CLIMA 2025

REHVA 15th HVAC World Congress

4th - 6th June, Milan, Italy

Decarbonized, healthy and energy conscious buildings in future climates

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Federation of European Heating, Ventilation and Air Conditioning Associations

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Associazione Italiana Condizionamento dell'Aria Riscaldamento e Refrigerazione

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Decarbonized, healthy and energy conscious buildings in future climates

Generation of building performance simulation models using semantic graphs and sensor measurements

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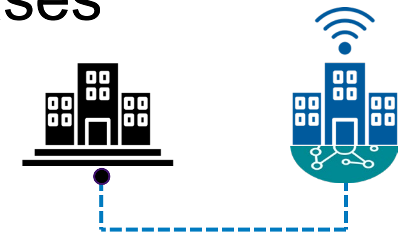
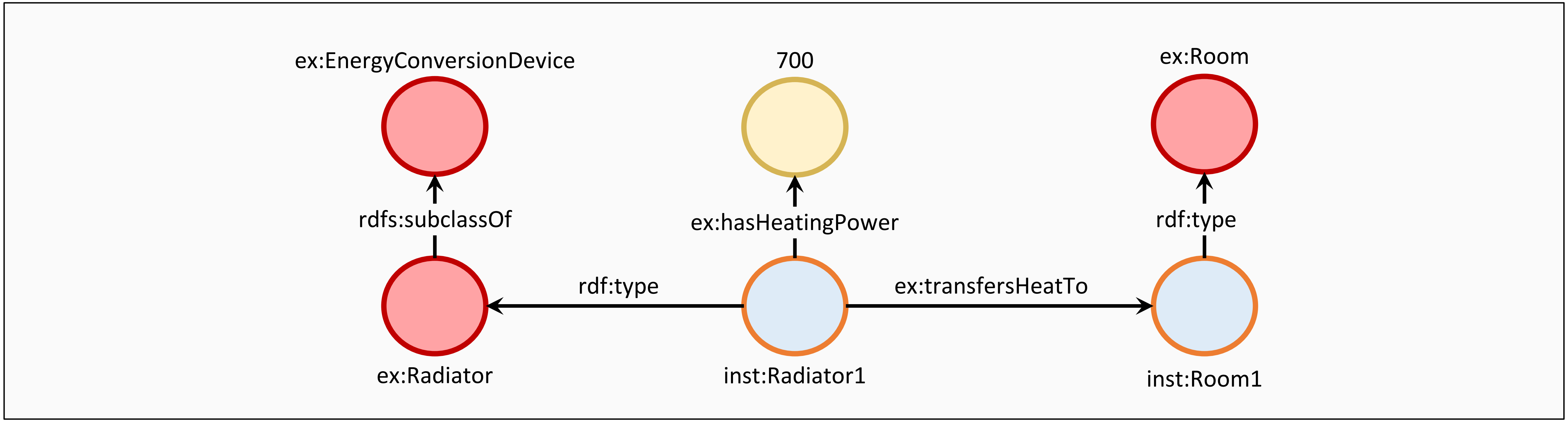
Motivation

- Building sector: Zero-emission of greenhouse gas by 2050
- Challenge: Modeling efforts for model-based optimization
- **Building Performance Simulation (BPS)**
  - White-box model that predicts dynamic of the buildings
  - Benefits: Less model inputs but good accuracy
  - Drawbacks: **High manual efforts**, complex to build in some cases



Background

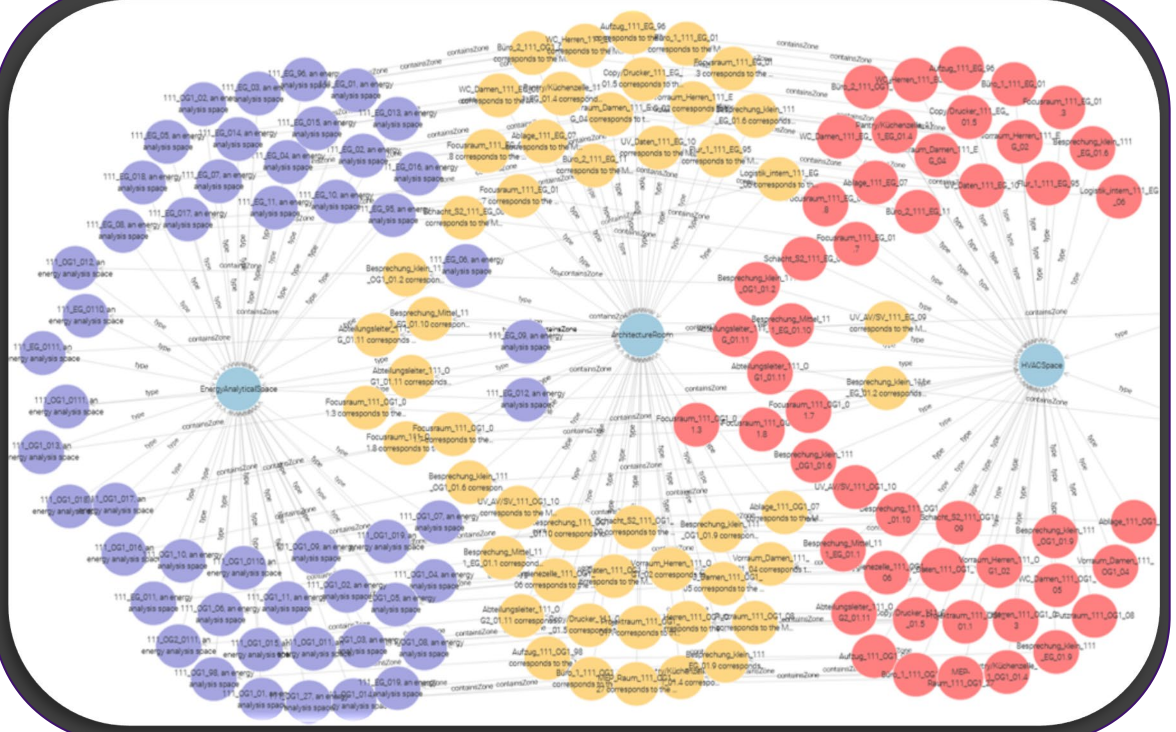
- **Semantics**: Machine interpretable data (Meta-data)
- **RDF**: Data model of the semantic web, framework for semantics



