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Prototyping the DOPTEST Framework for Simulation-Based Testing of System Integration Strategies in Districts

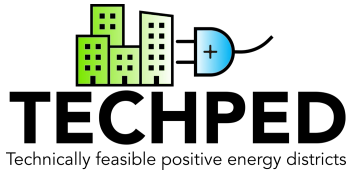
IBPSA Project 2: BOPTEST Expert Meeting

October 12th, 2023

Javier Arroyo

Outline

- Motivation
- The DOPTEST framework
- Relation to the TECHPED project
- A simulation example
- Conclusion
- Outlook



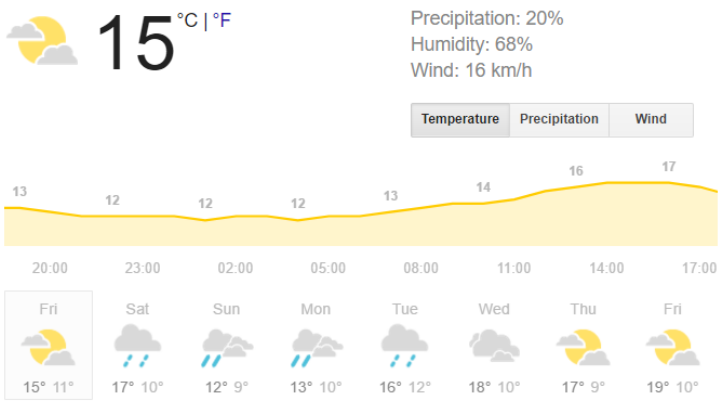
Motivation

Motivation

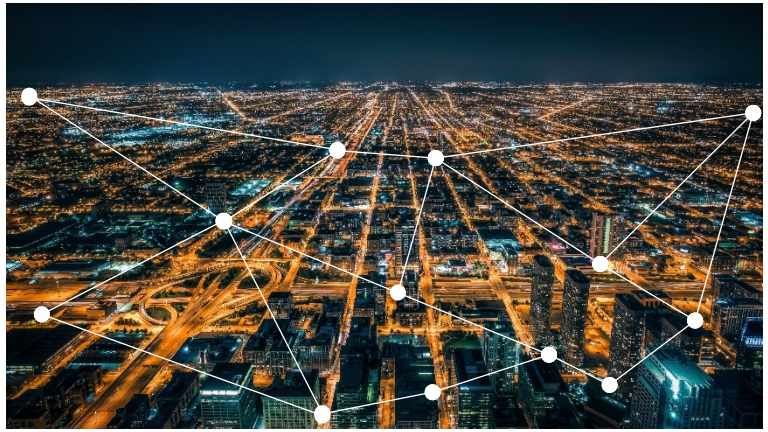
- Let's be **predictive**
  - To enhance energy efficiency in buildings
- Let's get **connected**
  - To enable demand response in buildings

⇒ Optimal predictive control

⇒ System integration in districts: Positive Energy Districts (PEDs)



Google weather forecast



http://www.justinbrownphotography.com/

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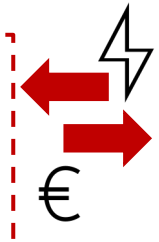
Motivation

System integration deals with:

- Different energy vectors
- Energy agents with competing objectives

*Note!
An energy agent any entity able to exchange energy with its surroundings and that is assigned a bill for the exchange.

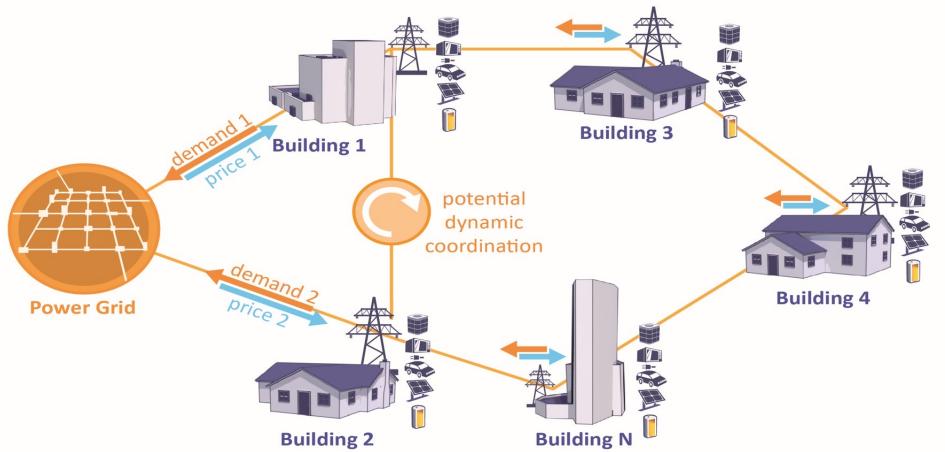


There is no unified framework for evaluating system integration strategies in districts

DOPTEST

DOPTEST – Previous work

CityLearn: OpenAI-Gym simulation-based framework for testing RL algorithms for DR at an urban scale

