Digital Information Infrastructures on the Semantic Interoperability in Buildings and 4-5th Generation District Heating and Cooling Systems

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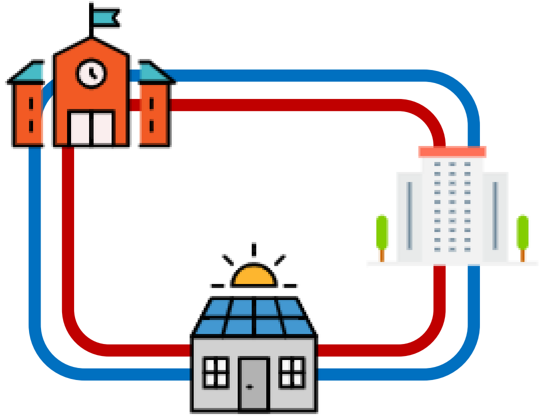
Zeng Peng, KTH

Smart buildings and DHC networks

Smart buildings and DHC networks are expected to be equipped with

- Advanced sensing
  - Large scale deployment of sensors
- Data management
  - Recording, Storage, Retrieval
- Smart applications
  - Fault detection & diagnosis, load prediction
- Control technologies
  - Supports the development and deployment of optimal control strategy



Physical systems

Proactive energy management

Data-driven Applications: FDD, load prediction

Automated reporting and analytics

Demand response optimization

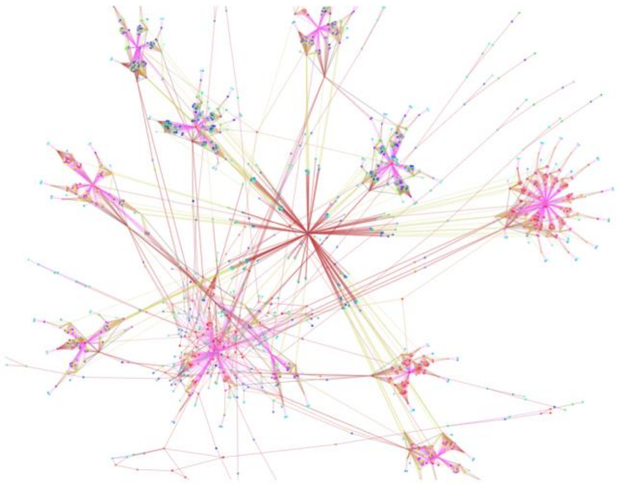
AI-powered decision support

Smart applications

Challenges

The complexity of 4-5GDHC networks presents unique challenges:

- Multiple decentralized renewables
- Distributed storage systems
- The low-temperature nature of DHC
- Smart control strategy
- Big data



A graph visualization of a building district

Advanced thermal networks evolve into complex graphs with countless nodes and intricate topologies

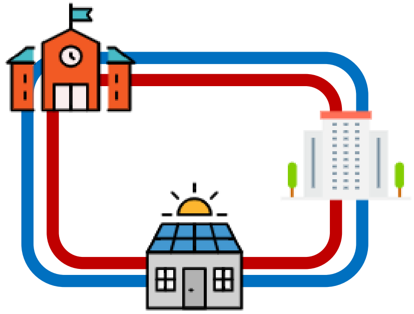
The data and information flow is complex in this graph

The roadblock: fluent transmission and effective utilization of data and information

