Modeling Coupled Urban Systems: Opportunities and Challenges

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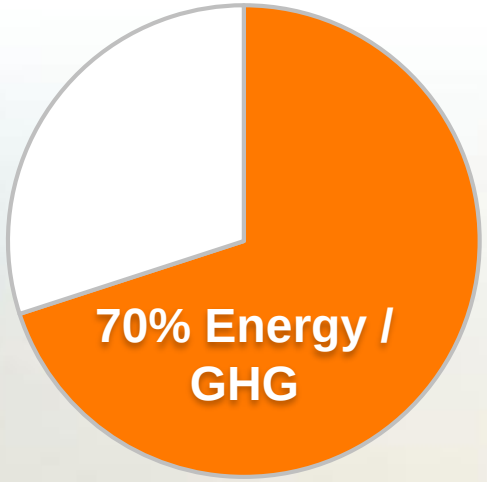
Energy ADE Workshop

TU Delft

December 6, 2018

Transforming Cities

Cities drive our economy and dominate energy and environmental challenges

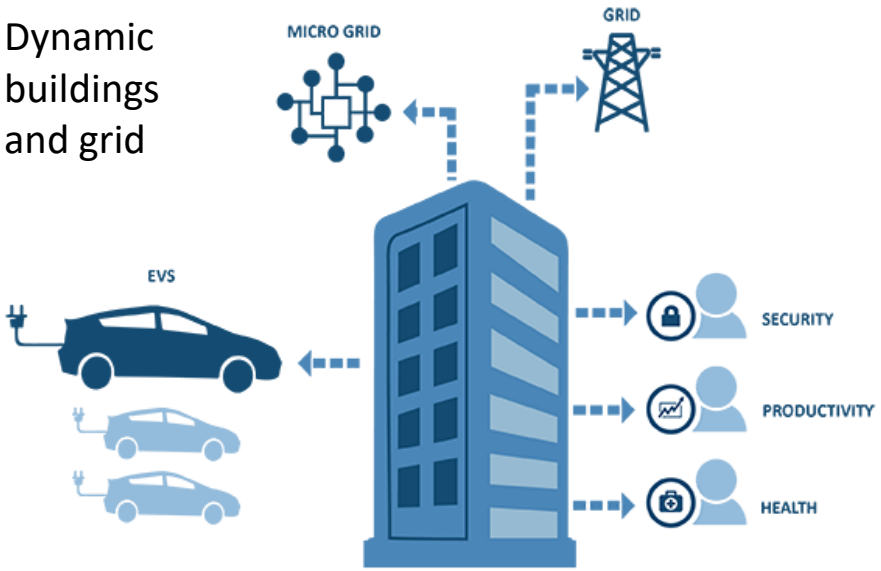


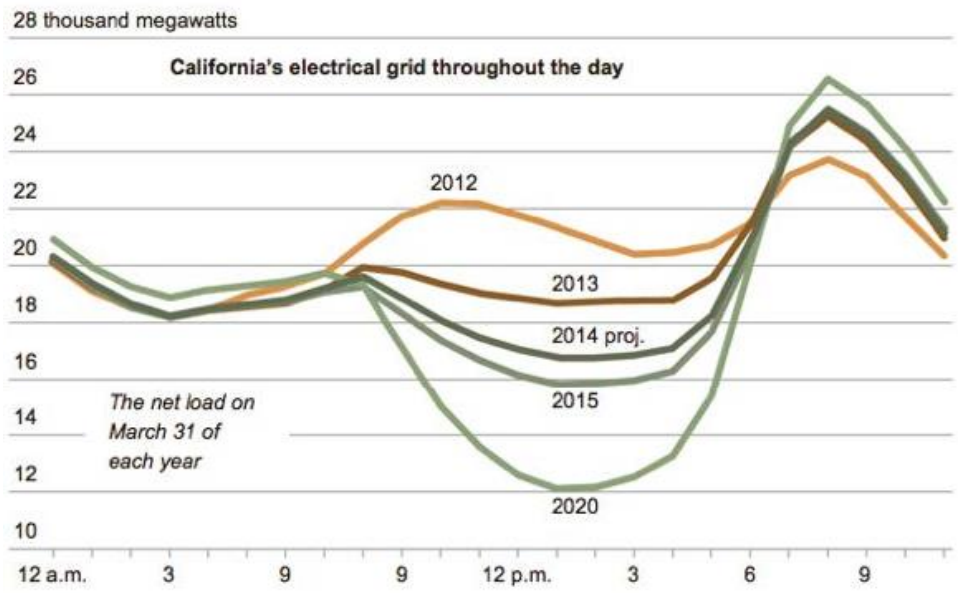
Imagine a City…

…that consumes 50% less total energy per person while improving economic vitality and quality of life and increasing resilience and sustainability

Research Context

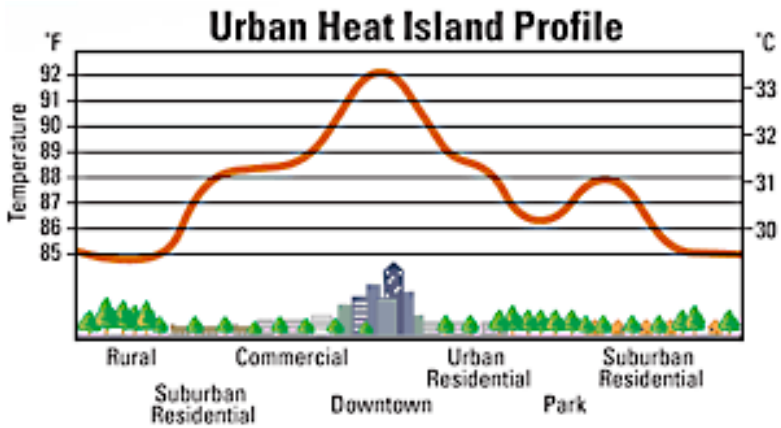
Dynamic buildings and grid



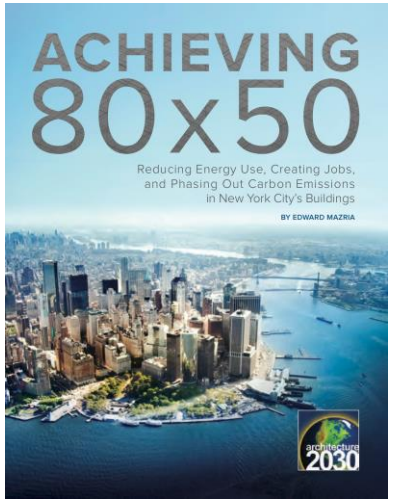


Source: CalISO

Changing urban climate



Need for city-scale and deep savings



Challenges

Urban systems are system of systems with complex interactions: human + urban climate + urban infrastructure + IoT/IcT technologies (sensing and data)

- Individual models exist with diverse computational requirements, but are not integrated with expanding new sources of data and are rarely coupled into multi-system simulations
- Silo single-sector solutions are not optimal and lead to problems (e.g., energy, environment, traffic)
- The complex interdependencies are difficult to quantify