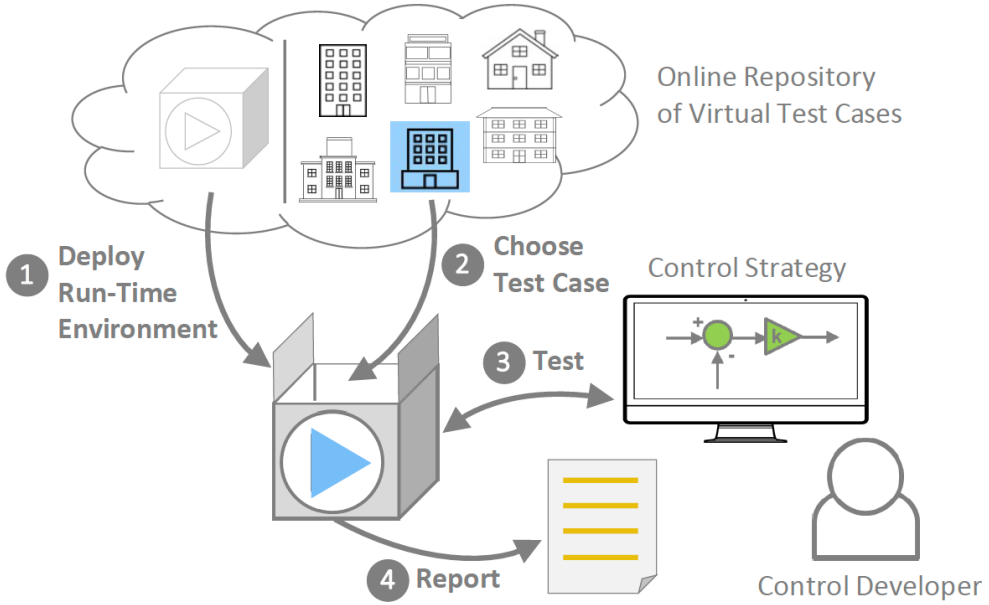


https://www.citylearn.net/

- ✓ District simulation and benchmarking
- ✓ Gym interface
- ✓ Established contest
- ✗ Not detailed emulators
- ✗ Not generic interface
- ✗ Linear electricity price model

DOPTEST

BOPTEST = Building optimization testing framework



D. Blum et al. Journal of Building Performance Simulation, 14(5), 586-610

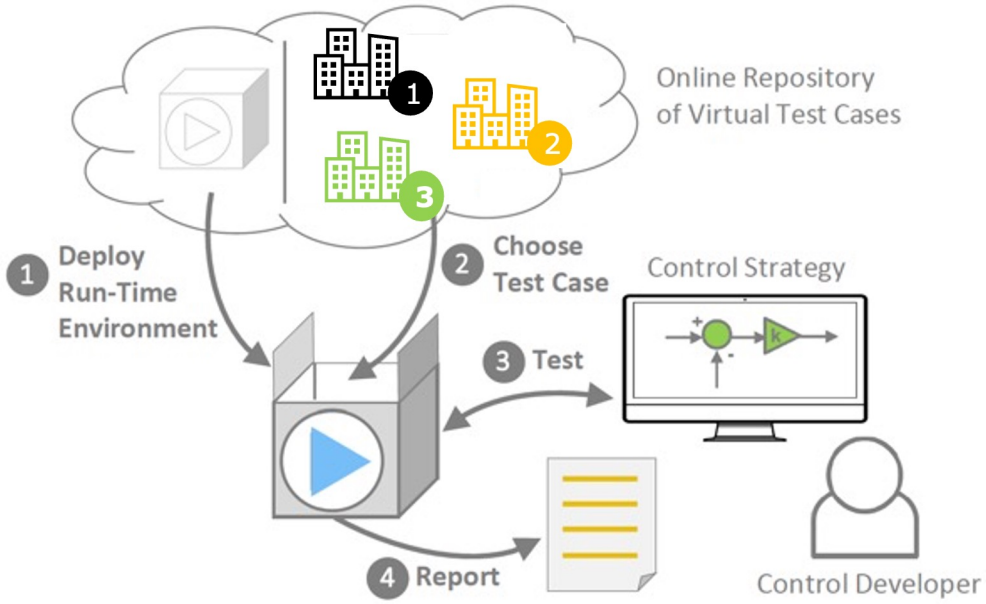
Main stakeholders :