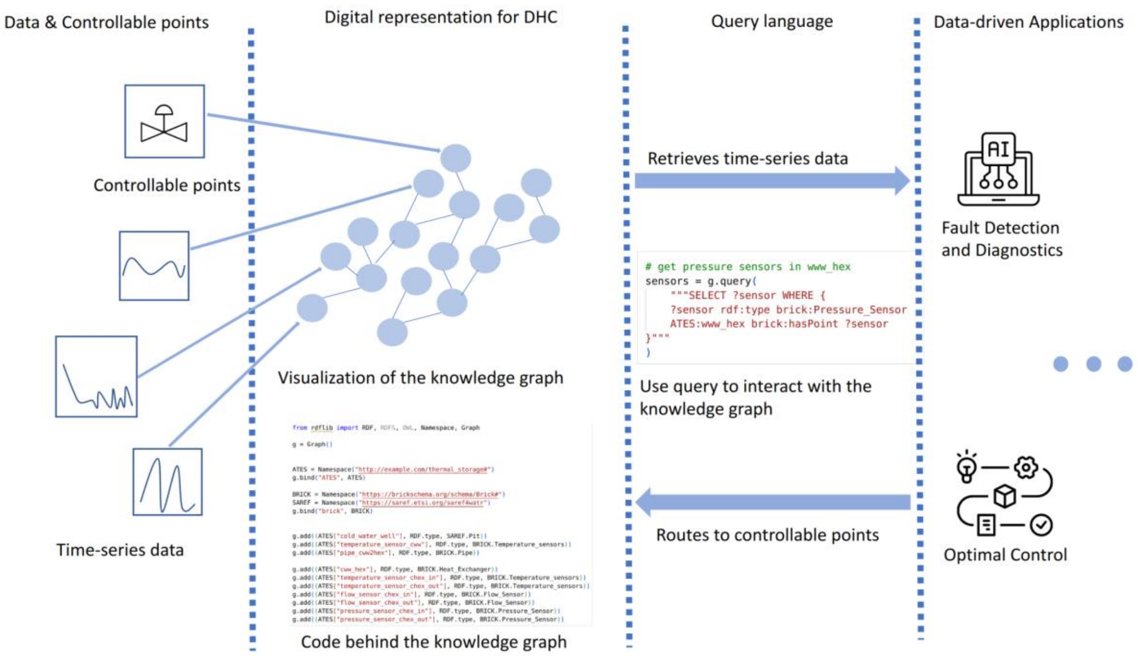
The idea

A layer that models the complex graph of thermal networks:

- Support querying language (database technology)
- Computer program can read & write data and information unambiguously



Physical systems

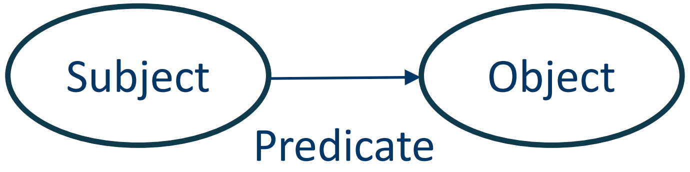


How smart applications interact with digital representations of DHC systems to acquire data and information.

Some preliminaries

Two key semantic web technologies:

- Resource Description Framework (RDF) for constructing the graph
- SPARQL as the standard query language, enabling efficient modeling and querying of data



Resource Description Framework (RDF)

```
SELECT *
WHERE {
    BIND(ex:sw003 AS ?targets)
    ?src  ex:linksWith ?targets .
}
```

