each is impossible**
- Chamari et al. (2023) present a generic reference architecture focusing on **data integration** and **system integration**
- The rest of this section focuses on the **data integration** part of this architecture



Service-oriented software architecture for a data-driven smart building
(Chamari et al., 2023)

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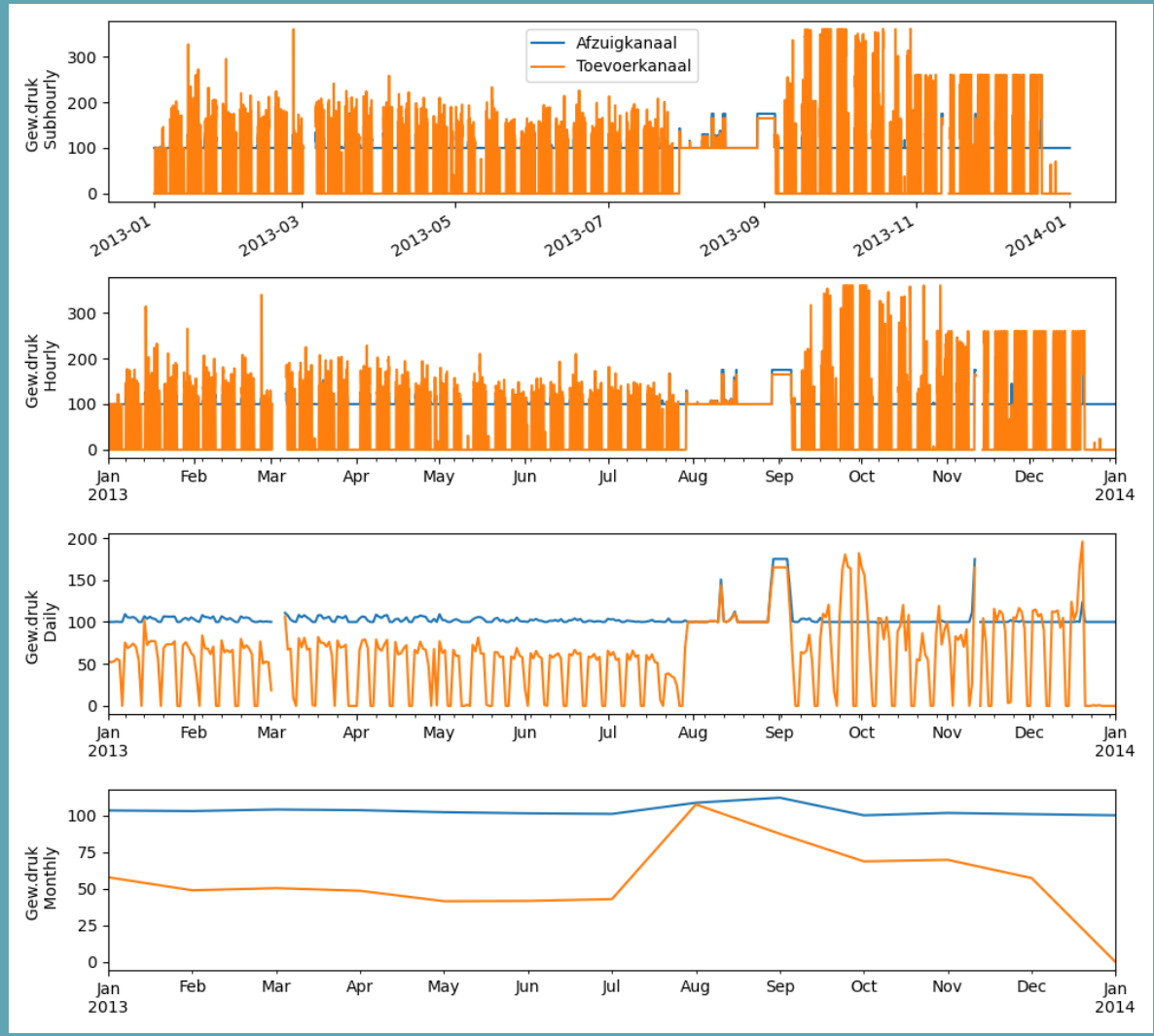
BMS Data Integration

- **Building Management Systems (BMS)** centralize, automate and make the management of building systems more efficient
- BMS data refers to **operational time series data** including operating temperatures, valve positions, etc.
- Main source of sensor data and **primary input for any data-driven application**
- **Integration software** is needed as **different vendors use different protocols** to extract and translate their data into desirable formats and communicate them to relevant services
- Example: communication of data from a BACnet device to a web service needs a gateway (driver) to:
  - translate BACnet data into a format suitable for web communication (like JSON)
  - communicate them via HTTP to a remote web service endpoint



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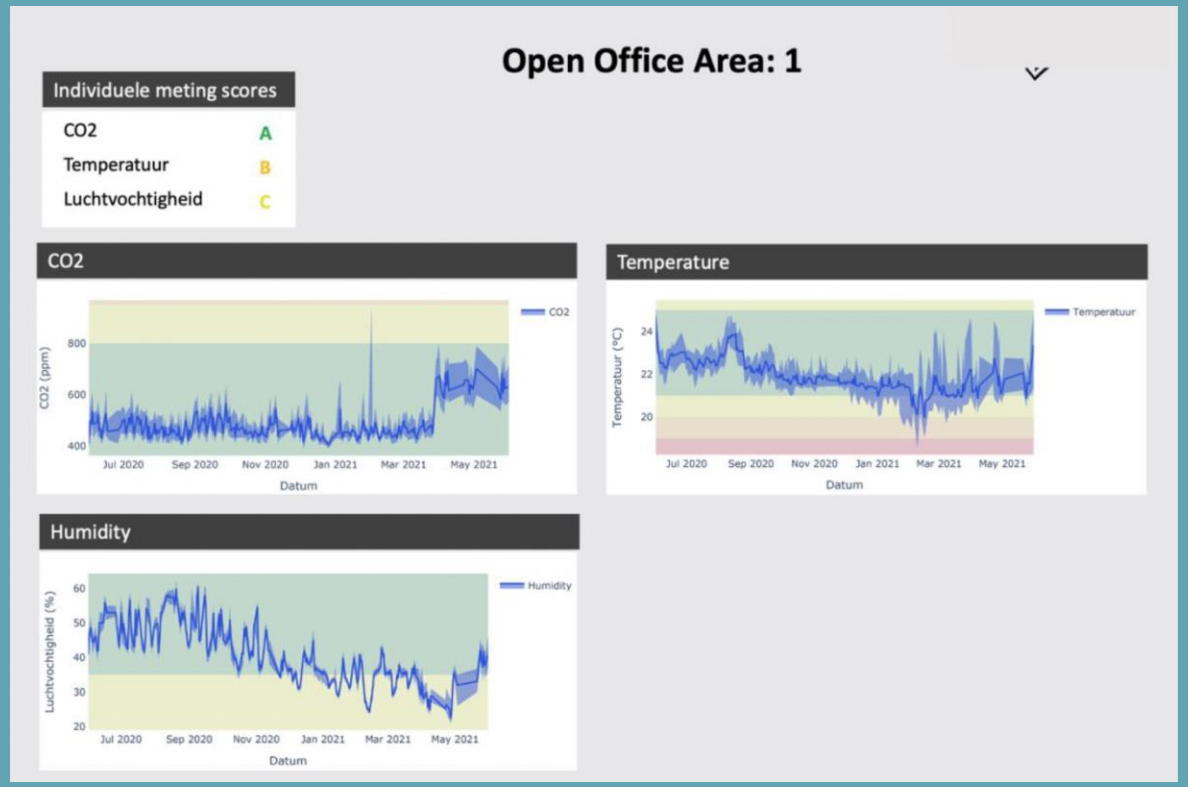
IoT Data Integration

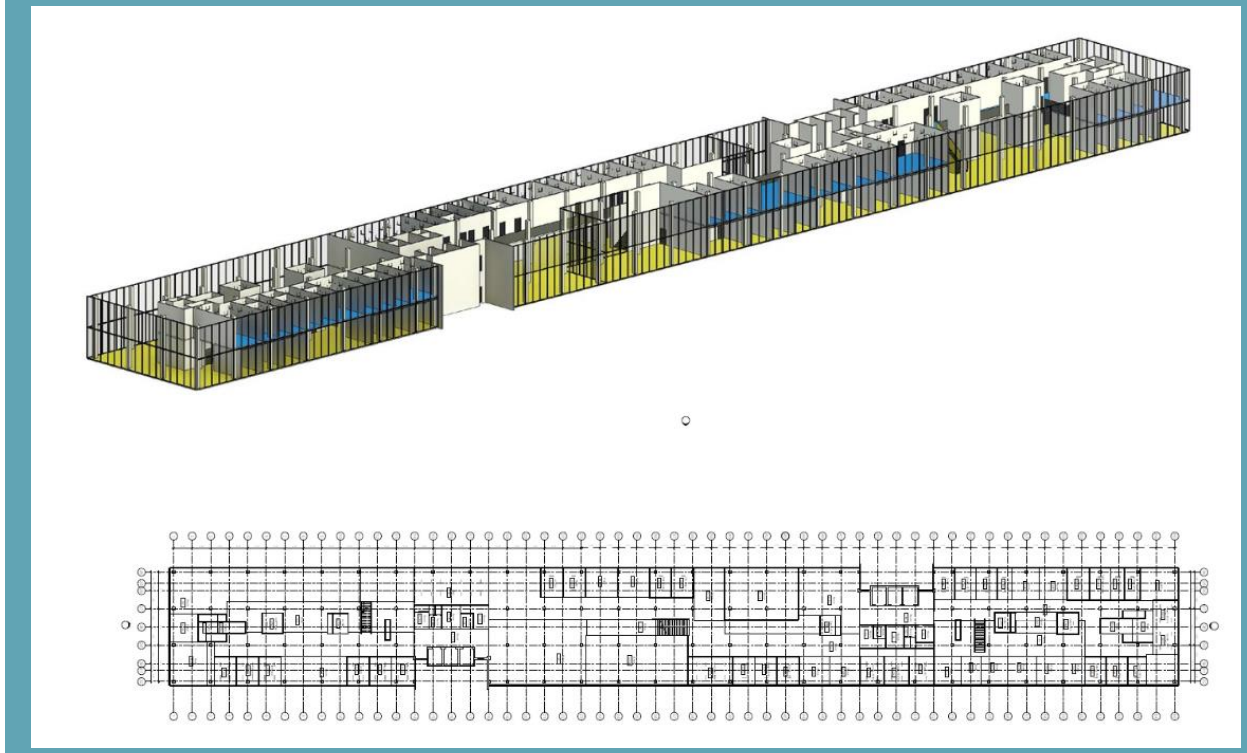
- In addition to BMS sensors, many buildings implement **IoT devices as a retrofit**
  - e.g., air quality sensors, smart sockets, etc.
- Provide access to **real-time sensor data**, e.g.:
  - ambient conditions (temperature, humidity, etc.)
  - energy usage
  - equipment-related parameters: vibration, faults, etc
- Accessed through a **message broker such as Mosquitto** using the **MQTT protocol** to transport messages between devices
- IoT data can also be recorded in a **time series database** for later usage