- Building owners
- Facility managers

https://github.com/ibpsa/project1-boptest

DOPTEST

From BOPTEST to → DOPTEST = District optimization testing framework

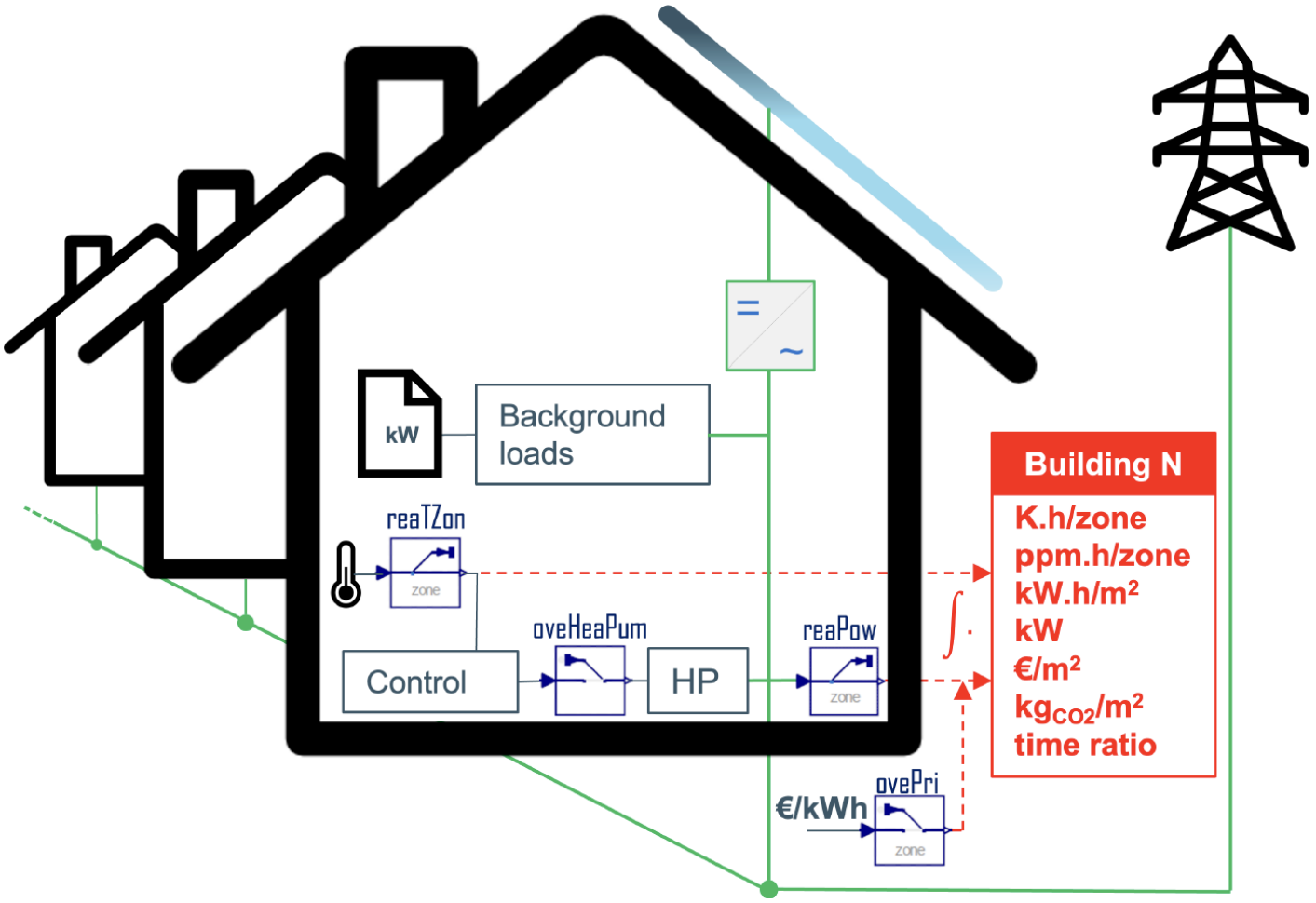


Main stakeholders :

- Aggregators
- Grid operators

Modified from D. Blum et al. Journal of Building Performance Simulation, 14(5), 586-610

DOPTEST



- **Goal**: Evaluation and benchmarking of system integration strategies in districts through simulation
- **Requirements**:

1. Widely used technologies & RWs
2. Substations to wider grids
3. Coherent weather & emissions & pricing
4. Testing scenarios & KPIs
5. Control & pricing signals
6. Price maker (inside) vs. Price taker (outside)

DOPTEST

- Overview of selected core Key Performance Indicators (KPIs):

We want to obtain the least possible …

Thermal discomfort

Indoor air quality discomfort

While minimizing …

Energy use

Peak power

CO_2 emissions

Operational cost

And keeping an eye on …

Computational time ratio

-- Profit --

$$\kappa_{prof} = \frac{\frac{\sum_{a \in \boldsymbol{\mathcal{A}}} \sum_{v \in \boldsymbol{\mathcal{V}}_a} \int_{t_s}^{t_f} \lambda'_{av}(t) P_{av}(t) dt}{A} - \kappa_{cost}}{\kappa_{cost}} \cdot 100$$

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The TECHPED Project

TECHPED
Technically feasible positive energy districts

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TECHPED Project

- **TECHPED** = Technically feasible positive energy districts
- A fundamental research project managed by KU Leuven and EnergyVille
- Runs for 4 years (Oct 2021 – Oct 2025)
- Project proposal, in a nutshell:

How to develop scientifically-backed and technically feasible "Positive Energy Districts" within cities?

TECHPED
Technically feasible positive energy districts

TECHPED Project

Prof. Johan Driessen
Electrical systems

Prof. Lieve Helsen
Thermal systems

Prof. Geert Deconinck
Smart grids

Prof. Erik Delarue
Energy markets

Javier Arroyo
Advanced building control

Lucas Verleyen
Positive energy districts

Cas Bex
Smart grids

Yucun Lu
Energy markets

Joris Deportere
Data science and AI

Louis Hermans
Multi-energy vector districts

Muhammad Hafeez Saeed
Control expert

Attila Bálint
Data science and information technology

TECHPED
Technically feasible positive energy districts

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TECHPED Project – District layouts

Technology	Acronym
Electric Boiler	EBoi
Gas Boiler	GBoi
Air-source heat pump (air-to-water HP)	ASHP
Ground-source heat pump (water-to-water HP)	GSHP
Air-to-air HP	AAHP
Floor heating	FH
Thermal energy storage	TES
Seasonal thermal energy storage	STES
Solar thermal collectors	STC
Solar photovoltaic panels	PV
Battery Energy Storage	BES
Electric Vehicle	EV

Table 1 - Selection of technologies and associated acronyms.

Other specifications	Acronym
Layout	L
Individual component	I
Collective component	C

Table 2 - Other specifications and their acronyms.

		Individual technologies only								Individual or collective technologies				Internal electricity market	Internal thermal network
		AAHP	FH	GBoi	TES	EV	PV	EBoi	ASHP	GSHP	STC	STES	BES		
Base cases	L1	I	I	I										No	No
	L2	I	I	I	I						I			No	No
Study individual electrific.	L3	I	I		I	I	I	I			I		I	No	No
	L4	I	I		I	I	I		I		I		I	No	No
	L5	I	I		I	I	I			I	I		I	No	No
Study internal market	L6	I	I		I	I	I	I			I		I	Yes	No
	L7	I	I		I	I	I		I		I		I	Yes	No
	L8	I	I		I	I	I			I	I		I	Yes	No
Study collective electrical resources	L9	I	I		I	I	I	I			I		C	Yes	No
	L10	I	I		I	I	I		I		I		C	Yes	No
	L11	I	I		I	I	I			I	I		C	Yes	No
Study collective thermal resources	L12	I	I		I	I	I			C	I		C	Yes	Yes
	L13	I	I		I	I	I			C	C		C	Yes	Yes
	L14	I	I		I	I	I			C	C	C	C	Yes	Yes

Table 3 - Inspiring system layouts of the tiny cluster. The columns are the technologies and the rows the selected layouts. An empty cell indicates that the technology is not present in the layout. Other possible elements in the cell are technologies that can be either individual (I) or collective (C). The shaded elements indicate the technology introduced/changed with respect to previous layouts.