Background

Thanks to BIM2Graph project, semantic graph is already generated

Building Information Modeling of Rng 111



Generated graph for Rng 111

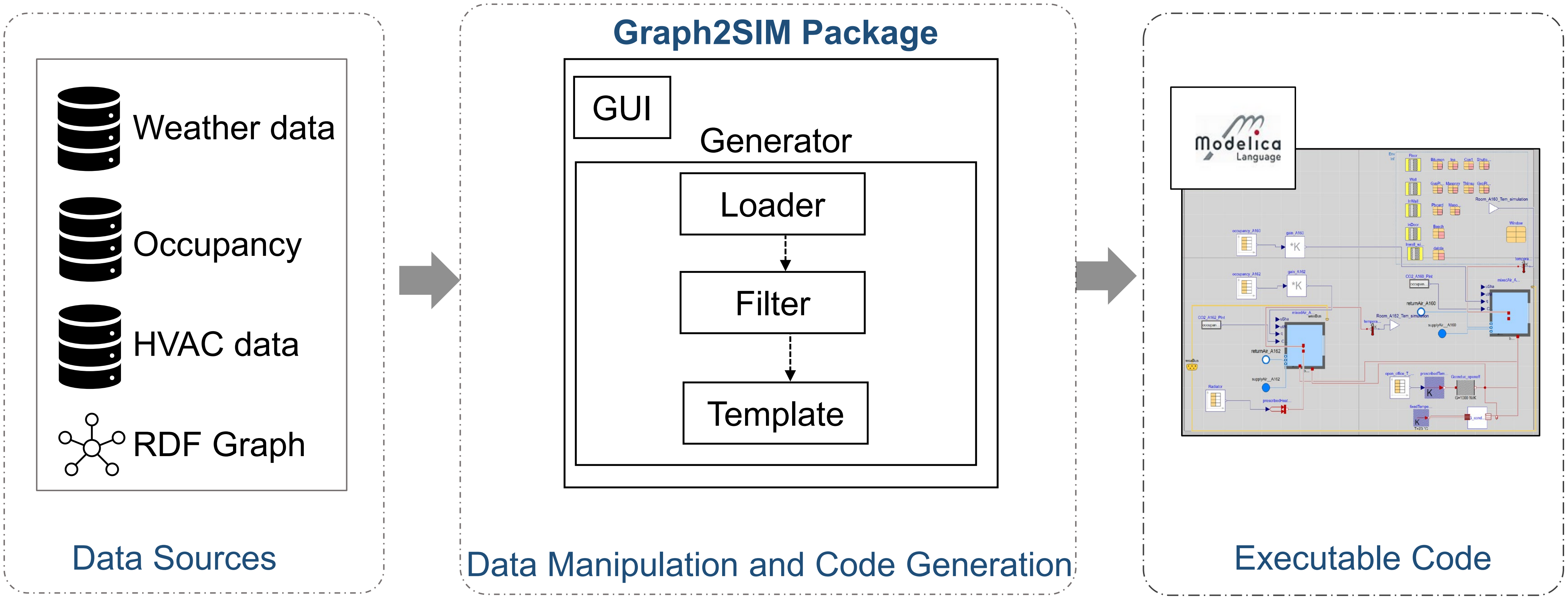
B

Semantic data required in BPS model

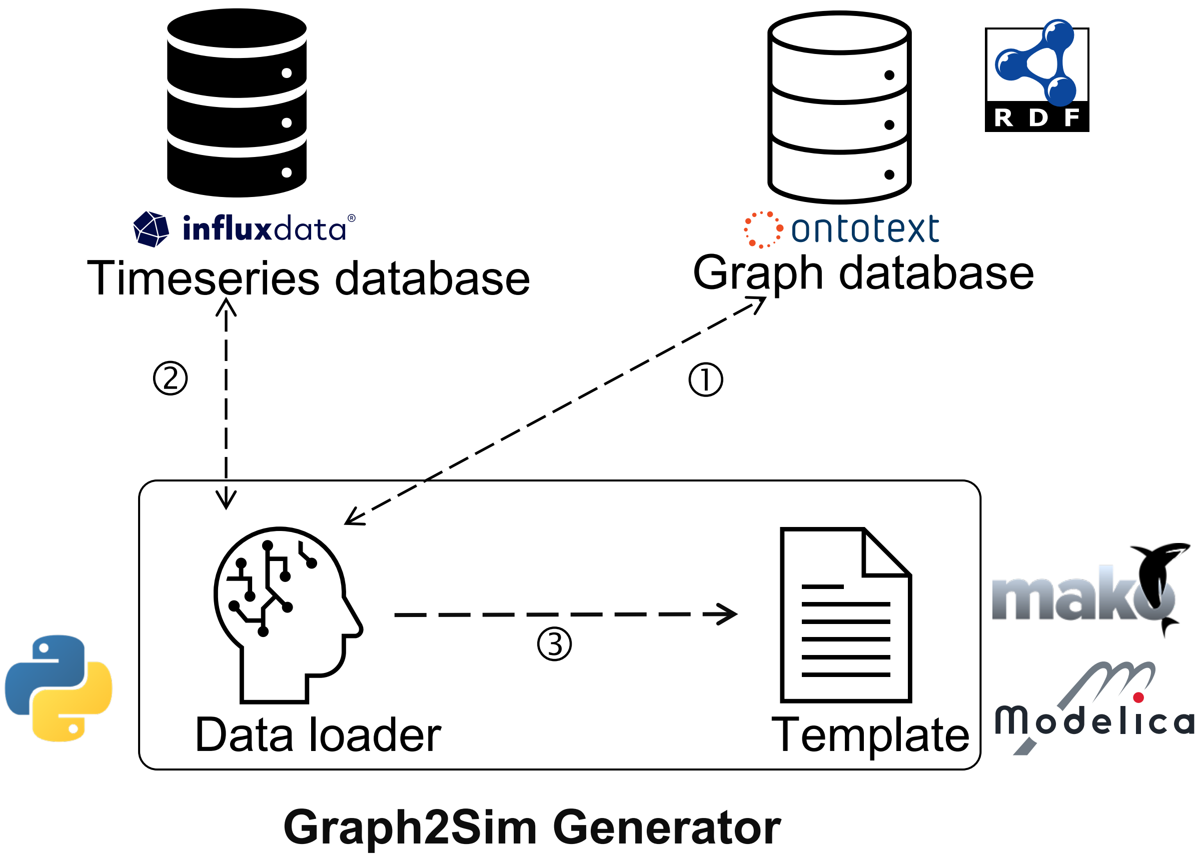
	Types of Information	Ontologies	Link and Abbreviation
1	**Building** - Element and hierarchy - Topology - Property	 BOT, BEO, BOT-EXT BOT PROPS, SOSA/SSN(-EXT), QUDT	Open-source: 1.Building Element Ontology (BEO) 2.Building Topology Ontology (BOT) 3.Brick Schema (Brick) 4.Distribution Element Ontology (MEP) 5.Flow System Ontology (FSO) 6.Geo ontology (GEO) 7.Property Set Ontology (PROPS) 8.QUDT Ontology (QUDT) 9.Smart Energy Aware System (SEAS) 10.Sensor, Observation, Sample, and Actuator / Semantic Sensor Network Ontology (SOSA / SSN) 11.Web of Things Hypermedia Controls Ontology (HCTL) 12.Web of Things Things Description Onology (TD) 13.Tubes System Ontology (TSO) Extensions: 14. BOT-EXT: Extensions made to BOT 15. SSN-EXT: Extensions made to SOSA/SSN 16. Control: Extensions made to SEAS for MPC
2	**HVAC systems** - Components and hierarchy - System topology and functionality - Property - Interaction with buildings	 FSO, MEP FSO, TUBES SOSA/SSN(-EXT), QUDT FSO	
3	**Sensors and Actuators** - Type - Property - Measurements (Timeseries and IoT)	 Brick SOSA/SSN SOSA/SSN, Brick, WoT (TD & HCTL)	
4*	**Control algorithms** - Control procedures - Link to the sensors and actuators	 SEAS, Control SOSA/SSN	