Example of sensor data in an open office
(Brains4Buildings Deliverable 3.02)

BIM Data Integration

- **Building Information Models (BIM)** are one of the main sources of contextual building data – **metadata**
- Consist of design-stage **architecture, structural and Mechanical Electrical and Plumbing (MEP)** models
- **Industry Foundation Classes (IFC)** is a standardised data model to describe architectural, building and construction data:
  - open international format for **BIM data**
  - **platform-neutral**
  - not all aspects of the built environment can be modelled, e.g. **sensor data**
- The **Global Unique Identifiers (GUID)** of elements in the BIM model can be used to link the objects with their operational data to create **Digital Twins**



BIM model of the Atlas Building at TU Eindhoven.
(Brains4Buildings Deliverable 4.3)

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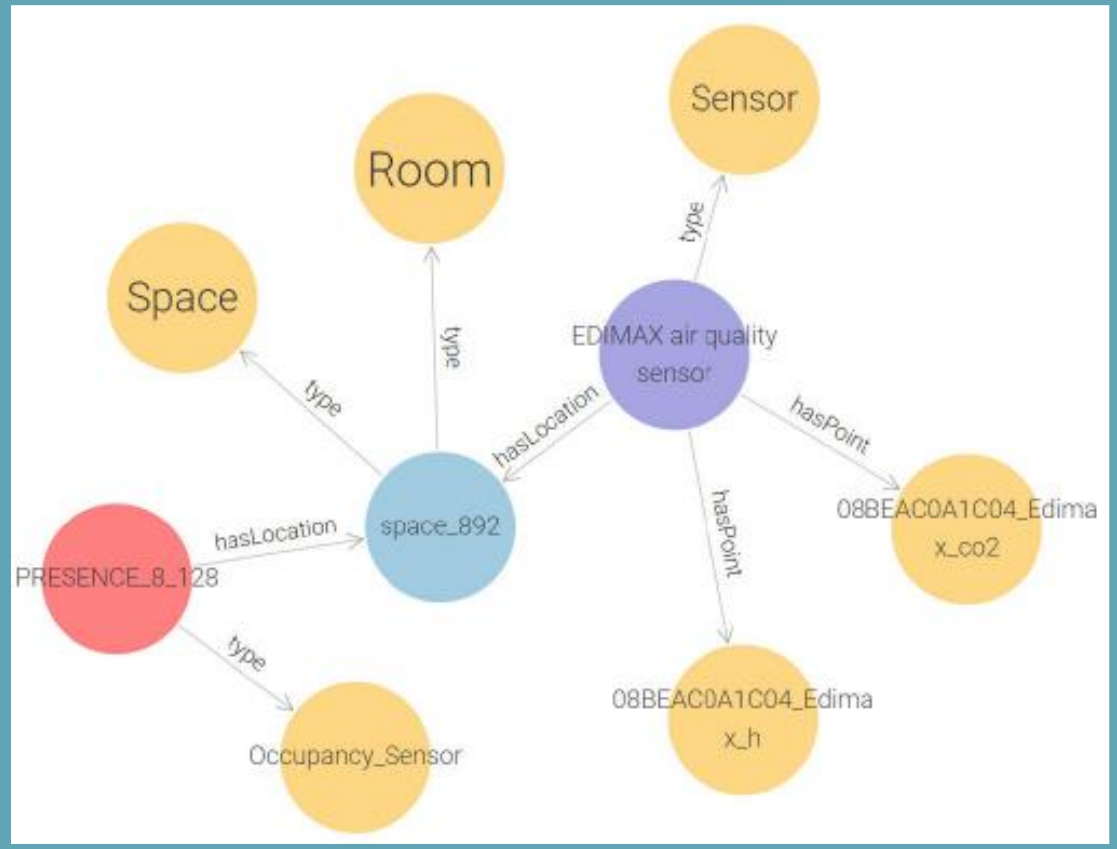
Metadata Integration

- Smart building **ontologies** are used to create an extensible **semantic graph** (also called a **metadata schema**) containing the contextual **information about the building and its data**
- The graph carries the **physical, logical and virtual assets** in buildings and the **relationships between them**
- It contains references to external systems such as **time series databases and IFC models**, enabling the automatic **querying and retrieval** of time series data associated with the instances in the metadata schema



Visual representation of a semantic graph showings the relationships between spaces and sensors for a Digital Twin and IoT integration
(Chamari et al., 2022)

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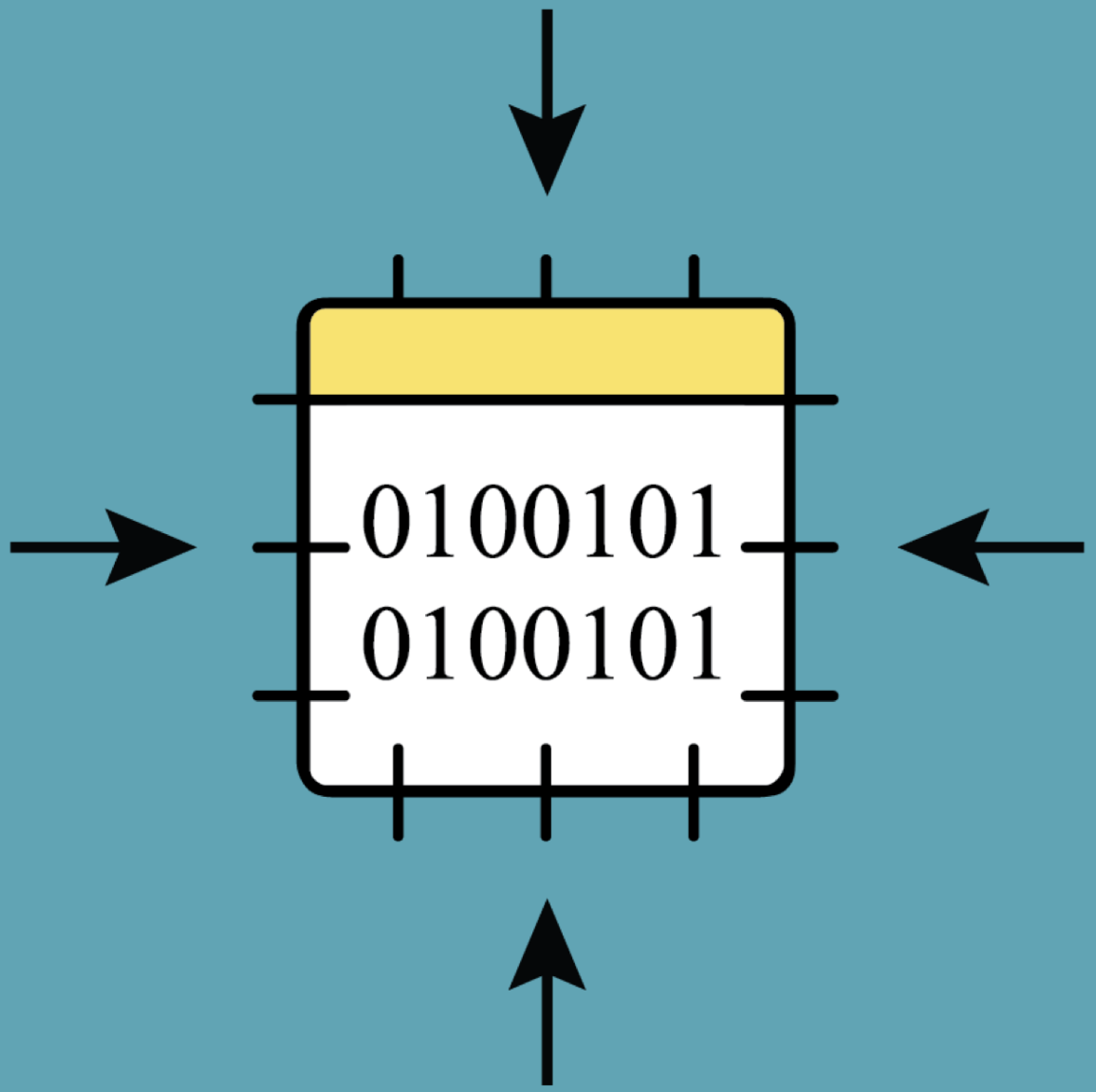
Data Integration

- Various techniques have been developed to **integrate these data** silos:
  - semantic tagging
  - data schemas
  - ontologies
- A large body of recent research explores the creation and use of domain **ontologies to link and integrate operational and contextual data with applications**



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Semantic Tagging

- Project Haystack is an open-source initiative to develop **tagging conventions and taxonomies** for building equipment and operational data
- **Standardized tags** for describing data, giving the data **more meaning** by adding metadata to it and making it **more discoverable** for other applications
- Tags can be applied at the **device level, controller level or server level**
- Can be encoded in file formats **Zinc, JSON, Trio, CSV or RDF**

```
id:@a-0001
dis:Alpha Airside AHU-2
ahu
chilledWaterCooling
chilledWaterRef:@a-07b8
elec
equip
hotWaterHeating
hotWaterRef:@a-07da
hvac
singleDuct
siteRef:@a-0000
vavZone
---
```

Haystack example of tagging of an Air Handling Unit in Trio format
(Project Haystack – Examples)