TECHPED Project - MoPED library

- **MoPED** = Models of positive energy districts
- We **INTEGRATE** component models for **dynamic district energy simulations**
- We are users of:
  - OpenModelica v1.21.0
  - Buildings v9.1.1
  - IDEAS v3.0.0

TECHPED
Technically feasible positive energy districts

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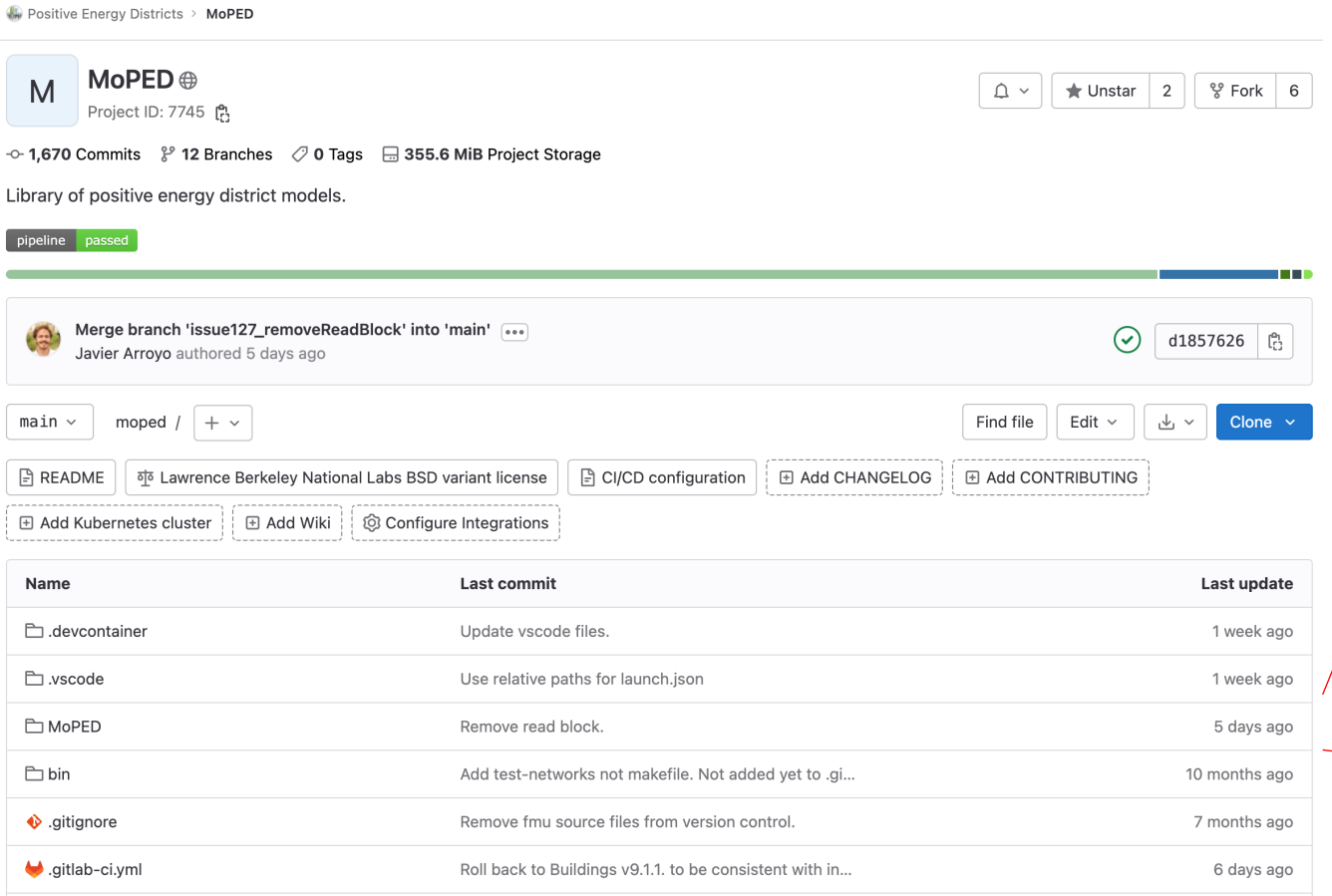
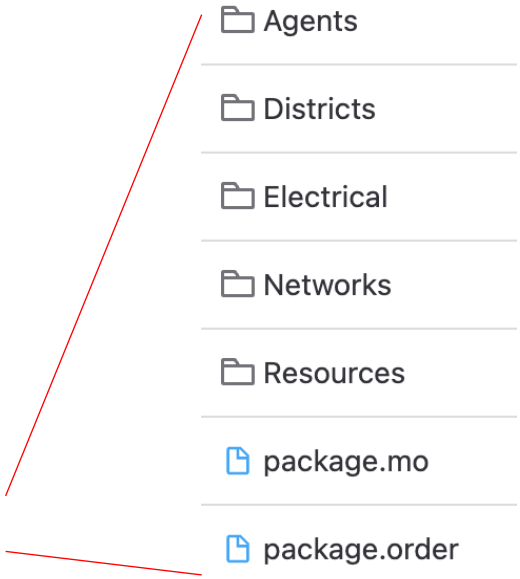
TECHPED Project - MoPED library