* The information not extracted from BIM

Semantic-graph-based BPS model generation

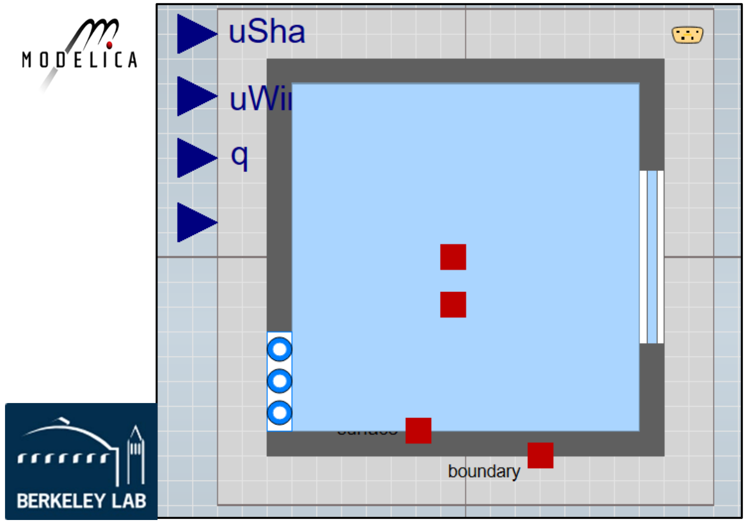


Semantic-graph-based BPS model generation



Semantic-graph-based BPS model generation

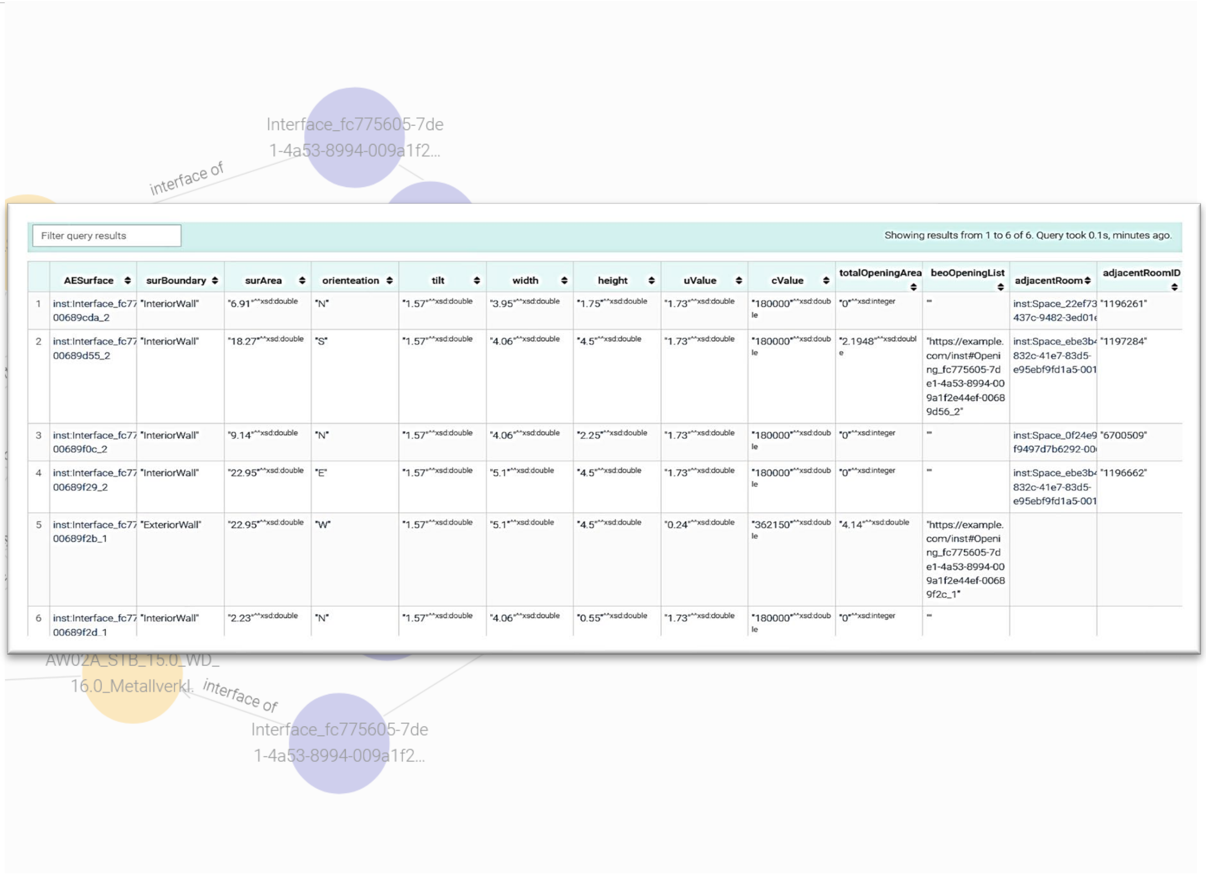
- Goal: to generate white-box model for multi-zone buildings
- Library: Modelica Buildings library
- Main parameters for the "Mixed-Air Model":
  - Fluid ports
  - Heat Ports
  - Occupancy
  - Shading
  - Window opening