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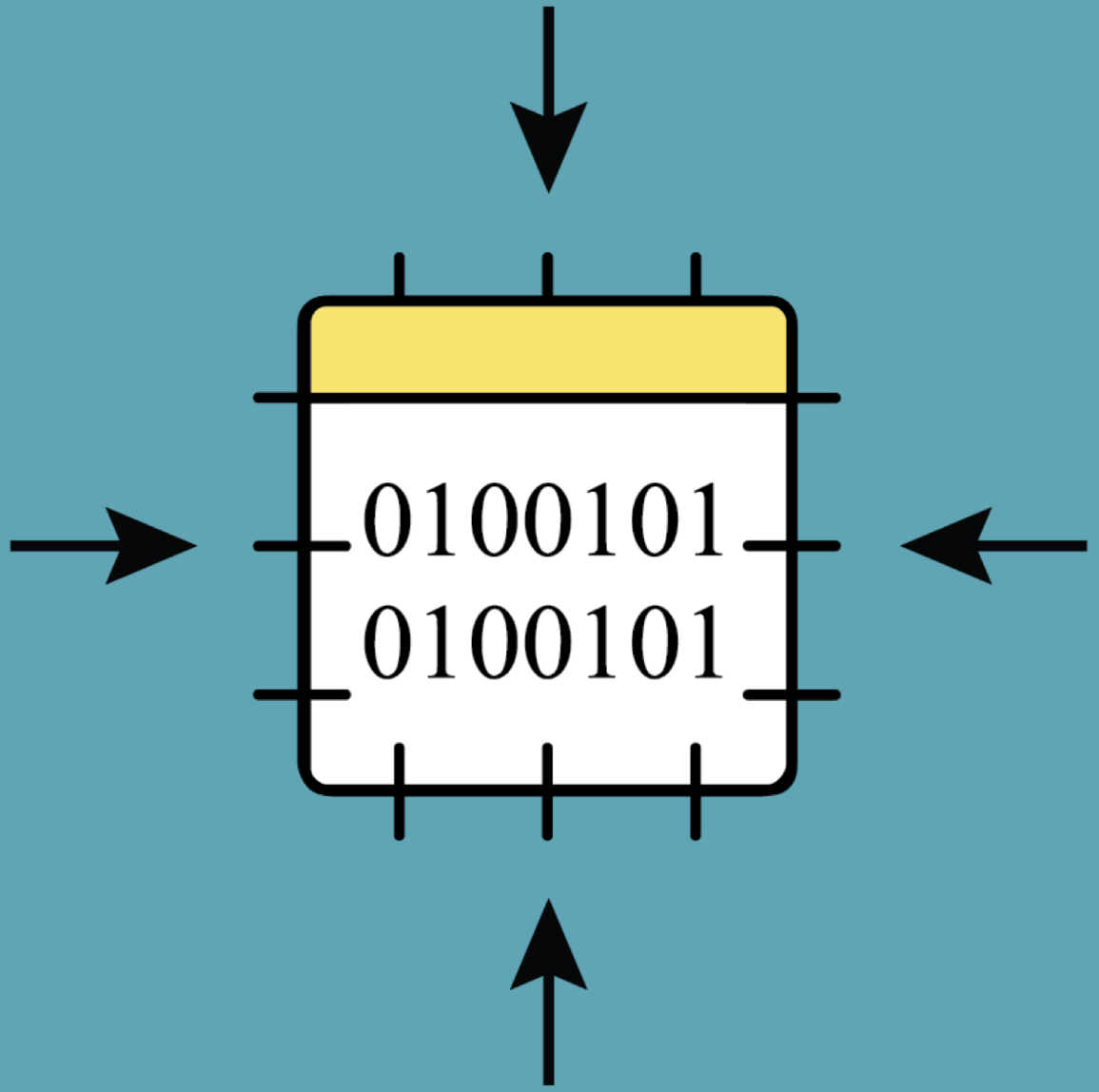
Ontologies

- An ontology is a **structured and formalized model** representing the **knowledge within a given domain** (Gruber, 1993)
- **Concepts** are represented as **nodes** in a graph data structure, while the **edges** represent the **relationships between them** (Chamari et al., 2023)
- Used for **integrating heterogeneous databases**
- In contrast to data models, they consist of **generic knowledge** that can be reused by **different applications**
- Most **commonly recognized** ontologies:
  - Haystack
  - Brick
  - REC



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Haystack

- Open-source initiative to develop **tagging conventions and taxonomies** for building equipment and operational data
- Standardised tags for describing data **giving the data more meaning by adding metadata**
- Standardised modelling of:
  - **site**: single building with its own street address
  - **space**: location/zone within a site
  - **equip**: piece of equipment in space
  - **point**: sensor, actuator or setpoint for an equip
  - **weatherStation**: observations
  - **device**: computers, controllers, networking gear

```
_:a-0001 a phIoT:ahu ;
    ph:hasTag phIoT:ahu,
        phIoT:chilledWaterCooling,
        phScience:elec,
        phIoT:equip,
        phIoT:hotWaterHeating,
        phIoT:hvac,
        phIoT:singleDuct,
        phIoT:vavZone ;
    rdfs:label "Alpha Airside AHU-2" ;
    phIoT:chilledWaterRef _:a-07b8 ;
    ph:dis "Alpha Airside AHU-2" ;
    phIoT:hotWaterRef _:a-07da ;
    phIoT:siteRef _:a-0000 .
```

Haystack example of representing an Air Handling Unit using Haystack Ontology in Turtle format
(Project Haystack – Examples)

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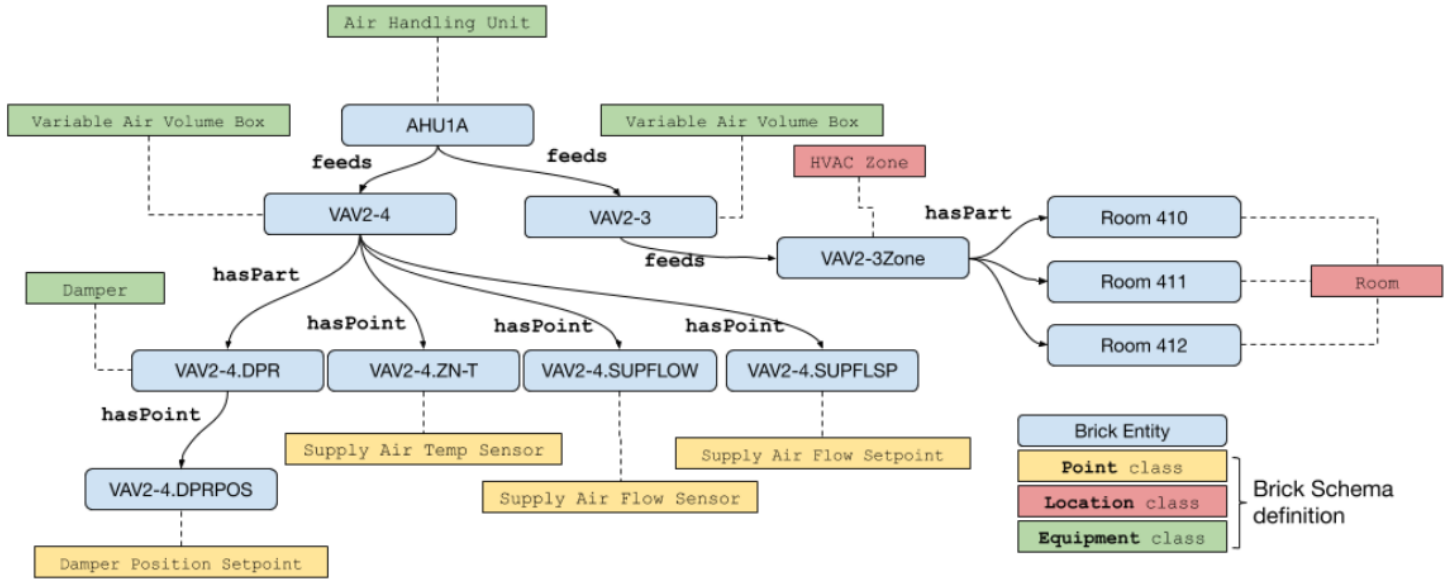
Brick

- The Brick ontology is designed with a **focus on energy applications** based on BMS
- It is capable of representing **physical, logical and virtual assets** in buildings and the **relationships between them**




```
soda_hall:ahu_A1 a brick:AHU ;
    brick:feeds soda_hall:vav_C180,
        soda_hall:vav_C300,
        soda_hall:vav_C300B,
        soda_hall:vav_R784 ;
    brick:hasPoint soda_hall:ahu_occpy_SODA1____OCCPY,
        soda_hall:ahu_start_stop_SODA1_____S_S,
        soda_hall:curtl_SODA1____CURTL,
        soda_hall:override_event_SODA1____EVENT,
        soda_hall:rat_SODA1_LOW_RAT2,
        soda_hall:rat_SODA1_LOW_RAT3,
        soda_hall:rat_SODA1_LOW_RAT4,
        soda_hall:rat_SODA1__LOW_RAT,
        soda_hall:smoke_alarm_SODA1_SMK_ALM2,
        soda_hall:smoke_alarm_SODA1_SMK_ALM3,
        soda_hall:smoke_alarm_SODA1_SMK_ALM4 ;
    brick:isLocationOf soda_hall:supply_fan_S11 .
```

Modelling with Brick (top) and Brick representation of an AHU (left)
(Brick, 2022)

Haystack vs. Brick

- Both ontologies are **machine-readable**
- **Flexible semantics** allow **Haystack** to represent a variety of buildings but compromises portability
- **Brick** represents concepts in a **prescribed manner**, allowing applications to be **portable**
- **Haystack** uses **Tags** to represent semantic concept, any inconsistency leads to difficulty in relating the tags to real-world meaning
- **Brick** supports **interoperability** with other ontologies, which allows **more holistic** smart building applications

