HUES: A holistic urban energy simulation platform for effective model integration

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Decentralized urban multi-energy systems (energy hubs)

- Buildings and other sources of energy demand
- Generators of heat and electricity
- Energy storage technologies
- Networks (electricity, heat, cooling)
The challenge of complexity

1. Variety of system components
   - Multiple generation & storage technologies
   - Multiple demand sources

2. Numerous interdependencies between components
   - Multiple networks
   - Multiple energy carriers

3. Multiple actors
   - Different demand patterns
   - Different preferences

4. Dynamic context
   - Fluctuating meteorological conditions
   - Changing institutional environment
   - Development of the urban landscape
Approach: Multi-model ecologies

Multi-model ecology: A set of modeling resources that can be configured and reconfigured in different ways to study a system from different perspectives.

As this set of resources grows and develops over time: new possibilities for model interaction emerge, and opportunities for addressing new questions arise.

The HUES platform

- **HUES** = Holistic Urban Energy Simulation platform
- An extendable simulation environment to facilitate the study of decentralized urban multi-energy systems.
Research in the HUES platform – example 1

Optimal energy hub design under uncertainty
Georgios Mavromatidis

- Occupant behavior
- Climate change
- Physical material properties
- Building design parameters
- ...

How can we identify an optimal energy hub design under conditions of uncertainty?

Building energy model
Calculation of building heat and electricity demand

MILP
Operational scheduling of energy production and storage

Genetic algorithm
Optimization of energy hub configuration

Robust energy hub design

Research in the HUES platform – example 2

Holistic optimisation of distributed multi-energy systems for sustainable urban areas
Boran Morvaj

Under what conditions should district-scale energy networks be based on thermal vs. electrical energy transport?

Building energy model
Calculation of building heat and electricity demand

MILP
Operational scheduling of energy production and storage

Genetic algorithm
Optimization of energy hub configuration

Electricity power flow model
Check non-linear power flow constraints

- CHP capacities
- PV capacities
- Storage capacities
- Boiler capacities
How does the size of an urban district influence the optimal sizing of energy hub infrastructure, given patterns of demand variability?

**Stochastic demand module**
Statistical generation of building occupancy profiles

**Building energy model**
Calculation of building heat and electricity demand

**MILP**
Optimization of district heat/electricity storage sizing

District size vs. infrastructure sizing

- Heat demand (kWh/minute per building)
- Heat storage size (kWh per building)
- Solar thermal capacity (kW per building)
- Electric heating capacity (kW per building)
Research in the HUES platform – example 4

Technology database module
L. Andrew Bollinger and Keno Omu

SQL Query

```
SELECT avg(Capital_cost), avg(Total_installation_cost) FROM Technologies WHERE Technology_general_name = "CHP" and Applicable_geographic_area = "Switzerland";
```
The HUES platform

... as a model repository

- Modules should serve as a resource for future research
- Modules should be designed and packaged to be accessible and useful to others.
- Model repository: a platform to enable the sharing of models and facilitate accessibility -> cloud-based code repository
The HUES platform
... as an information sharing system
The HUES platform wiki

Wiki page
Collection

Wiki page
Module

Wiki page
Module

Wiki page
Module

Wiki page
Module

Download URL

Licensing

Author

Files

Documentation

Description
Energy hub batch run with minute resolution

This model is a modified version of the energy hub model developed by Akomeno (2015), modified to operate at one minute resolution and to enable testing of energy hubs with varying numbers of buildings. The model takes the results of a building energy model as input and calculates an optimal operation schedule for energy hubs of different sizes. It is assumed that each building can connect to a centralized heat storage. The aim is to minimize the maintenance + energy given the goal of cutting carbon. Implemented in the optimization package Aimms as a mixed integer programming (MIP) model with a schedule of the energy hub and optimal sizing of the heat pump, investment, maintenance and operational costs of the solar collectors, and their performance. A single minute resolution.