Mixed-Air Model in Modelica Buildings library

Graph of room A.162 (Geometry)

```sparql
PREFIX beo: <https://pi.pauwel.be/voc/buildingelement#>
PREFIX bot-ext: <http://bosch-cr-aes//hsbc/bot-extension#>
PREFIX props: <https://w3id.org/props#>
PREFIX bot: <https://w3id.org/bot#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
SELECT DISTINCT ?AESurface ?surBoundary ?surArea ?orienteation ?tilt ?width ?height ?uValue ?cValue
(SUM(?AEOpeningArea) AS ?totalOpeningArea) (GROUP_CONCAT(?AEOpening;separator="\\n") AS ?beoOpeningList) ?adjacentRoom ?adjacentRoomID
WHERE
{{
?room a bot-ext:Room;
        props:hasRevitId '1196665'.

?space a bot-ext:HVACSpace ;
        bot:containsZone ?room;
        bot:containsZone+ ?AESpace.
?AESpace a bot-ext:EnergyAnalyticalSpace .
?AESurface a bot:Interface ;
        props:hasArea ?surArea;
        props:hasBoundary ?surBoundary;
        props:hasTilt ?tilt;
        props:hasWidth ?width;
        props:hasHeight ?height;
        props:hasOrientation ?orienteation;
        props:hasUvalue ?uValue;
        props:hasCvalue ?cValue;
        bot:interfaceOf ?element ;
        bot:interfaceOf ?AESpace .
?element   a bot:Element;
        props:hasArea ?eleArea;
.
OPTIONAL
{{
{{?AESurface bot-ext:inverseOf ?AESurface_2.}}
        UNION
{{?AESurface_2 bot-ext:inverseOf ?AESurface.}}
?AESurface_2 a bot:Interface;
                bot:interfaceOf ?AESpace_2.
?AESpace_2 a bot-ext:EnergyAnalyticalSpace.
?adjacentRoom a bot-ext:Room;
                bot:containsZone ?AESpace_2;
        props:hasRevitId ?adjacentRoomID;.
}}
OPTIONAL
{{?AEOpening a bot:Interface;
        props:relatesTo ?AESurface;
        props:hasHeight ?openingHeight;
        props:hasBoundary ?openingBoundary;
        props:hasWidth ?openingWidth.
BIND (?openingHeight*?openingWidth AS ?AEOpeningArea)
}}
}}
 GROUP BY ?element ?eleArea ?AESurface ?surBoundary  ?surArea ?orienteation ?uValue ?cValue  ?tilt ?width ?height  ?adjacent_room_label ?adjacentRoom
?adjacentRoomID
```

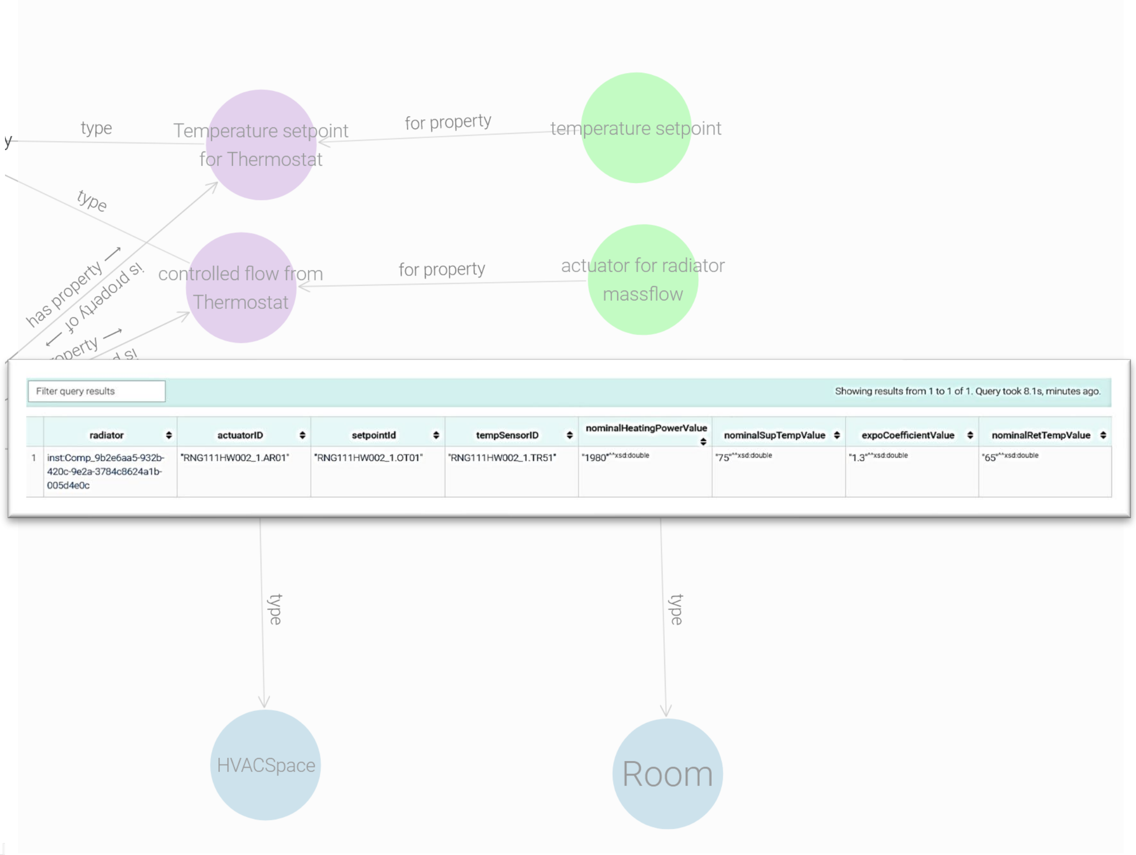


	AESurface	surBoundary	surArea	orienteation	tilt	width	height	uValue	cValue	totalOpeningArea	beoOpeningList	adjacentRoom	adjacentRoomID
1	inst:Interface_fc77 00689cda_2	"InteriorWall"	"6.91"^^xsd:double	"N"	"1.57"^^xsd:double	"3.95"^^xsd:double	"1.75"^^xsd:double	"1.73"^^xsd:double	"180000"^^xsd:double	"0"^^xsd:integer	""	inst:Space_22ef73 437c-9482-3ed01	"1196261"
2	inst:Interface_fc77 00689d55_2	"InteriorWall"	"18.27"^^xsd:double	"S"	"1.57"^^xsd:double	"4.06"^^xsd:double	"4.5"^^xsd:double	"1.73"^^xsd:double	"180000"^^xsd:double	"2.1948"^^xsd:double	"https://example.com/inst#Opening_fc775605-7de1-4a53-8994-009a1f2e44ef-00689d56_2"	inst:Space_ebe3b 832c-41e7-83d5-e95ebf9fd1a5-001	"1197284"
3	inst:Interface_fc77 00689f0c_2	"InteriorWall"	"9.14"^^xsd:double	"N"	"1.57"^^xsd:double	"4.06"^^xsd:double	"2.25"^^xsd:double	"1.73"^^xsd:double	"180000"^^xsd:double	"0"^^xsd:integer	""	inst:Space_0f24e9 f9497d7b6292-00	"6700509"
4	inst:Interface_fc77 00689f29_2	"InteriorWall"	"22.95"^^xsd:double	"E"	"1.57"^^xsd:double	"5.1"^^xsd:double	"4.5"^^xsd:double	"1.73"^^xsd:double	"180000"^^xsd:double	"0"^^xsd:integer	""	inst:Space_ebe3b 832c-41e7-83d5-e95ebf9fd1a5-001	"1196662"
5	inst:Interface_fc77 00689f2b_1	"ExteriorWall"	"22.95"^^xsd:double	"W"	"1.57"^^xsd:double	"5.1"^^xsd:double	"4.5"^^xsd:double	"0.24"^^xsd:double	"362150"^^xsd:double	"4.14"^^xsd:double	"https://example.com/inst#Opening_fc775605-7de1-4a53-8994-009a1f2e44ef-00689f2c_1"		
6	inst:Interface_fc77 00689f2d_1	"InteriorWall"	"2.23"^^xsd:double	"N"	"1.57"^^xsd:double	"4.06"^^xsd:double	"0.55"^^xsd:double	"1.73"^^xsd:double	"180000"^^xsd:double	"0"^^xsd:integer	""		