Challenges in Big Data and Computing

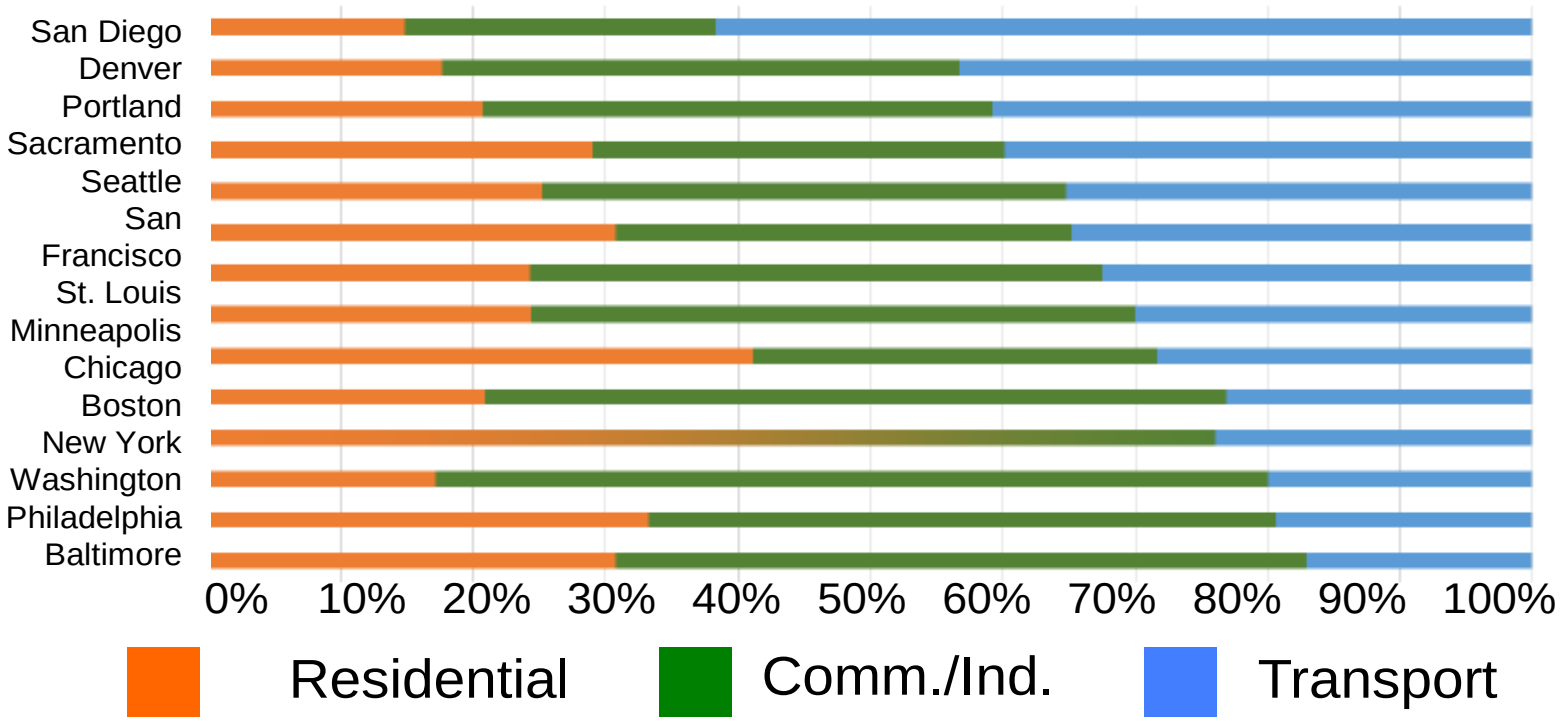
- Data: A big data problem integrating diverse sources with different temporal and spatial resolutions, quality, and structure/format.
- Modeling: Integration of multiple domain models with different scales and resolutions, using open standards
- Simulation: An exascale computing problem - 10^6 bldgs, 10^6-10^7 people, 10^6 vehicles, 10^{6-8} sensors and devices.

Opportunities

- IoT and IcT technologies enable city-scale sensing and data collection
- AI/ML enable big data analytics
- Supercomputing infrastructure becomes affordable
- Use holistic integrative system approaches to help us:
  - Gain deep understanding of urban systems dynamics and interactions
  - Quantify interdependencies
  - Provide insights to inform city decision making on sustainability, efficiency and resiliency