Effects of district size on optimal energy hub configuration considering demand variability

Energy demand may vary significantly between buildings in terms of the magnitude and timing of loads. In the residential sector, this variation is driven by the differing schedules, appliance portfolios, preferences and habits of individuals, as well as the differing physical characteristics of buildings and other factors. When the energy demand of multiple buildings is combined in the context of a district multi-energy system, the energy use patterns of different buildings are aggregated, affecting the sizing and cost of necessary infrastructure. The precise relationship, however, is unclear. This collection is used to address the following question: How does the size of a district energy system - in terms of the number of buildings included - influence the total system costs and the optimal sizing of the infrastructure? To address this question, the collection links three modules of the HUES platform, indicated above:

Authors
Andrew Bollinger

Documentation
Architecture of the HUES platform

- **Semantic wiki**
  - wikibot

- **Module repository**
  - Bitbucket

- **Module**
  - Data
  - Model

- **Module**
  - Data
  - Model

- **Module**
  - Data

- **Module**
  - Data

- **Module**
  - Model
  - Model
  - Model
Use of the HUES platform

1. Navigate the available modules/collections via the wiki
2. Identify and download useful modules
3. Modify the downloaded modules and/or integrate them with his own modules
4. Document and upload the new modules
5. HUES wiki is automatically updated with information about the new modules
Use of the HUES platform

Via this collective process:

• New modules/collections developed
• New combinations of modules emerge
• New research questions addressed
Advantages and key challenges

**Advantages:**
1. Creation of opportunities for model reuse and integration
2. Reduction of wasted model development effort
3. Enhanced ability to address increasingly complex problems

**Key challenges:**
1. Ensuring model validity
2. Proactive identification of module integration opportunities
3. Effective management of data
4. Deployment in planning/design practice
Conclusions

- **Complexity** is a significant challenge in the design of decentralized urban energy systems

- Adequately addressing this complexity requires a **modular, evolutionary** modeling approach -> multi-model ecologies

- The **HUES platform** implements such an approach, serving as both a model repository and an information sharing platform

- Continued development of this platform will facilitate addressing **increasingly difficult and complex problems** in the urban energy domain.

*The HUES platform can be accessed online at [https://hues.empa.ch](https://hues.empa.ch)*
Thank you for your attention

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Module development guidelines

1. **Build simple modules:** Simple modules with a clear purpose and function are preferable to complex modules; complex problems should be addressed via multiple interacting modules.

2. **Separate models and data:** Model input data should be maintained in separate files from the models using that data.

3. **Write comprehensible code:** Use clear variable and object naming conventions, comment extensively and preserve readability.

4. **Document clearly and concisely:** A module should be accompanied by documentation describing the composition and function of the module, how it can be used, the key assumptions underlying it and its scope of validity.

5. **Use open software and open data formats:** Where open software of equivalent quality is available, its use is preferred.
Background

• Sustainable, livable and resilient cities demand methods for studying urban infrastructures as integrated wholes.

• The complexity of these systems limits our ability to effectively study them holistically.

• We need novel modeling & simulation approaches.
The challenge of complexity

1. Variety of system components
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   • Multiple demand sources

2. Numerous interdependencies between components
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How can we capture the relevant aspects of this complexity in our models?
Approaches to dealing with complexity

1. **Integral modeling**: single, monolithic model

2. **Integrated modeling**: multiple, integrated models
   - Cosimulation
   - Multisimulation
   - Middleware

Challenge: Model systems evolve

But, we can also leverage the evolution of model systems to improve our ability to study complex systems.
The HUES platform

- Building occupancy model
- Statistical emulator
- Controller models
- Building data
- Solar radiation data
- Climate data
- Optimisation suite
- Energy system models
- Conversion / storage models
- Hydraulics model

Building energy models
Technology cost & performance data
Network models
Use of the HUES platform

Navigate the available modules/collections via the wiki

Identify and download useful modules

Modify the downloaded modules and/or integrate them with his own modules

Document and upload the new modules

HUES wiki is automatically updated with information about the new modules
Use of the HUES platform

Via this collective process:

• New modules/collections developed
• New combinations of modules emerge
• New research questions addressed

1. Navigate the available modules/collections via the wiki
2. Identify, understand and download useful modules
3. Modify the downloaded modules and/or integrate them with his own modules
4. Document and upload the modified and new modules
5. HUES wiki is automatically updated with information about the new modules
Use of the HUES platform

1. IDENTIFY useful modules/collections via the wiki
2. DOWNLOAD & INSTALL modules from the module repository
3. UNDERSTAND and explore the downloaded modules
4. DEVELOP, VALIDATE & EXPERIMENT to generate new research findings
5. UPLOAD newly developed modules to the repository, including documentation
Use of the HUES platform

Via this collective process:

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