Graph of room A.162 (Radiator)

```
SELECT DISTINCT ?radiator ?actuatorID ?setpointId
?tempSensorID ?nominalHeatingPowerValue ?nominalSupTempValue ?expoCoefficientValue ?nominalRetTempValue
WHERE {
      {
        SELECT ?radiator ?actuatorID ?setpointId ?nominalHeatingPowerValue ?nominalSupTempValue ?expoCoefficientValue ?nominalRetTempValue
        WHERE
        {
            ?room a bot-ext:Room;
                  props:hasRevitId "1196665".
            ?space a bot-ext:HVACSpace ;
                   bot:containsZone ?room.

            ?radiator fso:transfersHeatTo ?space ;
                      a fso-ext:Radiator ;
                      a sosa:FeatureOfInterest .

            ?radiator ssn:hasProperty ?flowProperty .
            ?actuator ssn:forProperty ?flowProperty;
                      a brick:Water_Flow_Sensor;
                      ref:hasTimeseriesID ?actuatorID.

            ?radiator ssn:hasProperty ?tempSetpointProperty .
            ?tempSetpoint ssn:forProperty ?tempSetpointProperty;
                          a brick:Air_Temperature_Setpoint;
                          ref:hasTimeseriesID ?setpointId .

            ?radiator ssn:hasProperty ?nominalHeatingPower, ?nominalSupTemp, ?nominalRetTemp, ?expoCoefficient .
            ?nominalHeatingPower a ssn-ext:NominalPower;
                                 brick:value ?nominalHeatingPowerValue .
            ?nominalSupTemp a ssn-ext:NominalSupplyTemperature;
                            brick:value ?nominalSupTempValue .
            ?nominalRetTemp a ssn-ext:NominalReturnTemperature;
                            brick:value ?nominalRetTempValue .
            ?expoCoefficient a ssn-ext:ExponentialCoefficient;
                             brick:value ?expoCoefficientValue .}}
     {SELECT  (COUNT(DISTINCT ?step) as ?distance) ?tempSensorID
      WHERE
      {
            ?room a bot-ext:Room;
                  props:hasRevitId "1196665".
            ?space a bot-ext:HVACSpace ;
                   bot:containsZone ?room.

        ?radiator fso:transfersHeatTo ?space ;
                  a fso-ext:Radiator ;
                  a sosa:FeatureOfInterest .
        ?component fso:feedsFluidTo* ?step;
                   a fso-ext:SensorFitting;
                   a sosa:FeatureOfInterest .
        ?step fso:feedsFluidTo+ ?radiator.
        ?sys a fso:SupplySystem;
             fso:hasComponent ?component, ?step.
        ?component ssn:hasProperty ?tempProperty .
        ?tempSensor sosa:observes ?tempProperty;
                    a brick:Temperature_Sensor;
                    ref:hasTimeseriesID ?tempSensorID .}
        GROUP BY ?tempSensorID ?component
        ORDER BY  ASC(?distance)
        LIMIT 1
     }
}
```

SPARQL



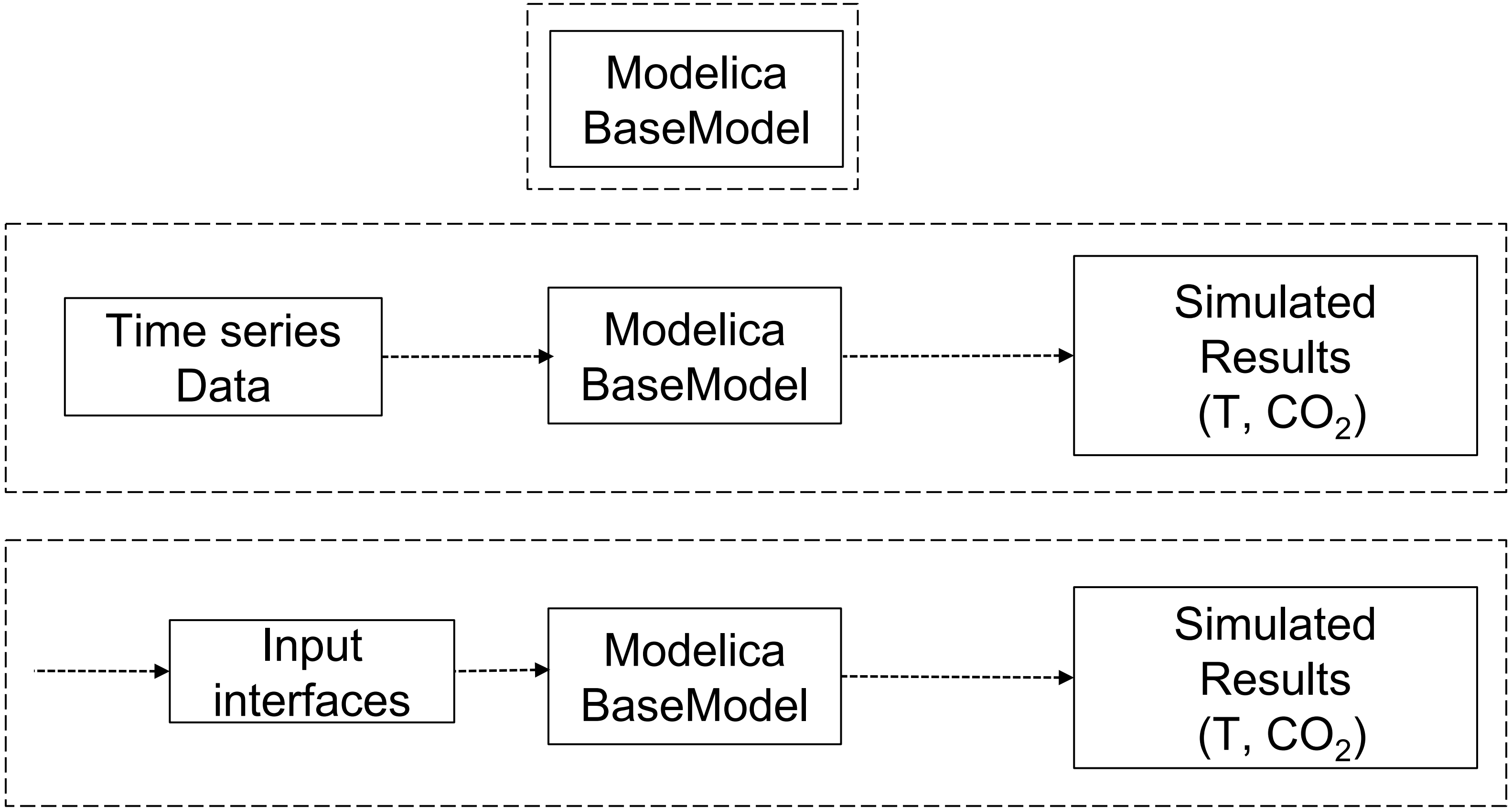
	radiator	actuatorID	setpointId	tempSensorID	nominalHeatingPowerValue	nominalSupTempValue	expoCoefficientValue	nominalRetTempValue
1	inst:Comp_9b2e6aa5-932b-420c-9e2a-3784c8624a1b-005d4e0c	"RNG111HW002_1.AR01"	"RNG111HW002_1.OT01"	"RNG111HW002_1.TR51"	"1980"^^xsd:double	"75"^^xsd:double	"1.3"^^xsd:double	"65"^^xsd:double