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Haystack

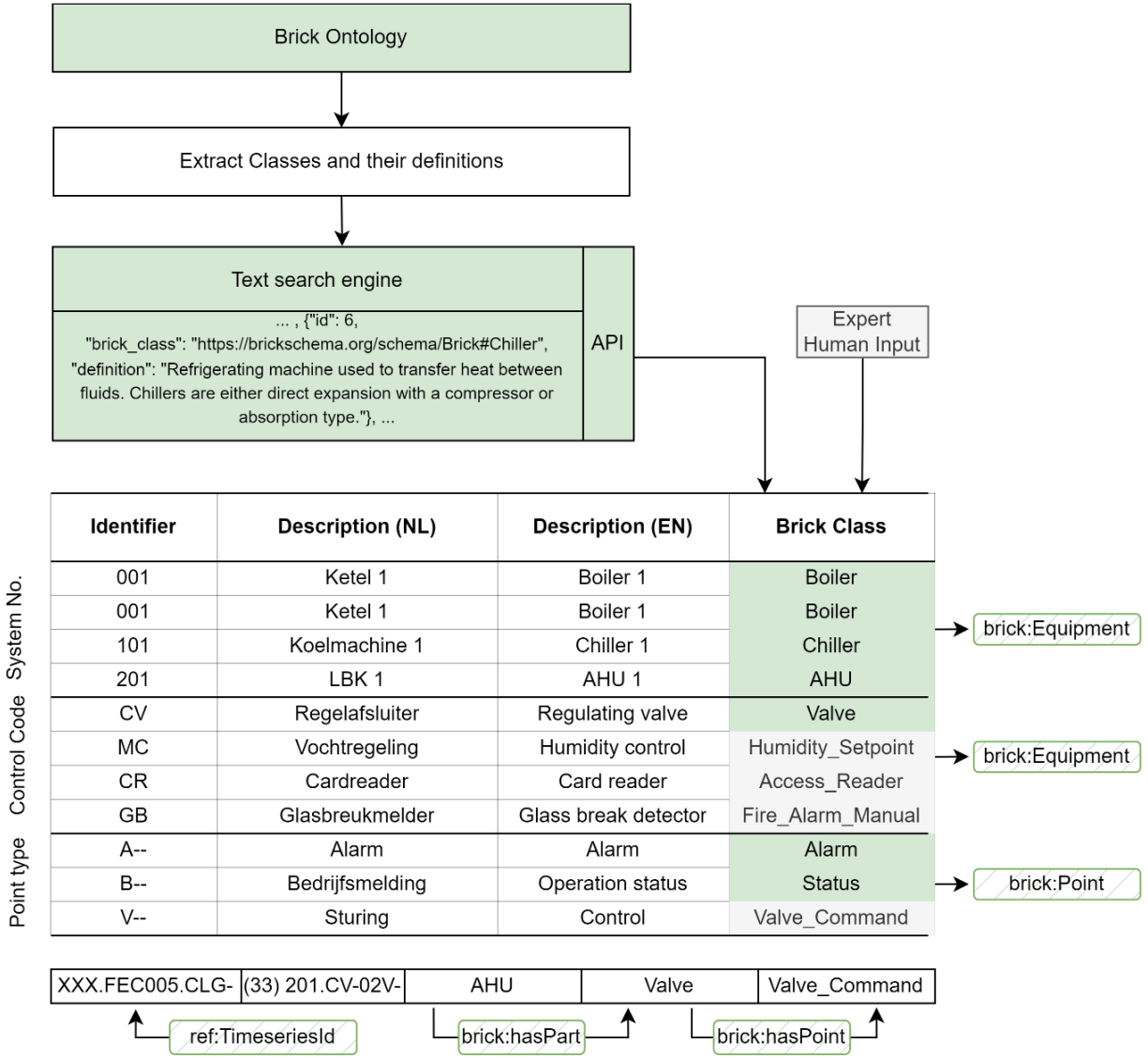
```
_:a-0001 a phIoT:ahu ;
    ph:hasTag phIoT:ahu,
        phIoT:chilledWaterCooling,
        phScience:elec,
        phIoT:equip,
        phIoT:hotWaterHeating,
        phIoT:hvac,
        phIoT:singleDuct,
        phIoT:vavZone ;
    rdfs:label "Alpha Airside AHU-2" ;
    phIoT:chilledWaterRef _:a-07b8 ;
    ph:dis "Alpha Airside AHU-2" ;
    phIoT:hotWaterRef _:a-07da ;
    phIoT:siteRef _:a-0000 .
```

Brick

```
soda_hall:ahu_A1 a brick:AHU ;
    brick:feeds soda_hall:vav_C180,
        soda_hall:vav_C300,
        soda_hall:vav_C300B,
        soda_hall:vav_R784 ;
    brick:hasPoint soda_hall:ahu_occpy_SODA1____OCCPY,
        soda_hall:ahu_start_stop_SODA1______S_S,
        soda_hall:curtl_SODA1____CURTL,
        soda_hall:override_event_SODA1____EVENT,
        soda_hall:rat_SODA1_LOW_RAT2,
        soda_hall:rat_SODA1_LOW_RAT3,
        soda_hall:rat_SODA1_LOW_RAT4,
        soda_hall:rat_SODA1__LOW_RAT,
        soda_hall:smoke_alarm_SODA1_SMK_ALM2,
        soda_hall:smoke_alarm_SODA1_SMK_ALM3,
        soda_hall:smoke_alarm_SODA1_SMK_ALM4 ;
    brick:isLocationOf soda_hall:supply_fan_S11 .
```

Mapping

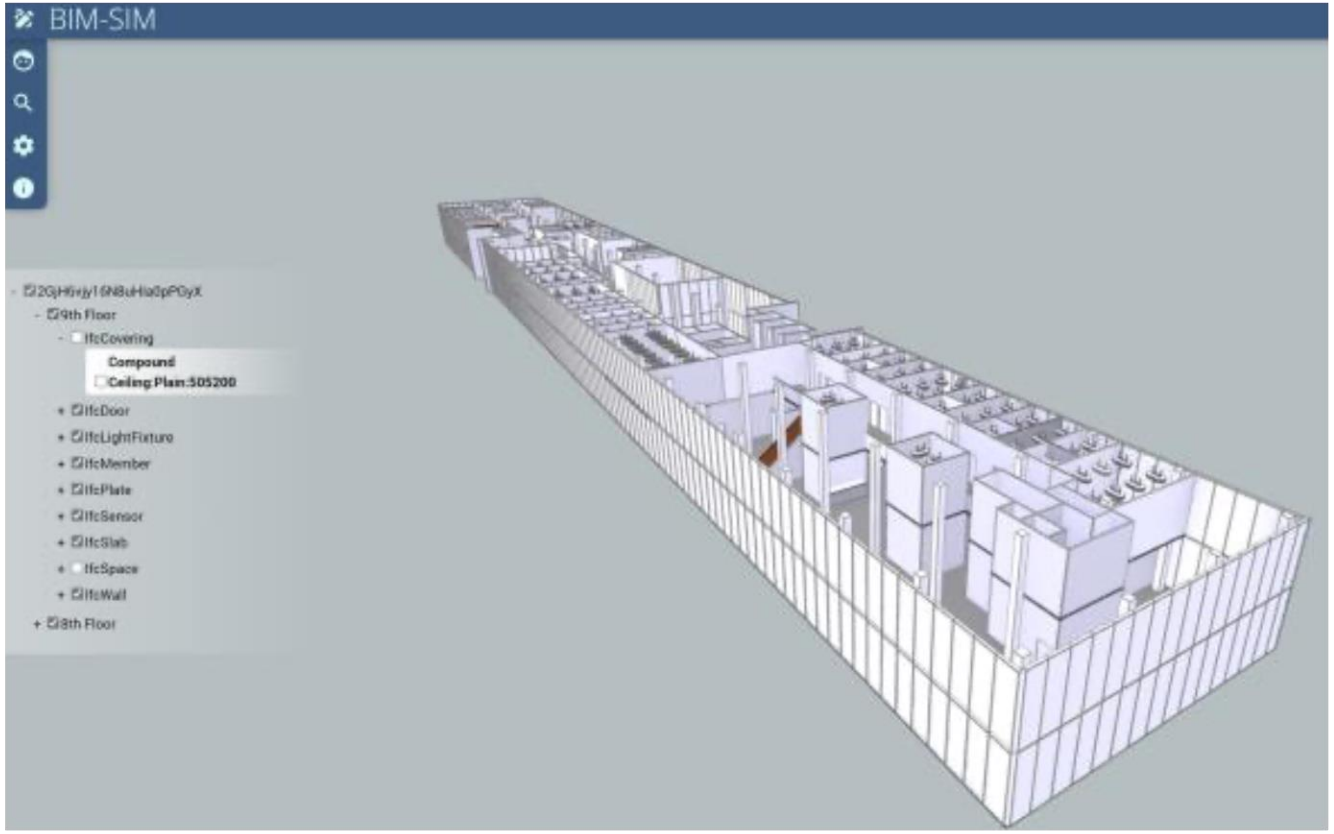
- Procedure for **mapping to a Brick ontology**



Procedure for mapping to a Brick ontology
(Chamari, L. et al. (2020), CEUR Workshop Proceedings CEUR-WS)

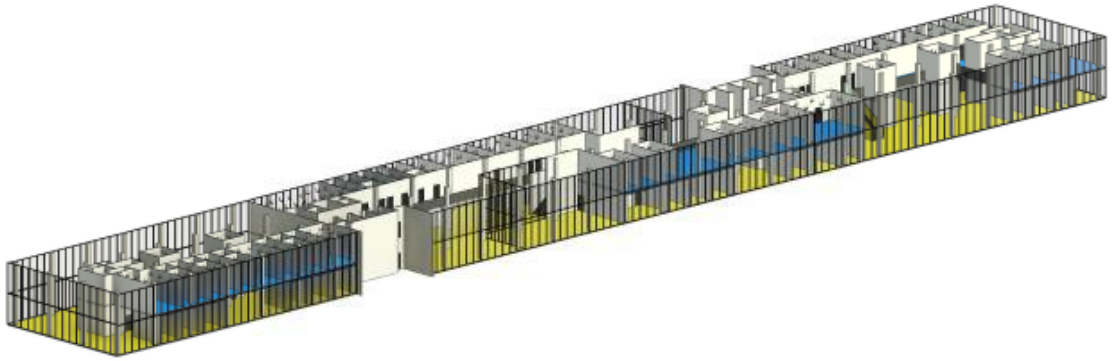
Example 1: Web-based integration of BMS, BIM and IoT

- Case study: 12-story building at TU Eindhoven
- More information: Chamari et al. (2022) https://doi.org/10.34641/clima.2022.228
- RDF building graph and documentation: https://github.com/ISBE-TUe/atlas-building-graph



Example 1: Web-based integration of BMS, BIM and IoT

- Case study: 12-story building at TU Eindhoven
- Available information:
  - BIM model for 8th and 9th floors created on Autodesk Revit
    - Space-related information: room name, room number, floor
    - Equipment-related information: Sensors and lighting fixtures
  - BMS timeseries data: hourly occupancy, temperature, and CO_2 data from a Honeywell BMS in Excel format
  - IoT timeseries data:
    - Lighting levels and color temperature data from Envision Manager API
    - An IoT sensor network is in development to collect real-time temperature humidity and illumination data