https://gitlab.kuleuven.be/positive-energy-districts/moped

BSD





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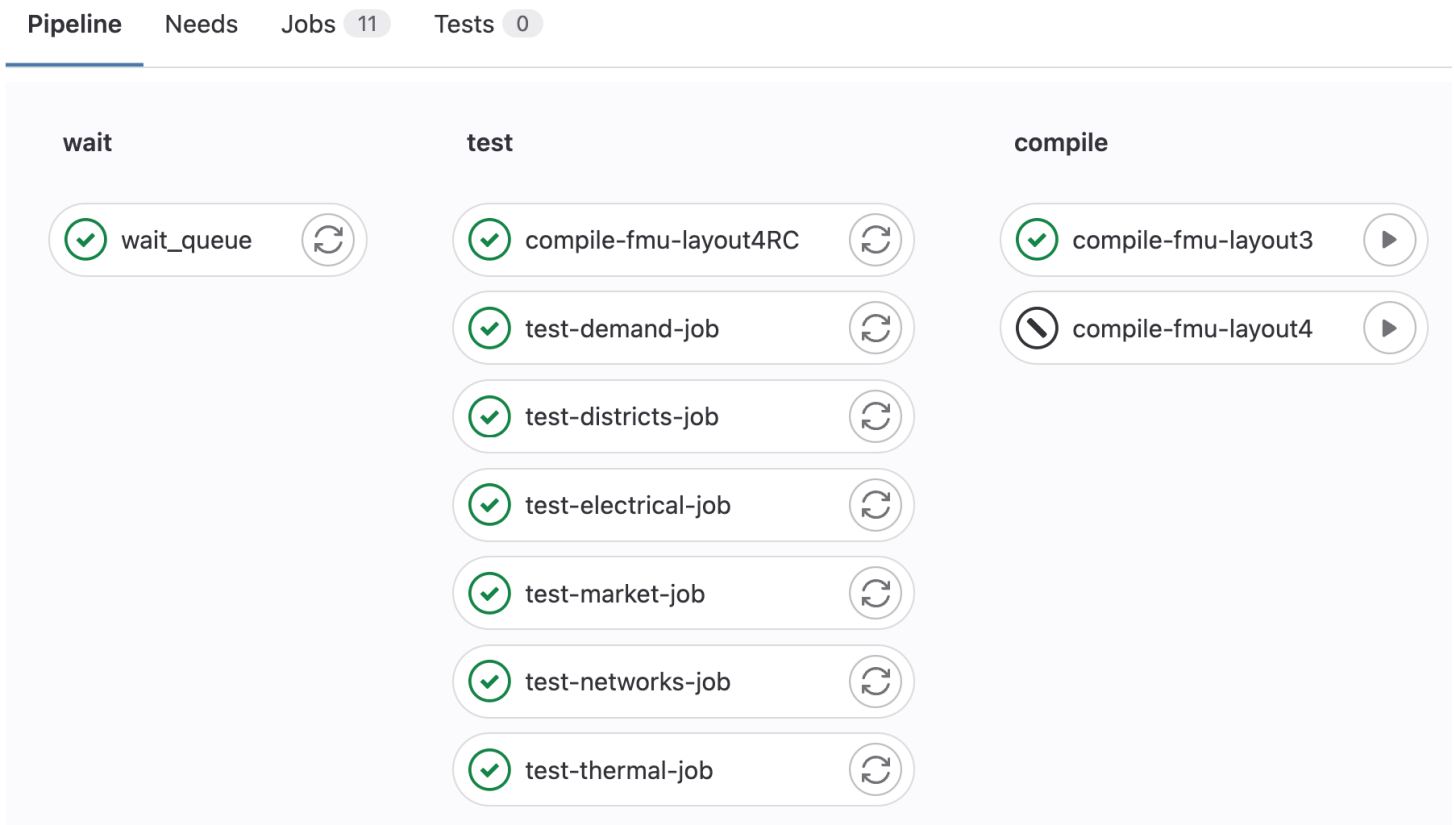
TECHPED Project – The “DOPTEST factory”