Templates

(1) Base model

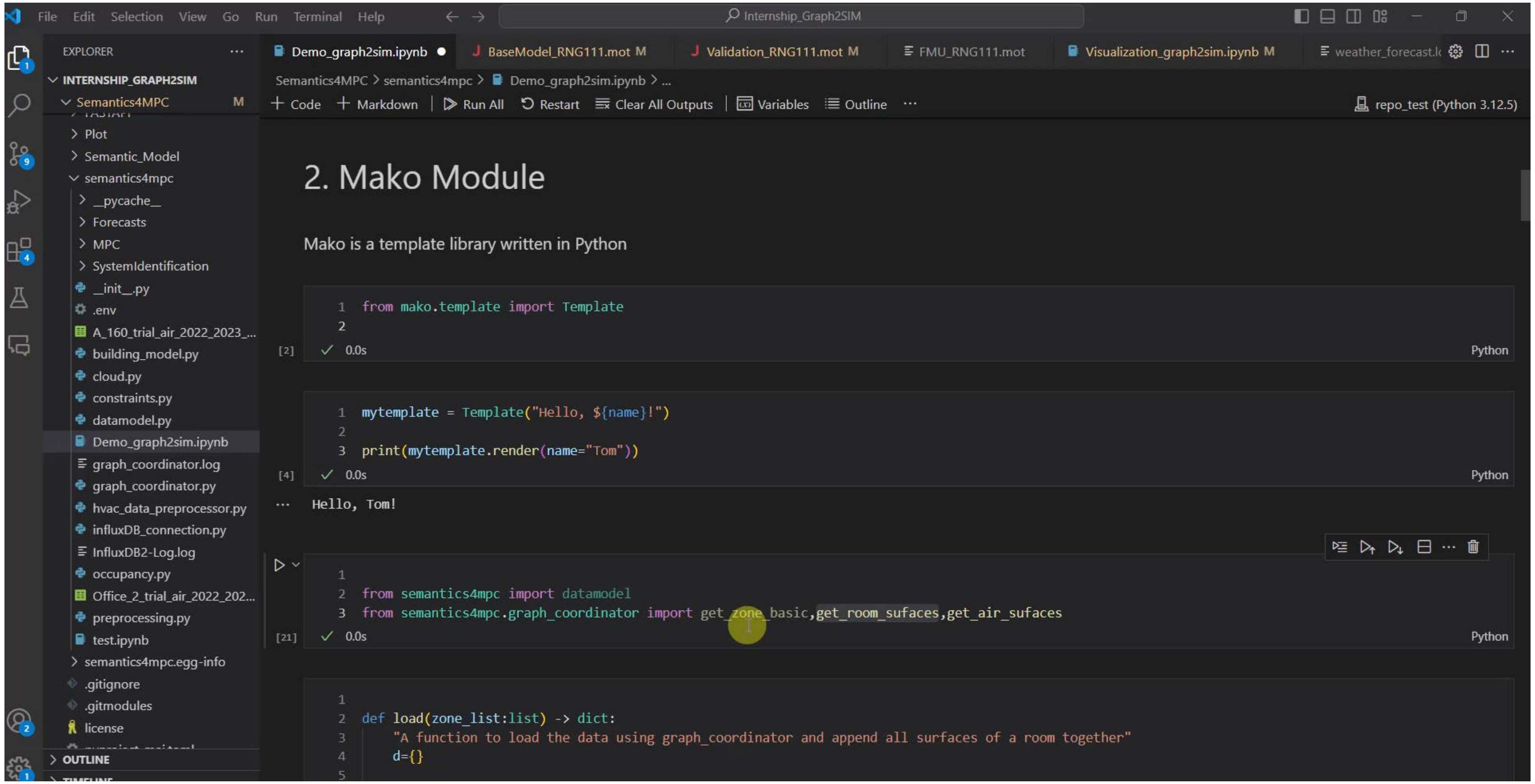
(2) Validation model

(3) FMU* of base model

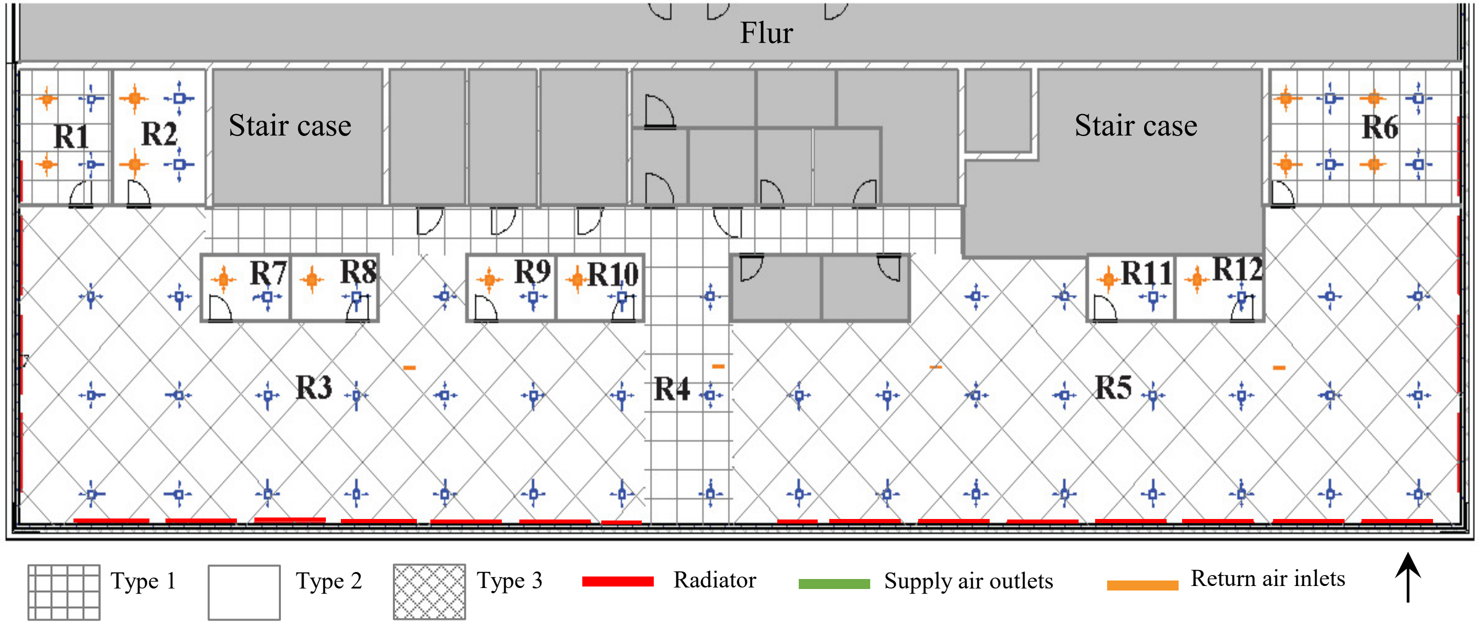


*Functional Mock-up Unit

Demonstration of automated toolchain



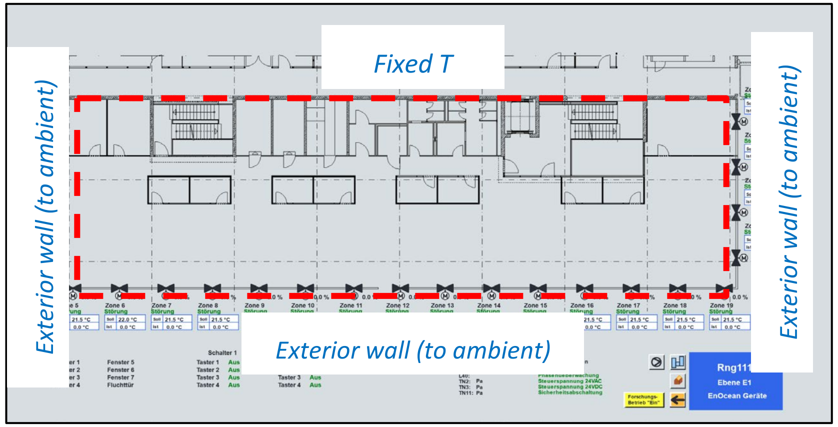
Case study and results



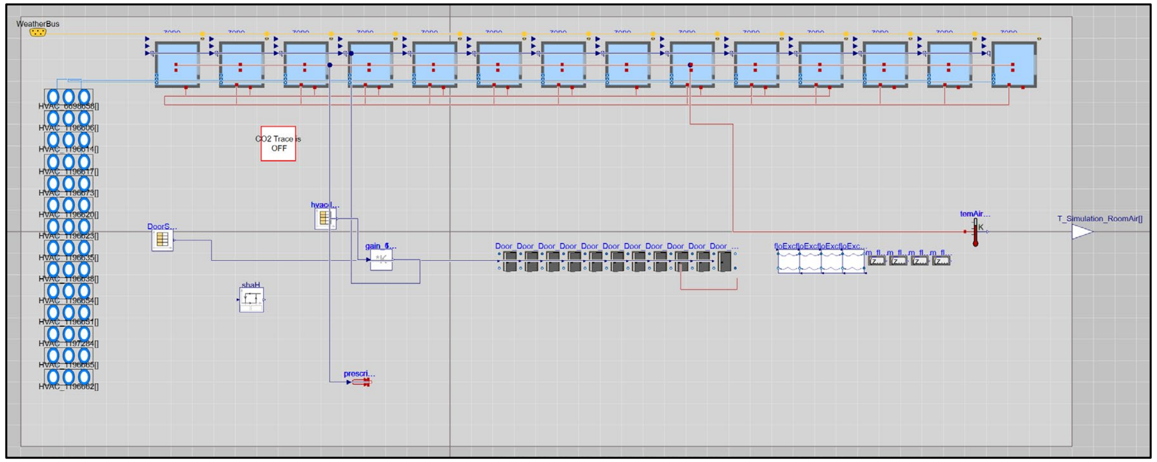
Floor plan RNG 111/1