Revit model for the case study building

Timestamp	11NR008TE-001TRL	11NR008TE-003TRL
28-02-2021 00:02:00	22.1	21.1
28-02-2021 01:02:00	22.0	20.9
28-02-2021 02:02:00	21.9	20.8
28-02-2021 03:02:00	21.7	21.2

BMS data: timestamps, sensor IDs and hourly values

Item name	Description
11NR008TE-001TRL	Room temperature 8_128
11NR008QT-040CO2	*CO2 measurement 8_323
11NR008LT-001PIRTM	Presence 8_128

Room number

Floor number

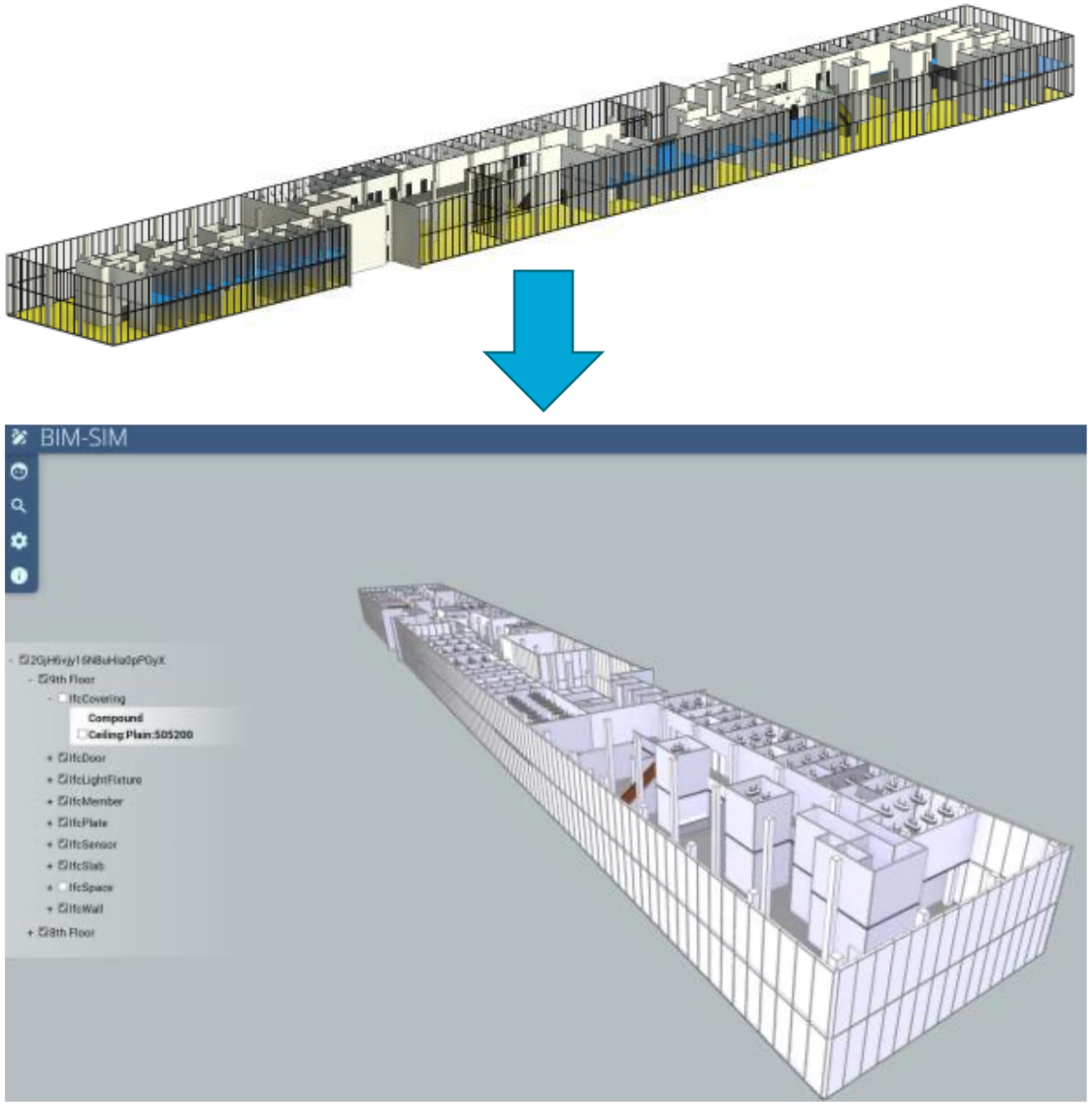
BMS data mapping table: Sensor IDs and descriptions

Chamari et al. (2022)

Example 1: Web-based integration of BMS, BIM and IoT

Procedure

1. Use an **IFC file** from the BIM model as the main source of building information
2. Convert the IFC file into a **web browser-compatible format**:
   - Visualizing on the web provides a **vendor-neutral platform** for collaboration and exchange of data
   - Here, **xeokit** (an open-source JavaScript 3D graphics Software Development Kit) was used



Chamari et al. (2022)

Example 1: Web-based integration of BMS, BIM and IoT

Procedure

1. Use an **IFC file** as the main source of building information
2. Convert the IFC file into a **web browser-compatible format**
3. Generate the **semantic graph** of the building, including information about spaces and sensors/equipment
   - IFCtoLBD converter used to generate a **first RDF graph** that semantically describes the **building context**
   - RDF (Resource Description Framework) can integrate datasets including **building geometry**, the relationship between **spaces, sensors and actuators**, and **time series data** into a single semantic graph
   - Rooms identified by their **Globally Unique Identifier (GUID)** in the IFC file

GUID

```
1. #1266=
   IFCSPACE('0KLkXPBfvES9D1y7EjijkE',#42,'9',$
   ,$,#1245,#1263,'test 1
   area',.ELEMENT.,.SPACE.,$);
2. #1269=
   IFCSPACETYPE('0H12gSHLX9KAhW1PyBN1jS',#42,'
   test 1 area
   9:543779',$,$,$,$,'543779',$,.NOTDEFINED.,$
   );
3. #1270=
   IFCPROPERTYSINGLEVALUE('Name',$,IFCLABEL('t
   est 1 area'),$);
4. #1271=
   IFCPROPERTYSET('2b$cWxcoTB9AhqrEJK8Q2s',#42
   ,'Pset_AirSideSystemInformation',$,(#1270))
   ;
```

Part of the IFC file containing information about room "test 1 area"

```
1. inst:space_1266 a bot:Space ;
2. bot:containsElement
   inst:lightFixture_241729,
3.       inst:lightFixture_241879,
4.       inst:sensor_239793 ;
5.    props:hasCompressedGuid
   "0KLkXPBfvES9D1y7EjijkE"^^xsd:string ;
6.    bot:hasGuid "1456e859-2e9e-4e70-9341-
   f073adb2db8e"^^xsd:string ;
```

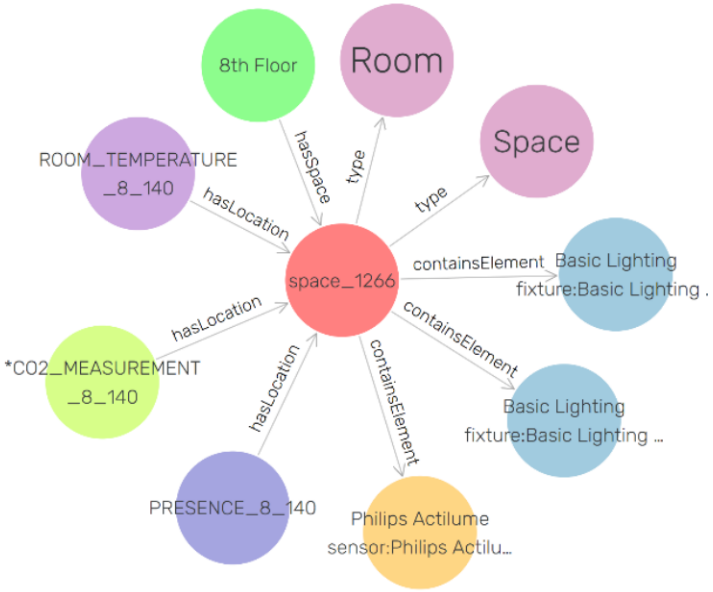
Part of the graph generated by the IFCtoLBD converter

Chamari et al. (2022)

Example 1: Web-based integration of BMS, BIM and IoT

Procedure

1. Use an **IFC file** as the main source of building information
2. Convert the IFC file into a **web browser-compatible format**
3. Generate the **semantic graph** of the building, including information about spaces and sensors/equipment
4. Use a BMS sensor mapping table to **populate the graph about sensors**
   - A **second RDF graph** that **describes the BMS sensors** is created using the tool Brick-builder using:
     - A **CSV file** is generated by joining the spaces and GUID relationships from the previous graph (from IFCtoLBD converter)
     - A **text file** defining the relationships



Graph representation of space_1266

Chamari et al. (2022)

Example 1: Web-based integration of BMS, BIM and IoT

Procedure

1. Use an **IFC file** as the main source of building information
2. Convert the IFC file into a **web browser-compatible format**
3. Generate the **semantic graph** of the building, including information about spaces and sensors/equipment
4. Use a BMS sensor mapping table to **populate the graph about sensors**
5. Choose appropriate databases to **store 3D models, time series data, and graph data**
   - **MongoDB** Timeseries Collection is used **to query BMS data** due to improved query efficiency and reduced disk usage
   - Data were formatted to **JavaScript Object Notation (JSON)** with the timestamp, sensor ID, and the value

1. {"timestamp":{"$date":"2021-03-31T22:02:00.000Z"},"sensor_id":"11NR008QT-301CO2","_id":{"$oid":"61bfcef2c72be614e6cda971"},"value":425}
2. {"timestamp":{"$date":"2021-03-31T22:02:00.000Z"},"sensor_id":"11NR008LT-302PIRTM","_id":{"$oid":"61bfceeac72be614e6caf861"},"value":2}
3. {"timestamp":{"$date":"2021-03-31T22:02:00.000Z"},"sensor_id":"11NR008TE-302TRL","_id":{"$oid":"61bfcec8c72be614e6c0d471"},"value":20.1}

Sensor data in MongoDB time series collection

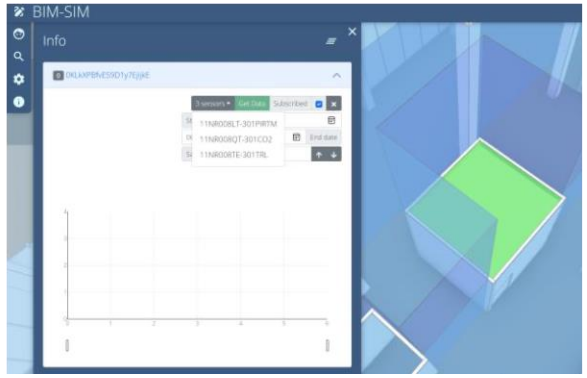
Chamari et al. (2022)