SPARQL

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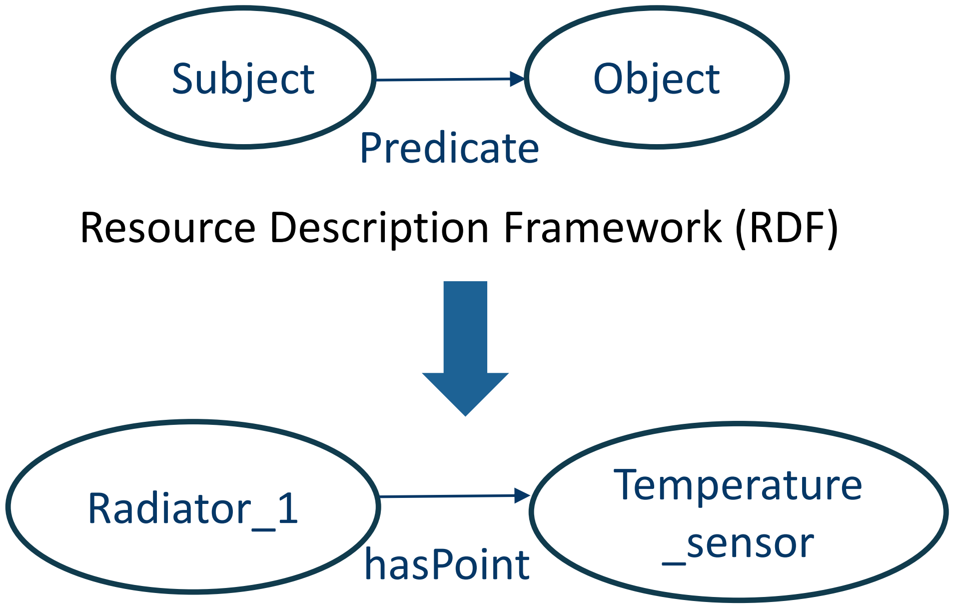
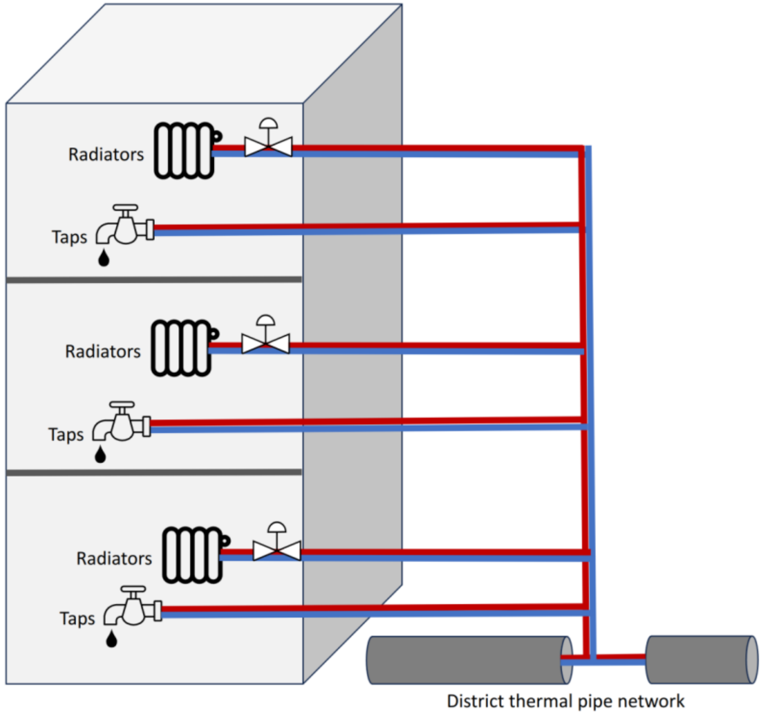



```
SELECT *
WHERE {
    BIND(ex:sw003 AS ?targets)
    ?src  ex:linksWith ?targets .
}
```