*R9, R10, R11, and R12 do not have enough sensor data

Toolchain validation: model generation



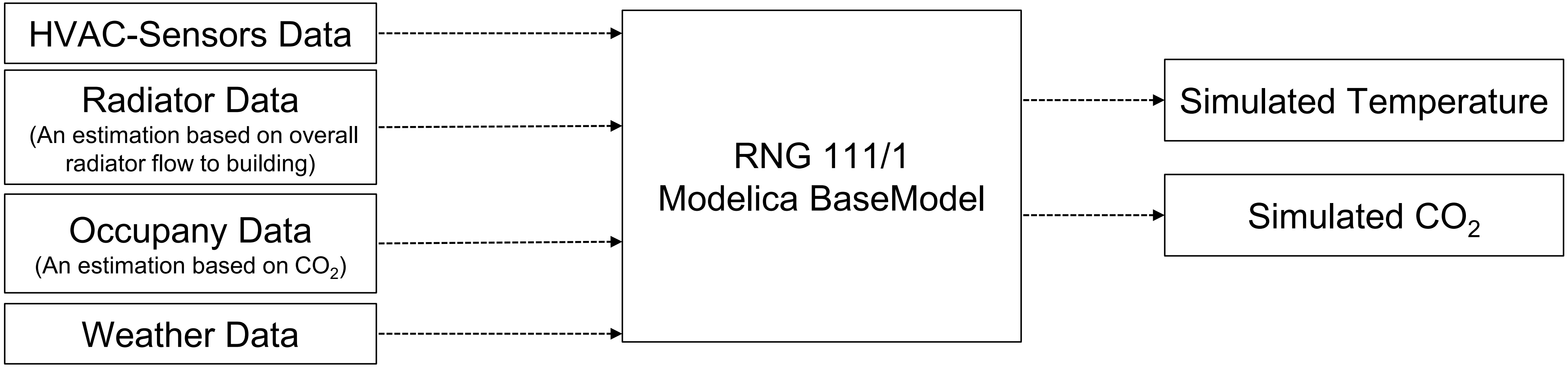
Top view of RNG 111/1



RNG 111/1 Modelica BaseModel

- The model is automatically created using toolchain, with following assumptions:
  - No Infiltration and zonal flow exchange (Constant pressure)
  - Doors are fully closed
  - Exterior shade based on radiation