Example 1: Web-based integration of BMS, BIM and IoT

Procedure

1. Use an **IFC file** as the main source of building information
2. Convert the IFC file into a **web browser-compatible format**
3. Generate the **semantic graph** of the building, including information about spaces and sensors/equipment
4. Use a BMS sensor mapping table to **populate the graph about sensors**
5. Choose appropriate databases to **store 3D models, time series data, and graph data**
6. Provide a **web application** for the user to interact with the BIM model and time series data
7. **Visualize real-time and historical data** in the front-end app
   - **When a space is selected**, its GUID is used to execute a SPARQL **query all sensors within that space** per the RDF graph, which are then shown in the "Info window"
   - **Selecting a sensor** calls the API, which sends a query to the MongoDB database using the sensor ID, and the **data is displayed in a chart** created using plotly.js

XKT file loaded in the web app



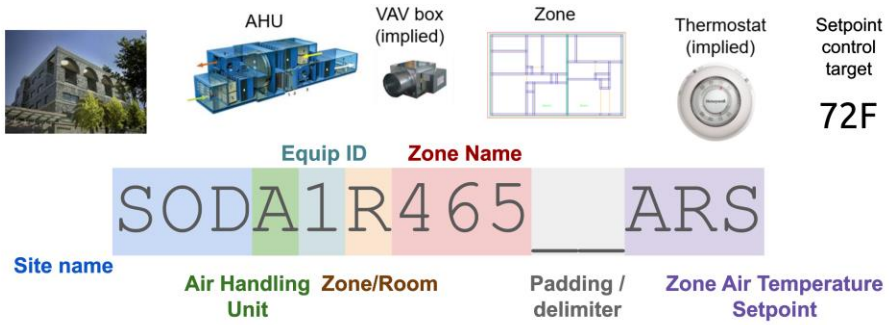
Info window populated with sensors from the SPARQL query

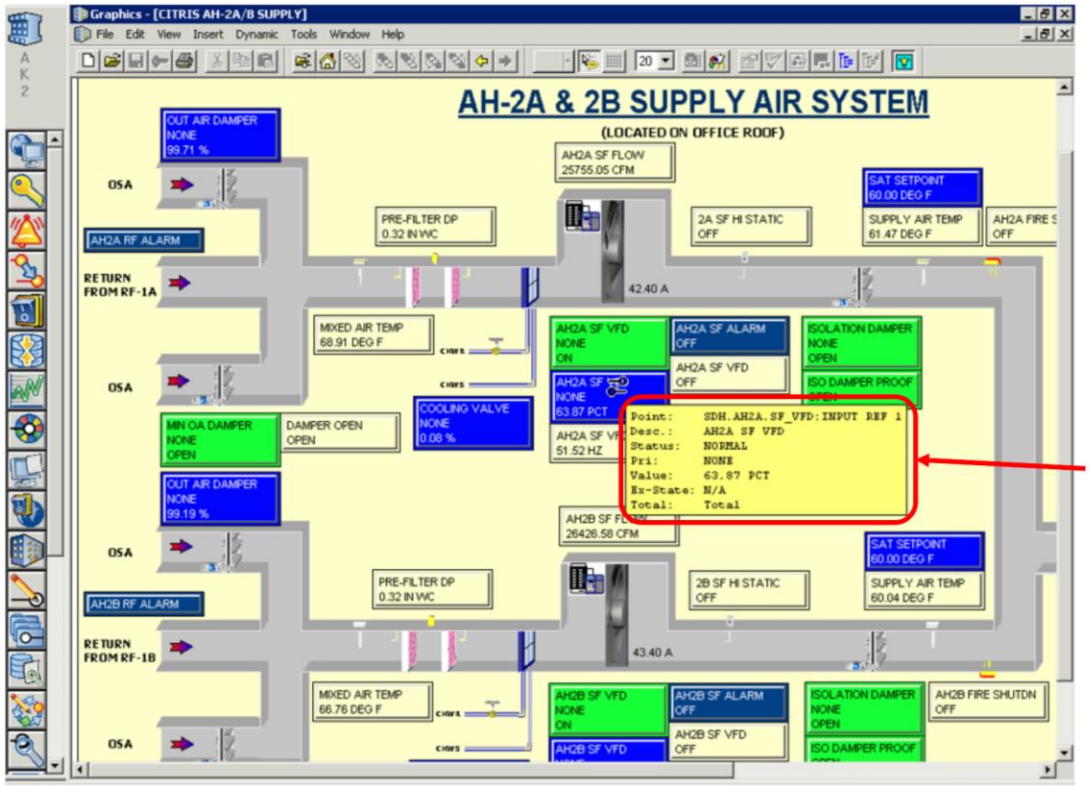
CO_2 sensor data visualization

Chamari et al. (2022)

Example 2: Hands-on Brick tutorial

- Lecture by Dr. Gabe Fierro: Slides | GitHub repository with Jupyter notebooks
- Looking at a metadata model of a real building
  - Query timeseries data: temperature sensors and power usage
  - Conduct data analysis





Point: a source of data from a cyberphysical system

10s or 100s of thousands of points in a typical system

04

Regulations on Data Privacy

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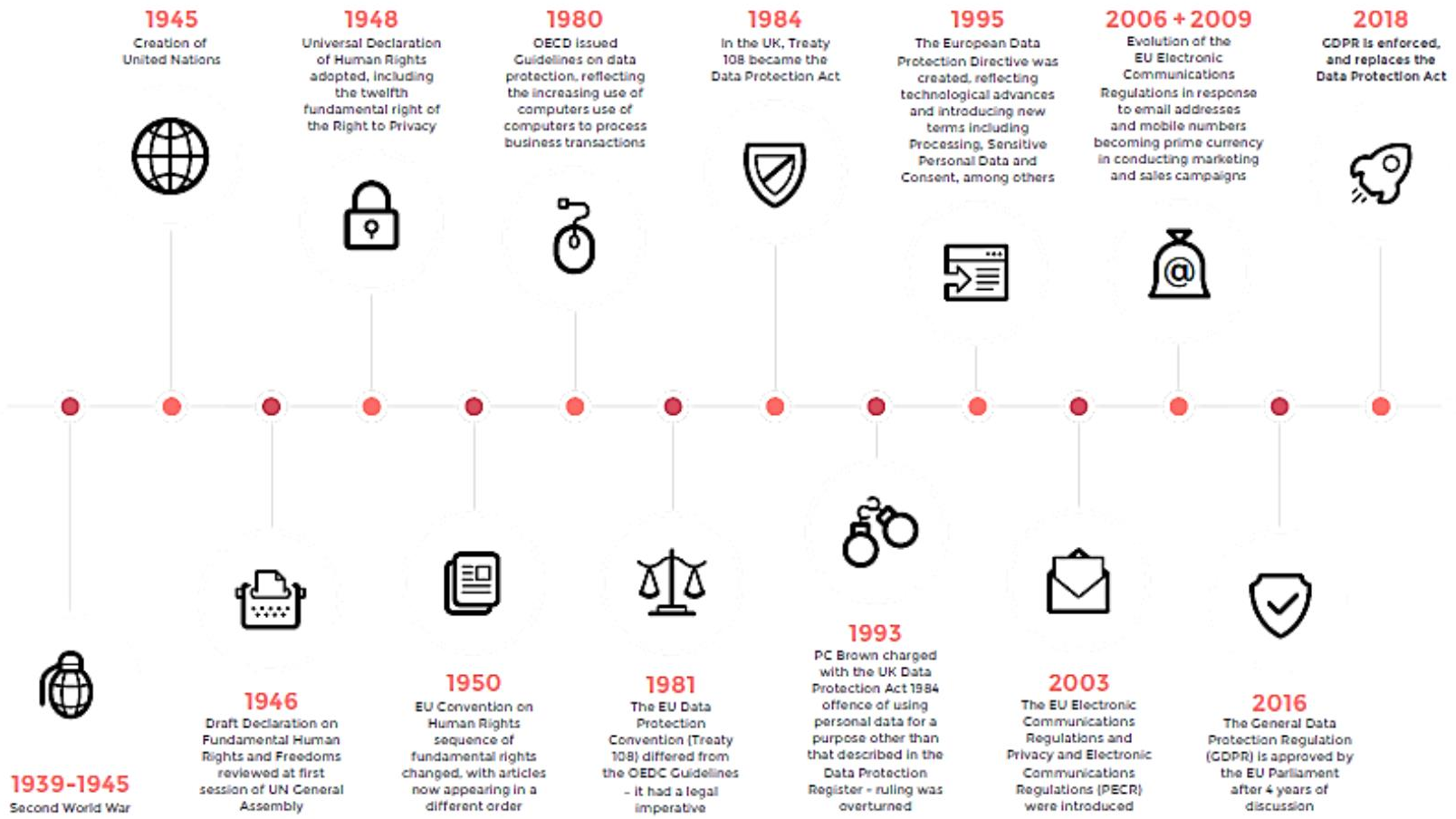
Introduction

- **Information and knowledge sharing** can be beneficial for society
- However, information can easily be **misused** or unknowingly used in indirect but **harmful** ways
- Therefore, **clear concepts of ethics, privacy and security are needed** as a framework to be applied in the context of information sharing
- The next sections give an overview of the existing regulations and **norms** for ensuring privacy, ethics and security, and their **implications** for smart building projects

(Brains4Buildings Deliverable 4.1)