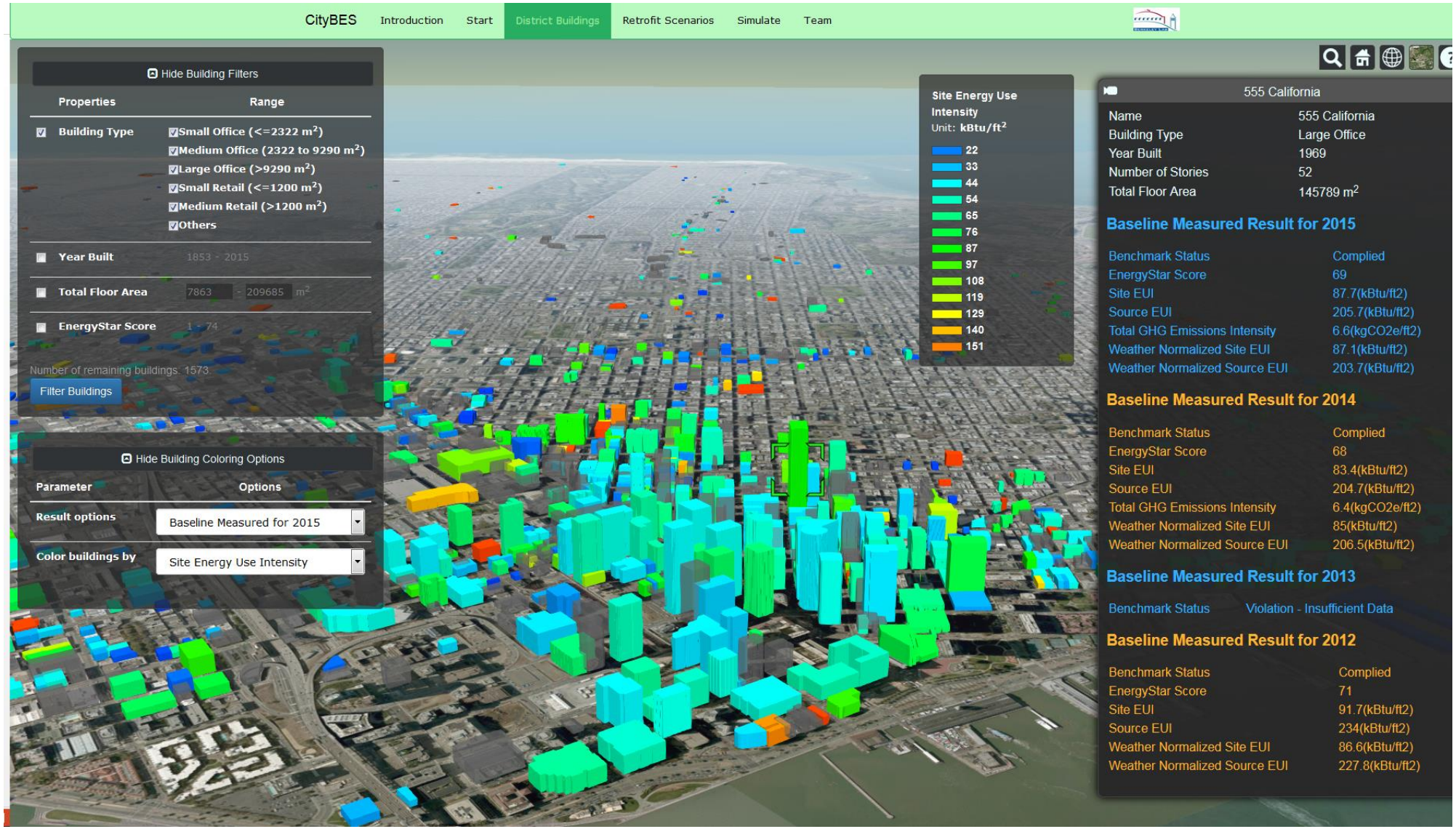
How to reduce 50% energy use in city building stock?