https://gitlab.kuleuven.be/positive-energy-districts/moped



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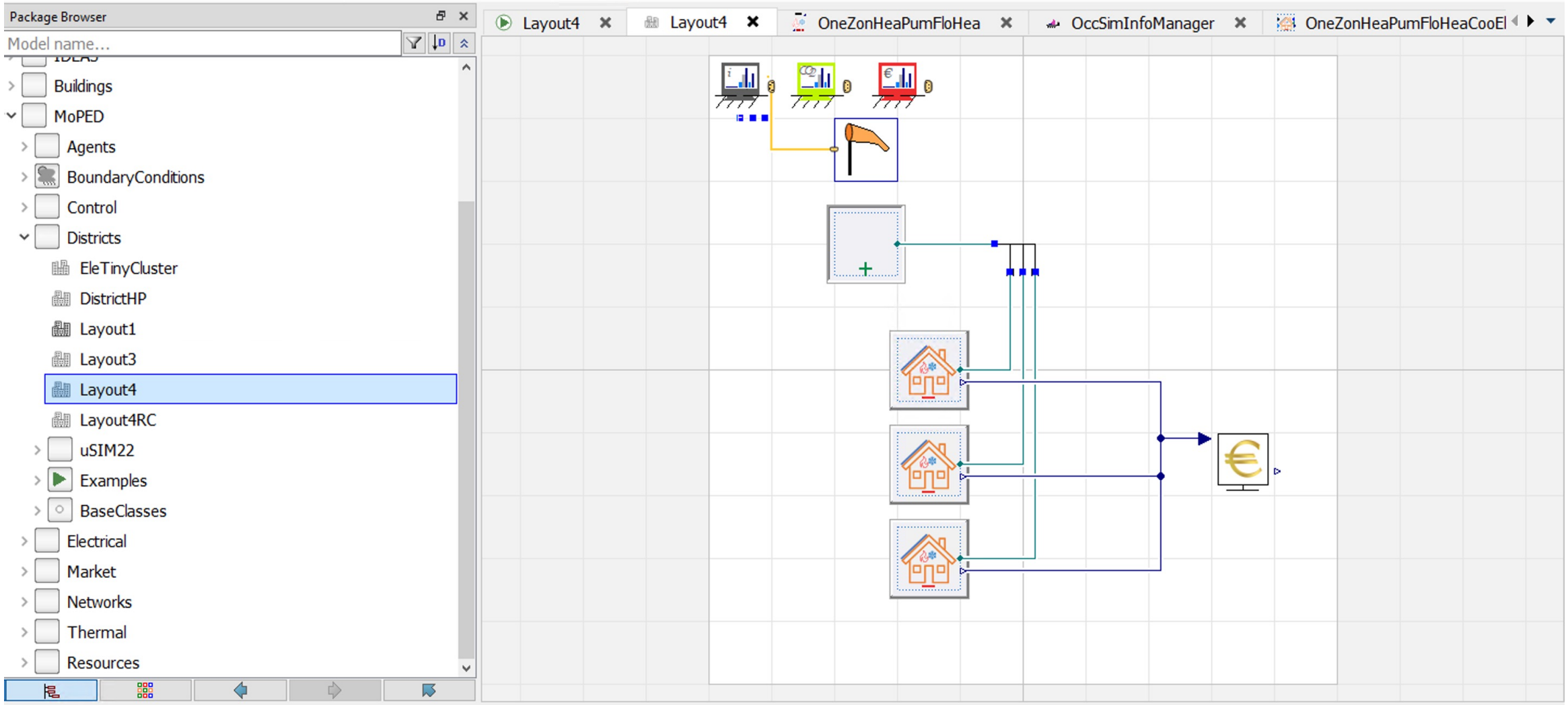
TECHPED Project - MoPED library



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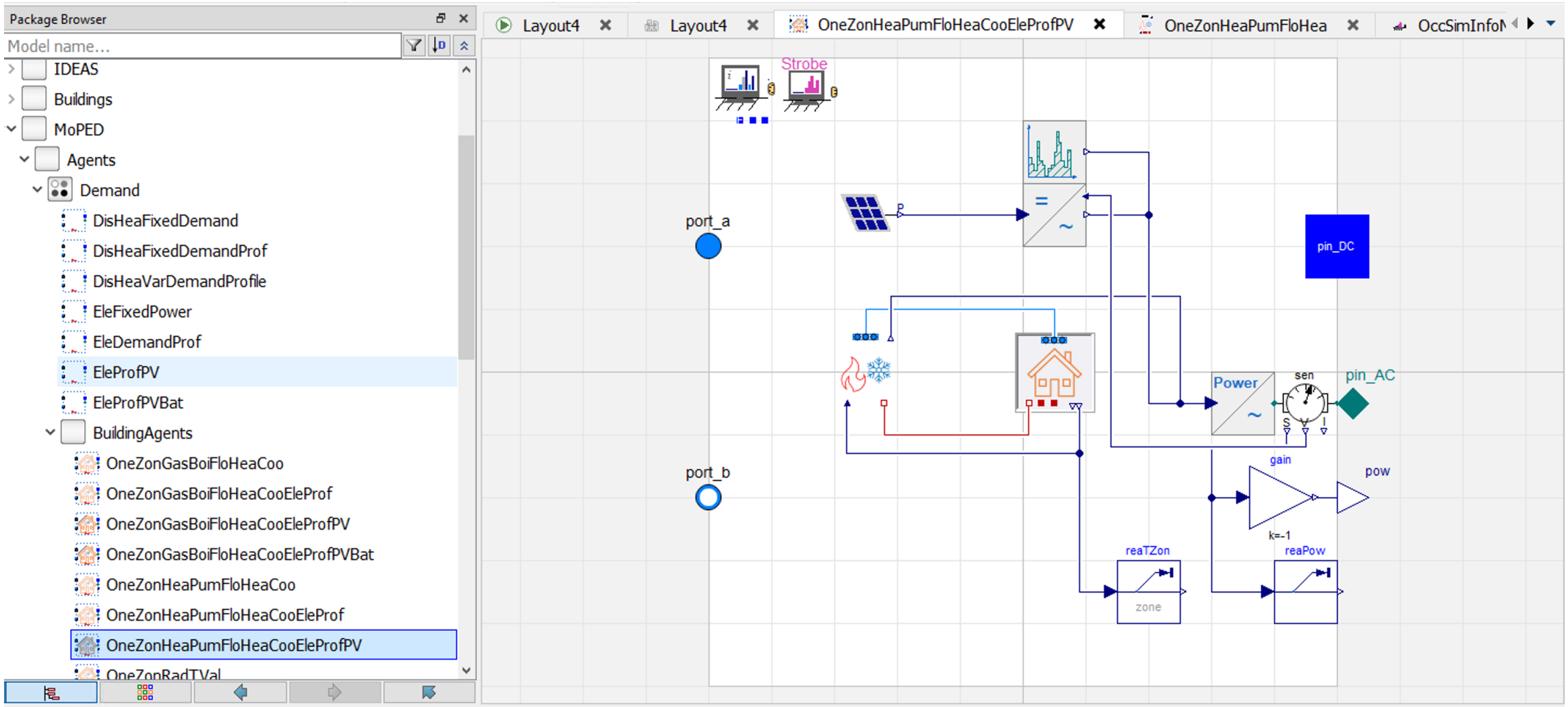
TECHPED Project - MoPED library