SPARQL

Get the temperature sensor in room 101 in building A

An example

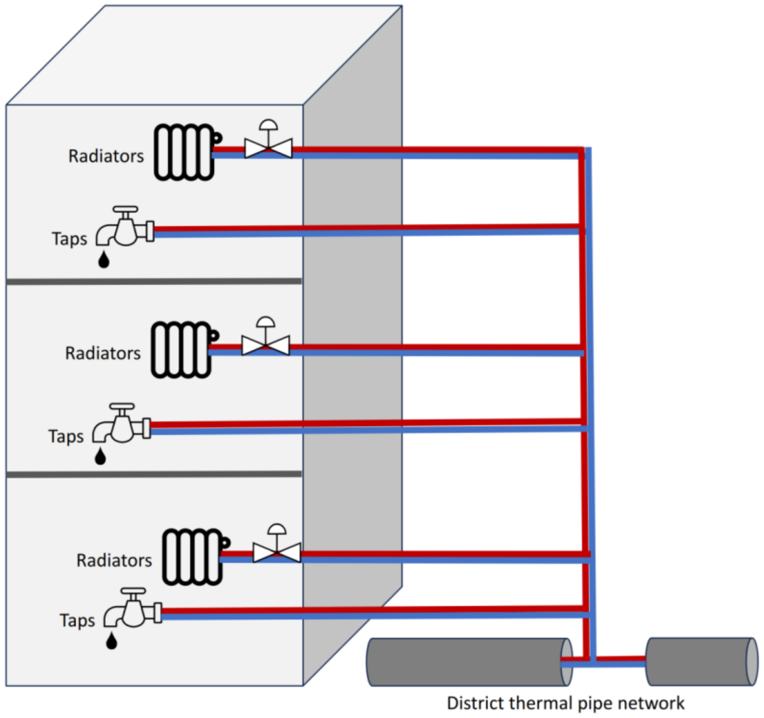


A building connected to district thermal pipe network

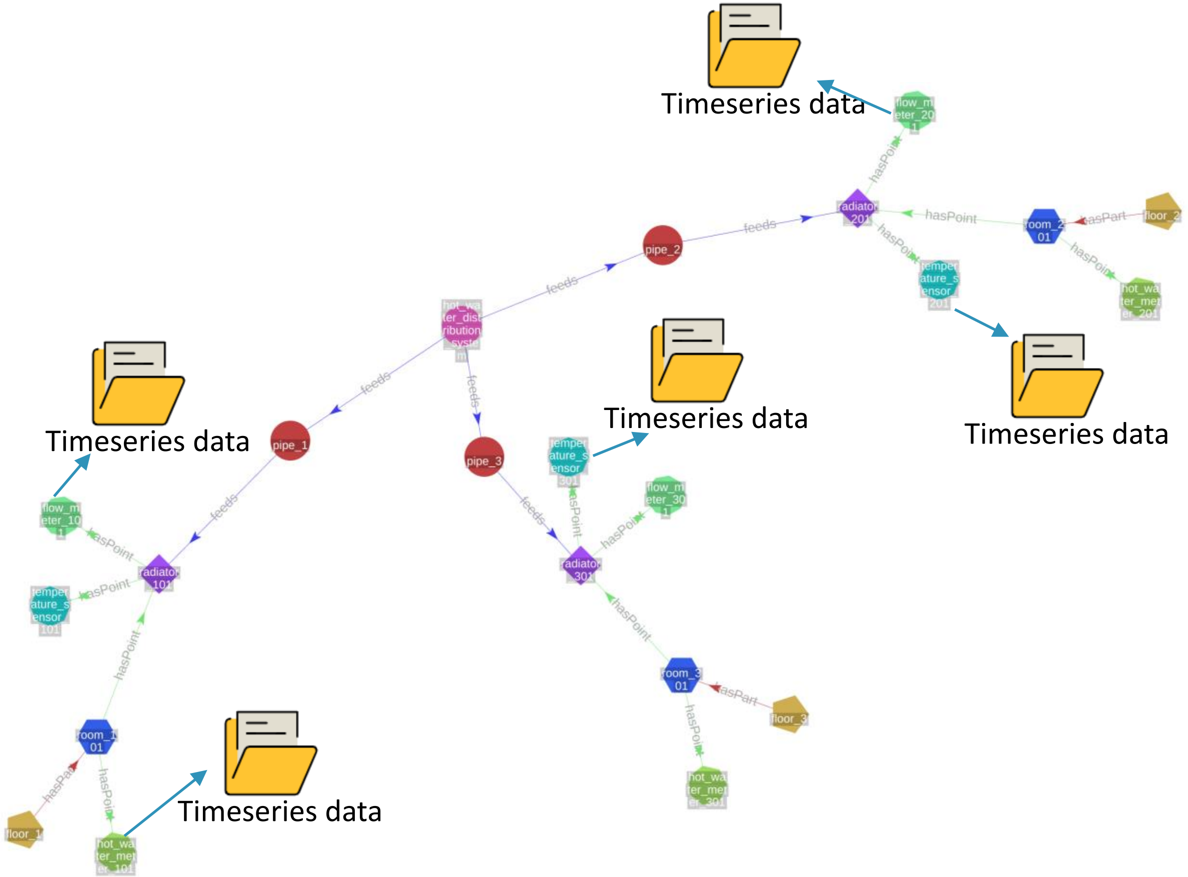
```
Building = Namespace("http://example.com/Buildings#")
g.bind("Building", Building)

BRICK = Namespace("https://brickschema.org/schema/Brick#")
g.bind("brick", BRICK)

g.add((Building["hot_water_distribution_system"], RDF.type, BRICK.Water_Distribution))

g.add((Building["pipe_1"], RDF.type, BRICK.Pipe))
g.add((Building["floor_1"], RDF.type, BRICK.Floor))
g.add((Building["room_101"], RDF.type, BRICK.Room))
g.add((Building["hot_water_meter_101"], RDF.type, BRICK.Hot_Water_Meter))
g.add((Building["radiator_101"], RDF.type, BRICK.Radiator))
g.add((Building["temperature_sensor_101"], RDF.type, BRICK.Temperature_Sensor))
g.add((Building["flow_meter_101"], RDF.type, BRICK.Flow_Meter))

g.add((Building["floor_2"], RDF.type, BRICK.Floor))
g.add((Building["pipe_2"], RDF.type, BRICK.Pipe))
g.add((Building["room_201"], RDF.type, BRICK.Room))
g.add((Building["hot_water_meter_201"], RDF.type, BRICK.Hot_Water_Meter))
g.add((Building["radiator_201"], RDF.type, BRICK.Radiator))
g.add((Building["temperature_sensor_201"], RDF.type, BRICK.Temperature_Sensor))
g.add((Building["flow_meter_201"], RDF.type, BRICK.Flow_Meter))
```