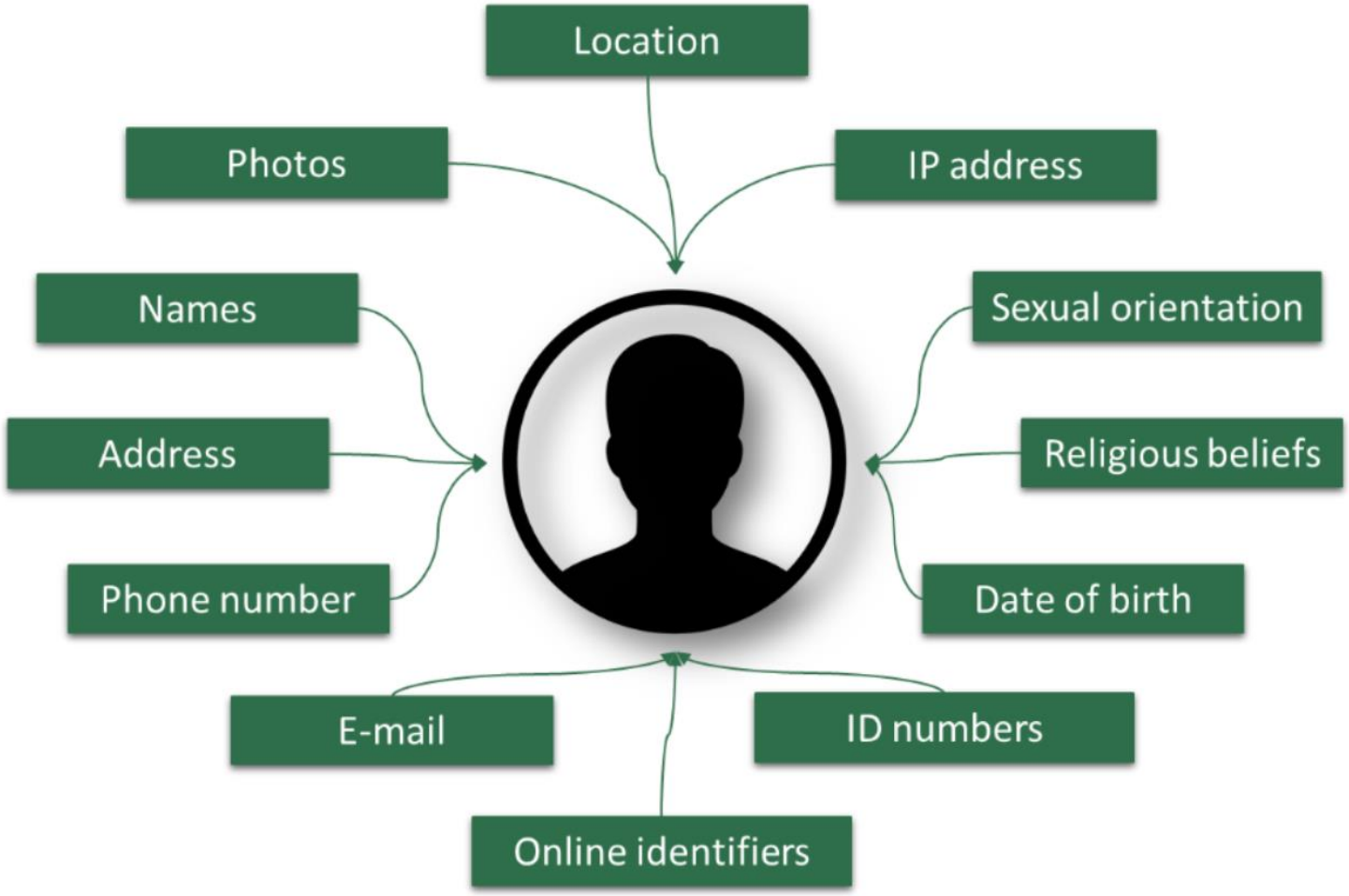
Historical overview



A historical overview of the development of data protection legislation
(Source: Sytorus)

General Data Protection Regulation (GDPR)

- In force in the European Union (EU) and the European Economic Area (EEA) since 25 May 2018
- Gives individuals the power to control their **personal data as a basic human right**
- Defines citizens' **personal data**
- Organizations who fail to comply with the GDPR can face **serious penalties**



Types of personal information that the GDPR protects
(Brains4Buildings Deliverable 4.1)

General Data Protection Regulation (GDPR)

- Data protection principles:
  1. **Lawfulness, fairness, and transparency**
  2. **Purpose limitation**: data to be collected for explicit and legitimate purposes only
  3. **Data minimization**: only relevant and necessary data should be collected
  4. **Accuracy**: steps to be taken to update or remove data that is inaccurate/incomplete
  5. **Storage limitation**: data should only be collected for as long as it is necessary
  6. **Integrity and confidentiality**: data to be kept safe and protected against unauthorized or unlawful processing
- The ability of the data controller to demonstrate compliance of these principles is called **Accountability**

(Brains4Buildings Deliverable 4.1)

Why is the GDPR important?

- The GDPR is about the right of a person to control their own data
- Within smart building projects there is a possibility to collect personal data for the purpose of gaining more insights on:
  1. **Occupancy:** usually **anonymous** information is collected (e.g., the number of people occupying a room at any time), but that information can be cross-referenced with owner or personal access pass data to become traceable to individuals
  2. Occupant **behaviours and comfort requirements:** personal preferences could provide information that **could be used to optimize energy use**

(Brains4Buildings Deliverable 4.1)

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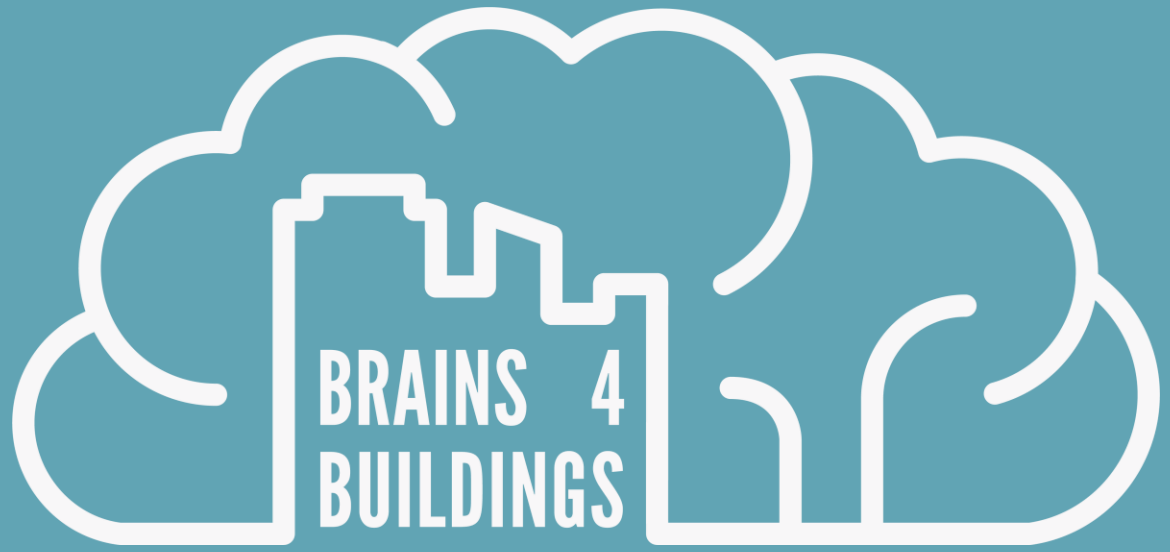
Data Protection Impact Assessments (DPIA)

- Mandated by GPDR **under certain circumstances**
- Part of the **“protection by design”** principle
- When implementing **new technologies** or **processing operations**
- Compulsory for **smart city data applications**
- For **Smart Grid and Smart Metering** systems, the European Commission has published a **standard template** for DPIA

(Brains4Buildings Deliverable 4.1)

How do these concepts affect the operation of smart buildings?

- Energy grids
- Smart meters
- Occupant sensing
- Building Management Systems (BMS)



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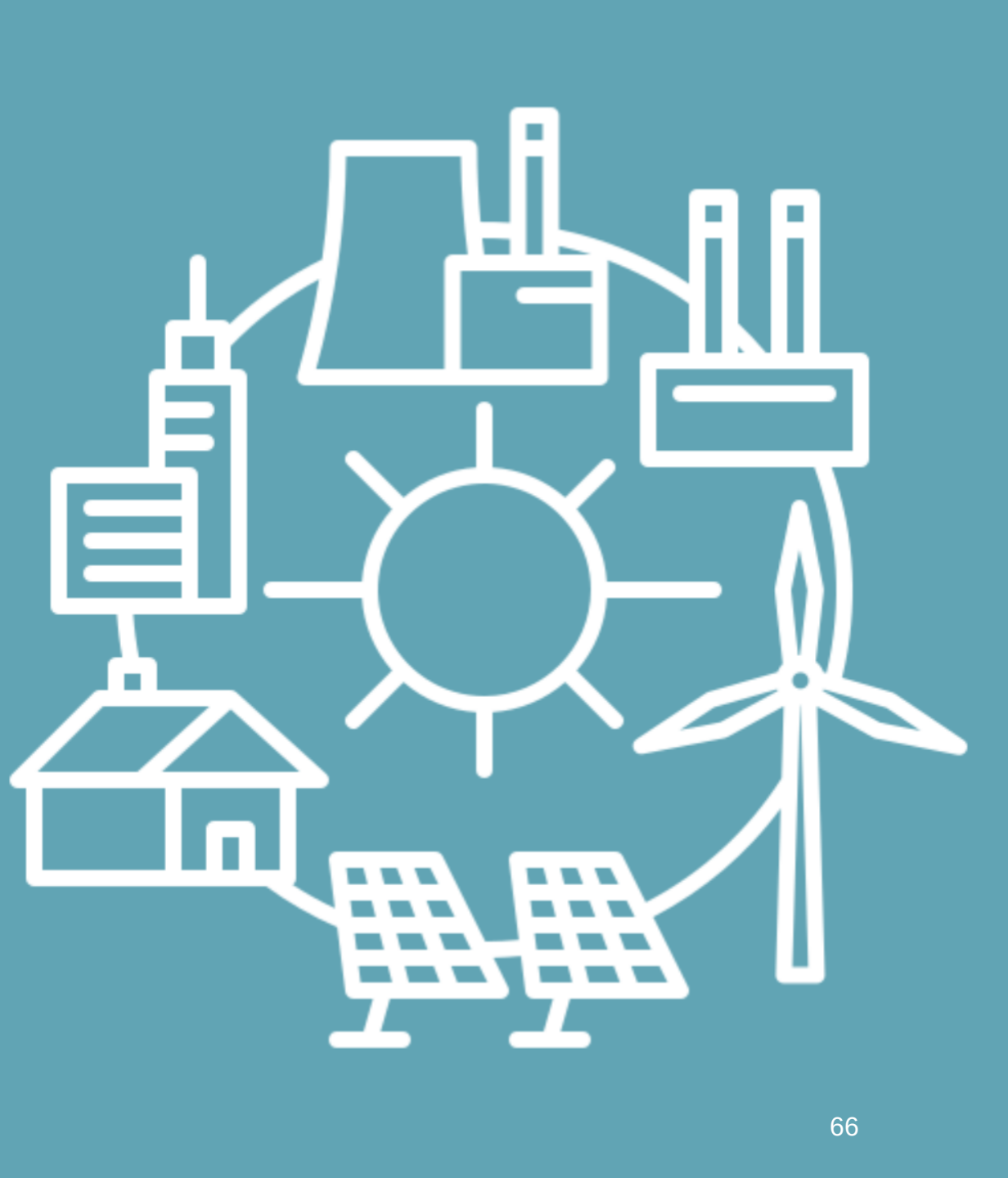
Energy grids