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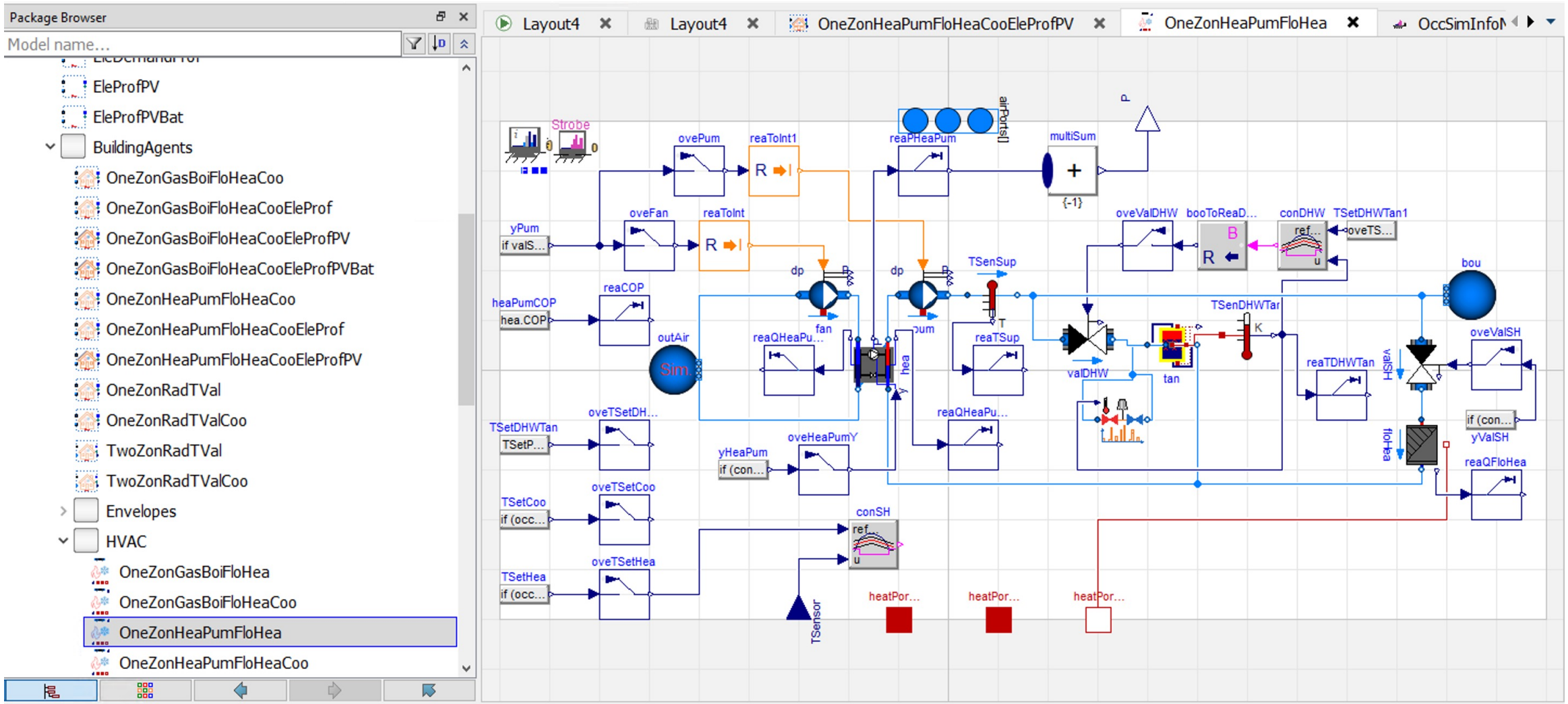
TECHPED Project - MoPED library



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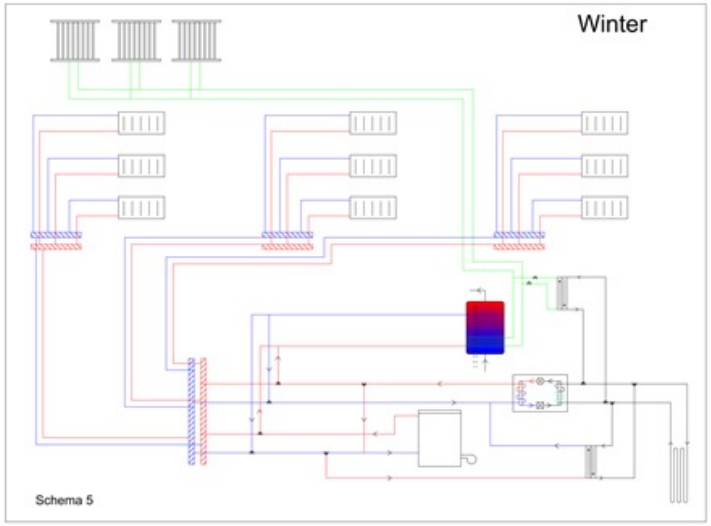
A simulation example

A simulation example

The tiny cluster use case: preliminary idea was launched and pre-explored in combined student master thesis work of Ghent University and KU Leuven in 2020-2021-2022*



* Gommers & Meessens & Van Regenmortel, supervised by prof Boydens & Helsen

A simulation example

The tiny cluster use case: simulation example with baseline control

	House 1 (small)	House 2 (medium)	House 3 (large)
Length $[m]$ Width $[m]$ Height $[m]$	10 10 2.8	8 8 5.6	10 10 5.6
Windows (N-E-S-W*) $[m^2]$	3 - 3 - 3 - 5	4 - 6 - 8 - 6	6 - 10 - 10 - 10
Occupancy ****	FTE+PTE	FTE+PTE+SCH	FTE+PTE+SCH+SCH
Installed heating** - cooling*** power $[kW]$	3 - 1	4 - 1.5	6 - 3.5
PV installation $[kW]$	3.7, W	5.2, S	6.6, S