A simplified semantic model using RDF triplets

An example



A building connected to district thermal pipe network



Visualization of the semantic model with timeseries data

An example

If we want to find all temperature sensors

```
sensors = g.query(
    """SELECT ?sensor WHERE {
    ?sensor rdf:type brick:Temperature_Sensor
}"""
)
```

SPARQL query

```
(rdflib.term.URIRef('http://example.com/Buildings#temperature_sensor_101'),)
(rdflib.term.URIRef('http://example.com/Buildings#temperature_sensor_201'),)
(rdflib.term.URIRef('http://example.com/Buildings#temperature_sensor_301'),)
```

Results

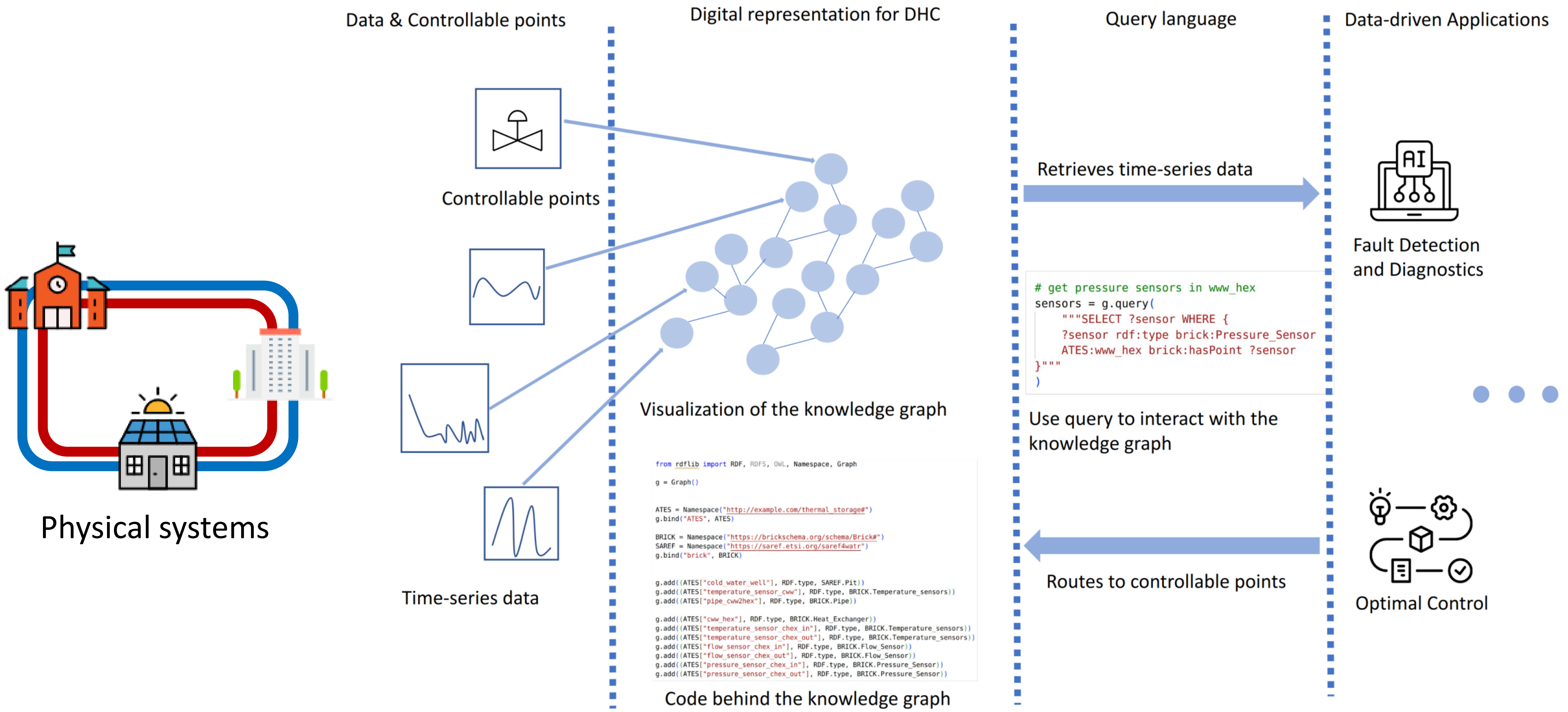
If we just need the temperature sensor from Room 301

```
sensors_floor3 = g.query(
    """SELECT ?sensor WHERE {
    ?sensor rdf:type brick:Temperature_Sensor .
    ?radiator brick:hasPoint ?sensor .
    ?room brick:hasPoint ?radiator .
    Building:floor_3 brick:hasPart ?room
}"""
)
```

SPARQL query

```
(rdflib.term.URIRef('http://example.com/Buildings#temperature_sensor_301'),)
```

Results



How smart applications interact with digital representations of DHC systems to acquire data and information.

A challenge

- **Standarization**

  "Tags" need to be standardized and consistent across & between systems

```python
Building = Namespace("http://example.com/Buildings#")
g.bind("Building", Building)

BRICK = Namespace("https://brickschema.org/schema/Brick#")
g.bind("brick", BRICK)

g.add((Building["hot_water_distribution_system"], RDF.type, BRICK.Water_Distribution))

g.add((Building["pipe_1"], RDF.type, BRICK.Pipe))
g.add((Building["floor_1"], RDF.type, BRICK.Floor))
g.add((Building["room_101"], RDF.type, BRICK.Room))
g.add((Building["hot_water_meter_101"], RDF.type, BRICK.Hot_Water_Meter))
g.add((Building["radiator_101"], RDF.type, BRICK.Radiator))
g.add((Building["temperature_sensor_101"], RDF.type, BRICK.Temperature_Sensor))
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g.add((Building["flow_meter_201"], RDF.type, BRICK.Flow_Meter))
```

```python
sensors_floor3 = g.query(
    """SELECT ?sensor WHERE {
    ?sensor rdf:type brick:Temperature_Sensor .
    ?radiator brick:hasPoint ?sensor .
    ?room brick:hasPoint ?radiator .
    Building:floor 3 brick:hasPart ?room
}"""
)
```

Ontology - standardization

Brick
A uniform metadata schema for buildings

ASHRAE Standard 223P

RealEstateCore

Semantic Sensor Network Ontology

Project Haystack

The Smart Applications REFerence Ontology (SAREF)