- Privacy-by-Design can be effectively integrated into the design of energy networks
- **Transparency and user-centred implementation** by providing the option to:
  - manage the system **in-house** only (more **privacy-friendly**), or
  - with the use of a **smartphone** over the internet (**more user friendly, less privacy** without additional measures)



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Smart meters

- A smart meter is an electronic device that **records energy consumption** and **exchanges data with energy suppliers**
- Can help to increase the **efficiency and safety** of electricity distribution
- However, they **can also reveal information** about a home's socio-economic status, dwelling, and appliance use
- The ability to infer occupant behavior can constitute a **security risk**

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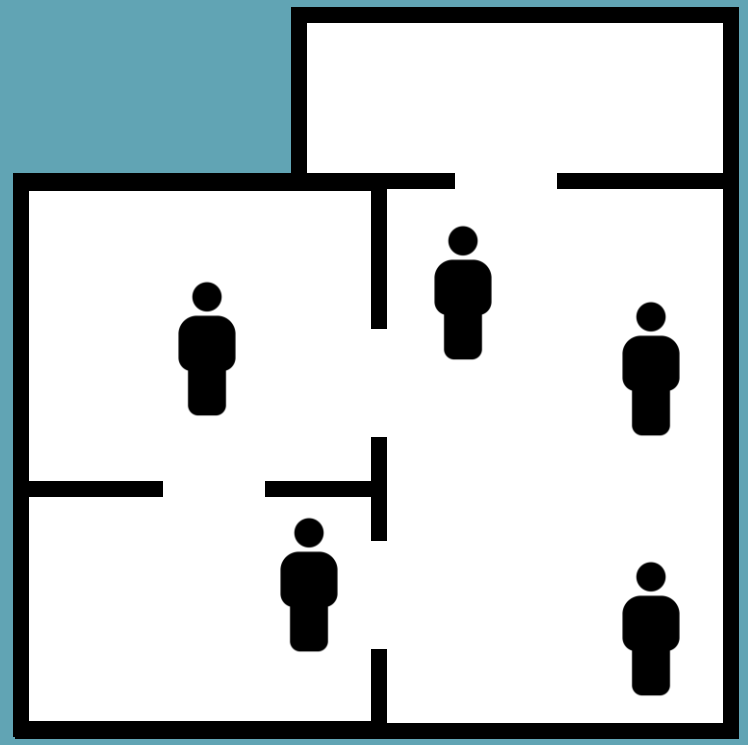
Occupant sensing

- Tracking people in buildings has various **applications**:
  - keeping people safe in case of **emergency**
  - **identifying threats** in case of intrusion
  - maximizing **occupant comfort**
  - increasing **energy efficiency**
  - collecting data for **research**
- This information can be used to **violate the privacy and confidentiality** of the occupants
- Individuals' **anonymity** need to be preserved while maintaining **localization accuracy**



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Building Management Systems (BMS)

- BMS are **cyber-physical systems** to manage buildings by monitoring different **utility services**
- Distinct patterns can reveal the **absence or presence of people and their activities**

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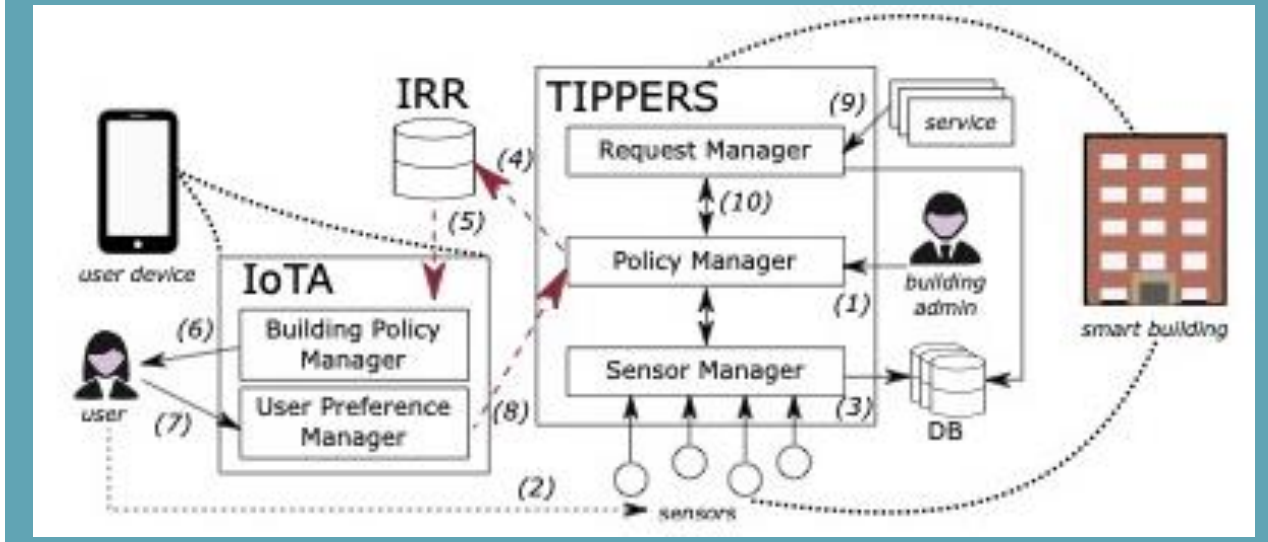
So what can we do about it?

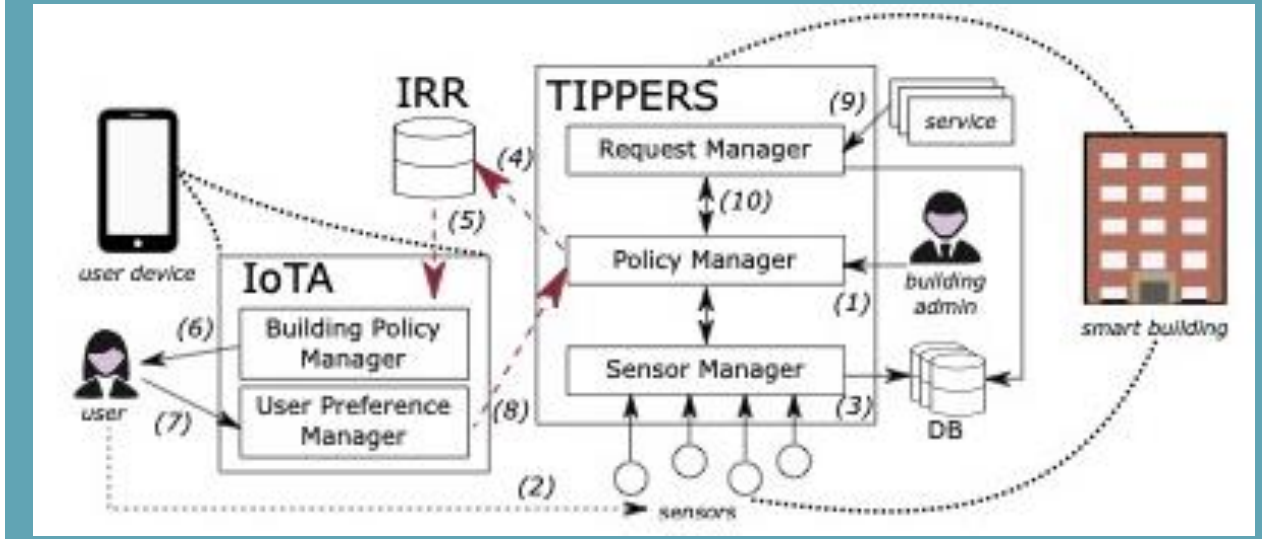
- Pappachan et al. (2017) proposed a **framework** for smart buildings:
  - **IoT Resource Registries (IRRs)** broadcast data collection and sharing policies of the IoT technologies with which users interact
  - **IoT Assistants** selectively notify users about these policies and configure any available privacy settings
  - **Privacy-Aware Smart Buildings** publish building policies, receive the privacy settings of users, and enforce them when collecting or sharing user data



Interaction between privacy-aware smart building management system (TIPPERS), IoT Resource Registries (IRR) and IoT Assistants (IoTA)
(Brains4Buildings Deliverable 4.1)

So what can we do about it?

- **Privacy-Aware Smart Building** measures comprise:
  - A **building policy** that states requirements for data collection and management set by the **temporary or permanent owner**
  - A **user preference** that is a representation of the **user's expectation** of how data pertaining to them should be managed
  - For example:
    - When a user connects to a **WiFi Access Points**, the event is logged for security purposes as part of the **building policy**
    - Using background knowledge it is possible to **infer the real-time location of a user** based on that connection
    - Therefore, it is important to **understand user preferences and expectations** with respect to the information collected



Interaction between privacy-aware smart building management system (TIPPERS), IoT Resource Registries (IRR) and IoT Assistants (IoTA)
(Brains4Buildings Deliverable 4.1)

References

- Section 1 is largely based on:
  - Chamari, L., Pauwels, P., Petrova, E., Chochanova, E., Sebastian, R., Mutsaers, N., Veldhuis, B., Hopkins, S., de Jong, N., van der Velden, J., Dubbeldam, J.W., and van der Weijden, J. (2022). *Study of data needs and requirements in smart buildings.* Brains4Buildings Deliverable 4.3.
- Section 3 is largely based on:
  - Chamari, L., Pauwels, P., Petrova, E., Dubbeldam, J.W., De Jong, N., and Gunderi, K. (2022). *Reference Architecture for Smart Buildings.* Brains4Buildings Deliverable 4.6.
- Section 4 is largely based on:
  - Sebastian, R., Chochanova, E., Petrova, E., Chamari, L., and Pauwels, P. (2022). *Literature and market study of existing regulations and approaches regarding data privacy, ethics, and security, including GDPR constraints.* Brains4Buildings Deliverable 4.1.