*N = north, E = east, S = south, W = west

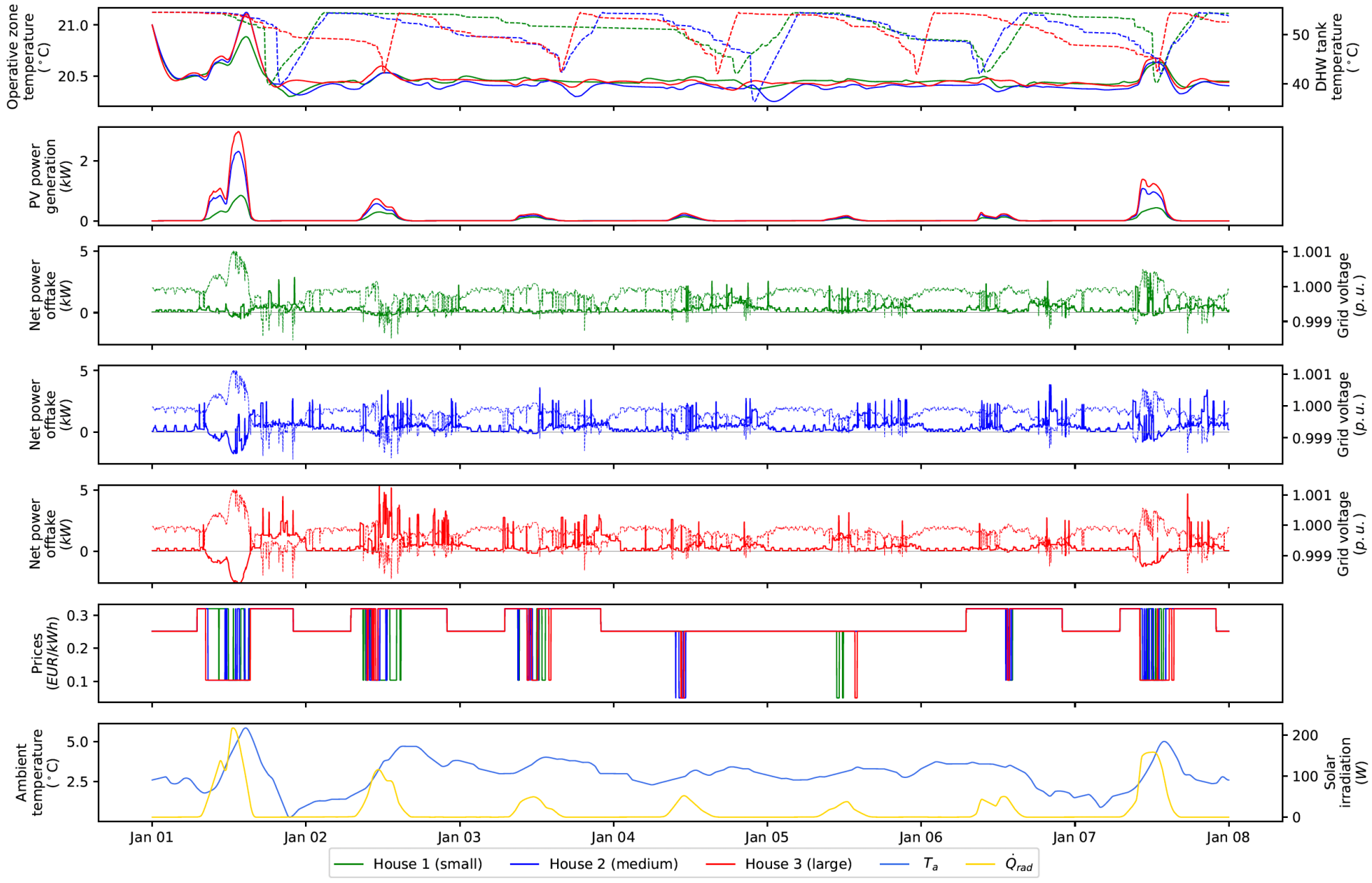
**Gas boiler, ***Air-to-air heat pump

**** FTE = Full-Time Equivalent, PTE = Part-Time Equivalent, SCH = Schoolgoing child

	Peak	Off-peak
Offtake price (c€/kWh)	31.96	25.12
Injection price (c€/kWh)	10.35	5.00

A simulation example

```
KPI RESULTS
-----------
cost_tot: 0.13555299559622944 Euro or \$/m$^2$
emis_tot: 0.4927021096008929 KgCO2/m$^2$
ener_tot: 2.7209278776353214 kWh/m$^2$
idis_tot: 0.0 ppmh/zone
pdih_tot: None kW/m$^2$
pele_tot: 1.4220232168463612e-05 kW/m$^2$
pgas_tot: 0.030373827421699817 kW/m$^2$
tdis_tot: 0.08729019482141889 Kh/zone
time_rat: nan s/s
```



Conclusion

Conclusion

- It is needed a unified framework for testing system integration strategies in districts.
- This work settles the design requirements of DOPTEST.
- A simulation example shows a proof-of-concept of the framework.
- Further work includes the calculation of new district-related KPIs and the implementation of larger clusters

Outlook

Outlook

- Overwrite building and district actuators/setpoints
- Implement price-reactive building agents and **overwrite pricing!**
- Implement district KPIs → Needs:
  - To distinguish between agents (which may have zones)
  - New enumeration entries in read blocks for KPI calculation
- Coordinate with BOPTEST overhaul
  - Same repo **vs.** Fork **vs.** Separate repo
  - Conflicts?

Thank you!

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