Some existing ontologies

- Physical object
  - Device
    - Building device
      - Distribution device
        - Distribution control device
          - Actuator
          - Alarm
          - Controller
          - Flow instrument
          - Protective device tripping unit
          - Sensor
          - Unitary control element
        - DistributionFlowDevice
          - Energy conversion device
            - Air to air heat recovery
            - Boiler
            - Burner
            - Chiller
            - Coil

- Classes
  - Collection
    - Loop
    - PV Array
    - Photovoltaic Array
    - Portfolio
    - System
  - Equipment
    - Camera
    - Electrical Equipment
    - Elevator
    - Fire Safety Equipment
    - Furniture
    - Gas Distribution
    - HVAC Equipment
    - Lighting Equipment
    - Meter
    - Motor
    - PV Panel
    - Relay
    - Safety Equipment
    - Security Equipment
    - Shading Equipment
    - Solar Thermal Collector
    - Steam Distribution
    - Valve
    - Water Distribution
    - Water Heater
    - Weather Station
  - Location
  - Measurable
  - Point

A "Dictionary" that you can lookup

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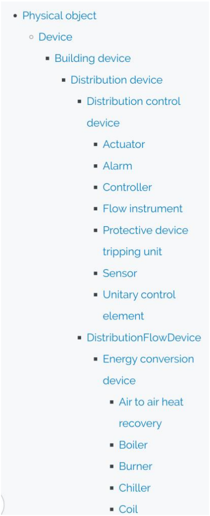
Ontology?

- The unique requirements of thermal networks.



"Dictionary" is not big enough

- Choose which one to follow?

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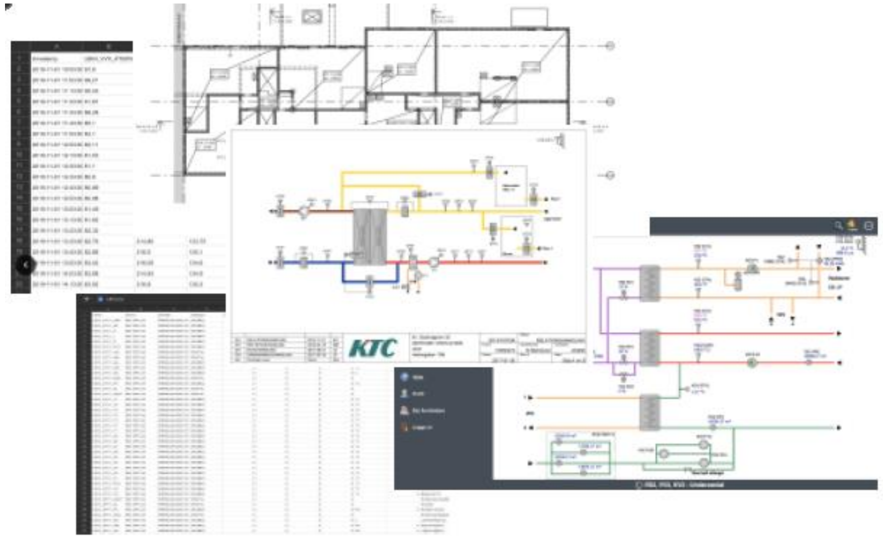
Some other challenges

- **Standarization**
  "Tags" need to be standardized and consistent across & between systems
- **Automation**
  Manual creation of graphs is time-consuming and error-prone



- **Application**
  Research is needed to fully understand and effectively utilize these graphs in practical applications

Summary - semantic interoperability for building and DHC

Semantic Interoperability:

- Read & Write data, exchange information unambiguously

Digital Information Infrastructure:

- (Data) Time series data
- (Information) Relational information

→ (Knowledge) Knowledge derived from data and connectivity patterns

Ontologies is leveraged for consistency and scalability:

- Provides consistent semantic information across and between systems
- Supports expansion to diverse building and DHC scenarios

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THANK YOU FOR YOUR ATTENTION

Zeng Peng, Thomas Ohlson Timoudas, Qian Wang