Model validation: Simulation of generated model

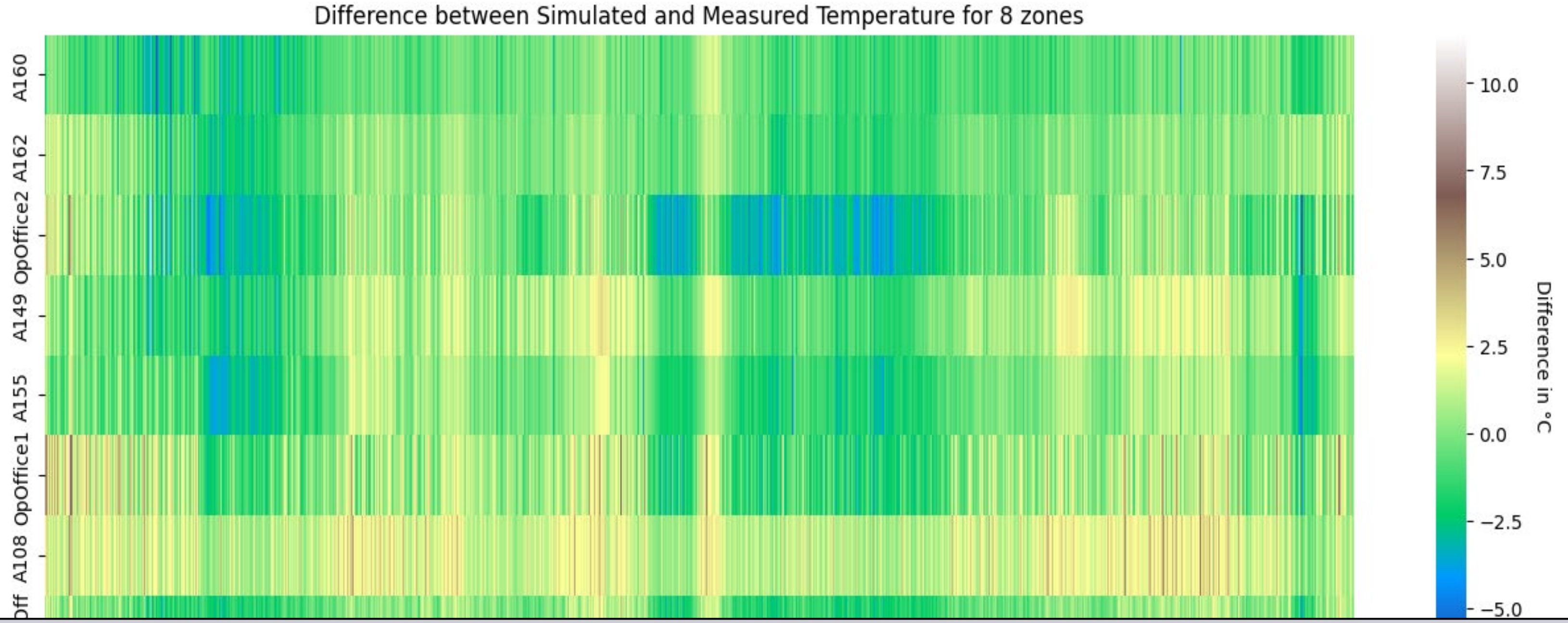


Simulation of 12 zones (RNG 111/1) for 2 years (2022-2023)

- 22k scalar equations
- Simulation time: 4.97e+4 s ≃ 14 h

Preliminary evaluation of temperature

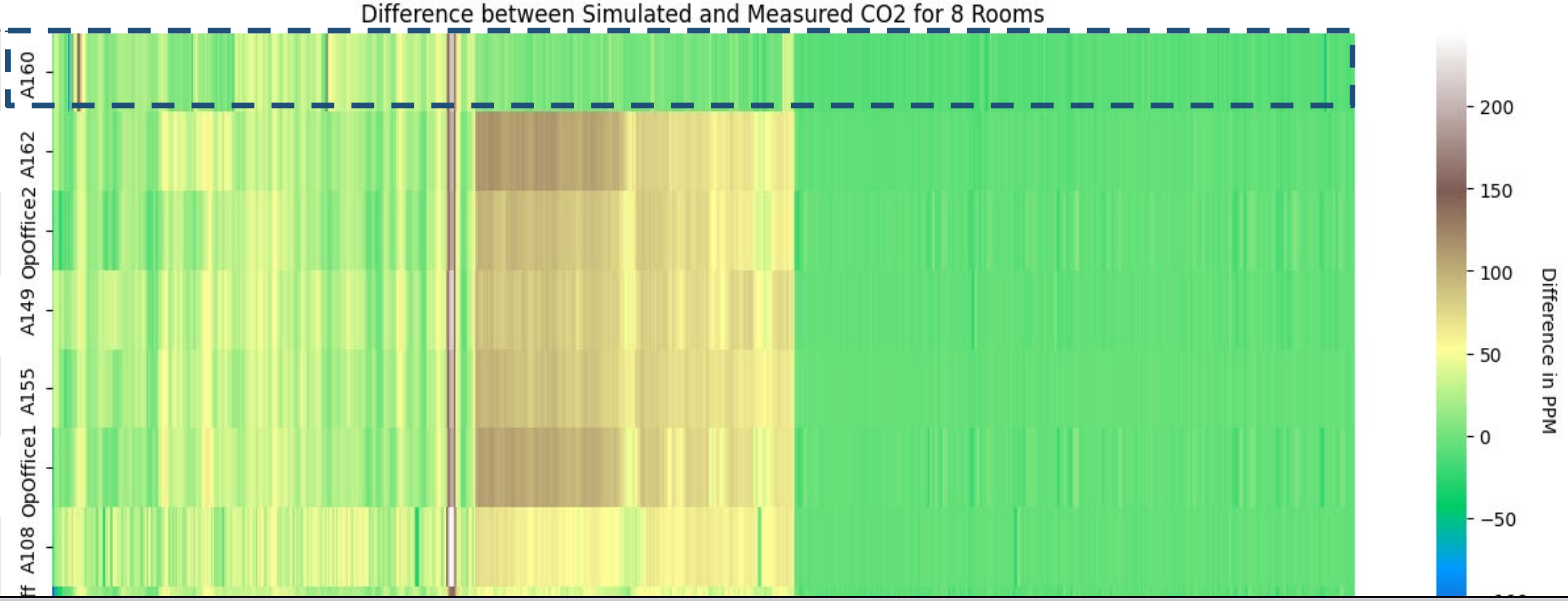
RMSE of A160 = 1.28°C
RMSE of A162 = 1.08°C
RMSE of OpOff 2= 1.98°C
RMSE of A149 = 1.47°C
RMSE of A155 = 1.47°C
RMSE of OpOff 1= 1.86°C
RMSE of A108 = 1.97°C



- Plausible temperature result with all RMSE < 2 °C

Preliminary evaluation of CO_2

RMSE of A160 = 25.0 PPM	
RMSE of A162 = 49 PPM	
RMSE of OpOff 2= 43 PPM	
RMSE of A149 = 45 PPM	
RMSE of A155 = 44 PPM	
RMSE of OpOff 1= 47 PPM	
RMSE of A108 = 40 PPM	



- Plausible CO_2 result with RMSE = 25 PPM for A160
- CO_2 sensor calibration

Conclusion and outlook

Conclusion

- RDF-based data exchange streamlines BPS models for the operation stage
- Development of Modelica templates for multi-zone model
- Plausible simulation results of temperature and CO_2 prediction

Outlook

- Further validation and calibration of the generated models
- Using the generated model for designing optimal controllers
- Templates development e.g. Air Handling Unit (AHU)

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Thank you for your kind attention

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