- Buildings in cities consume 30-70% of the primary energy
- Cities have different building energy use profiles
- The building sector has the most potential to save energy

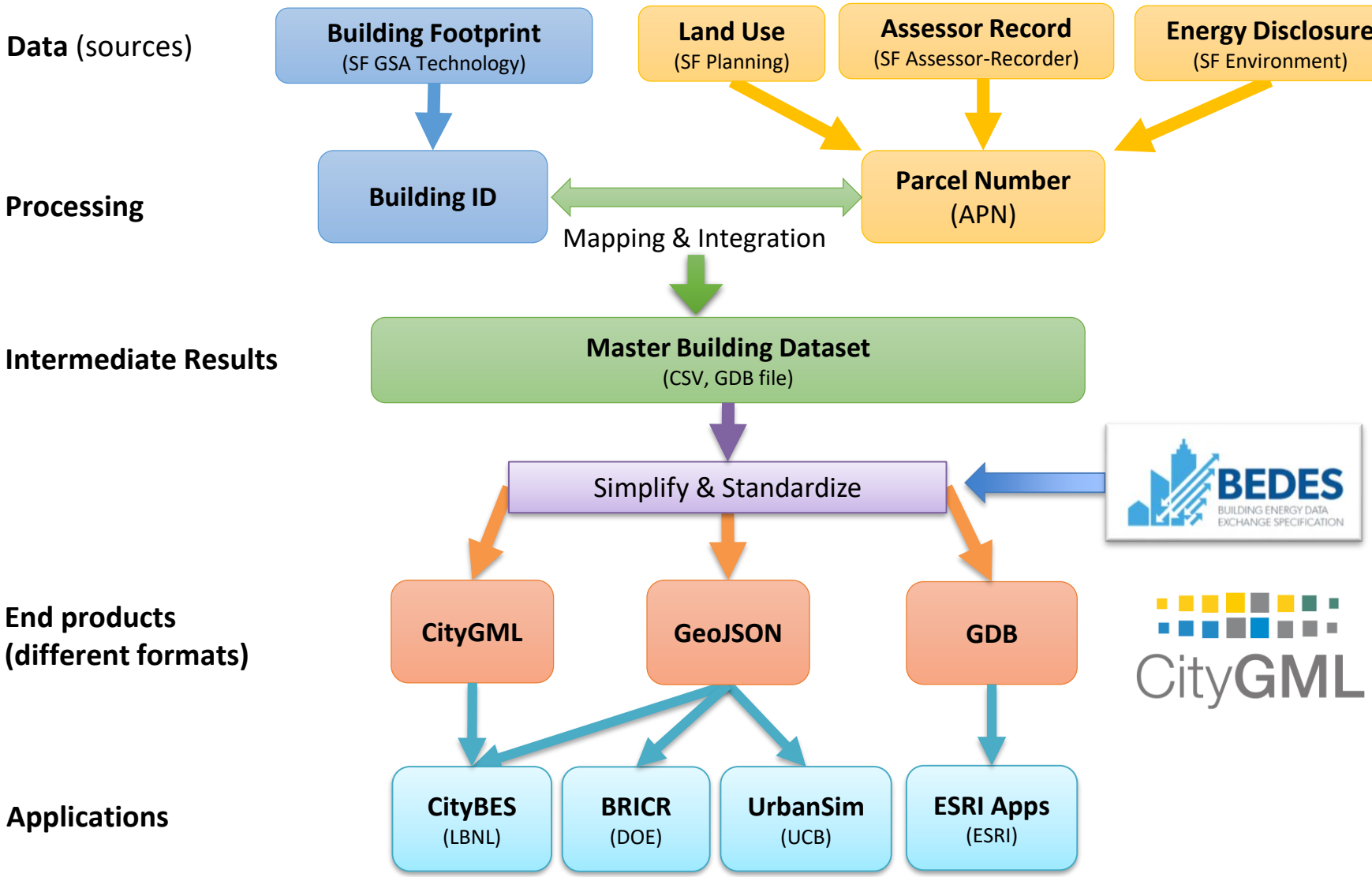


City Energy Profiles

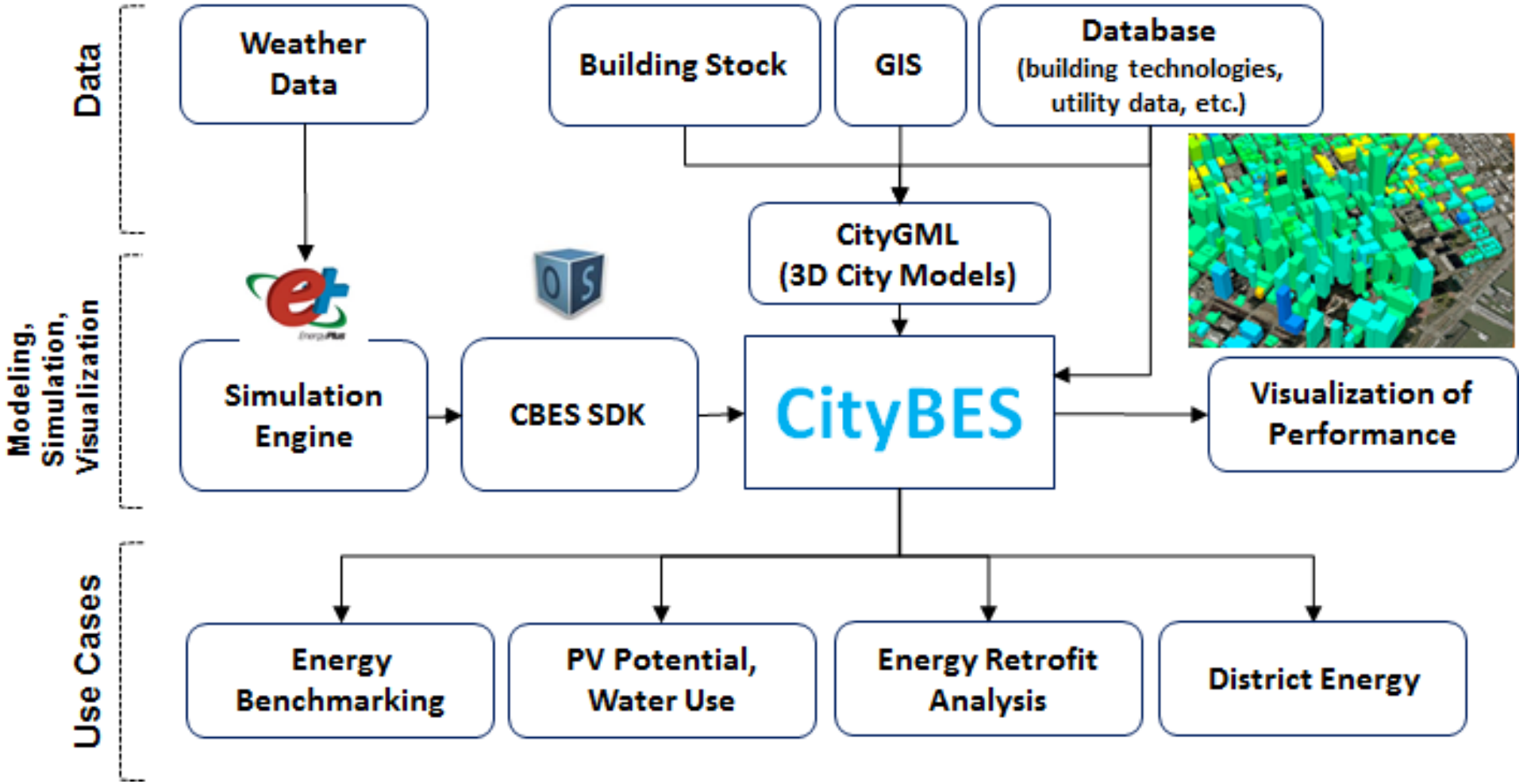
CityBES.LBL.gov



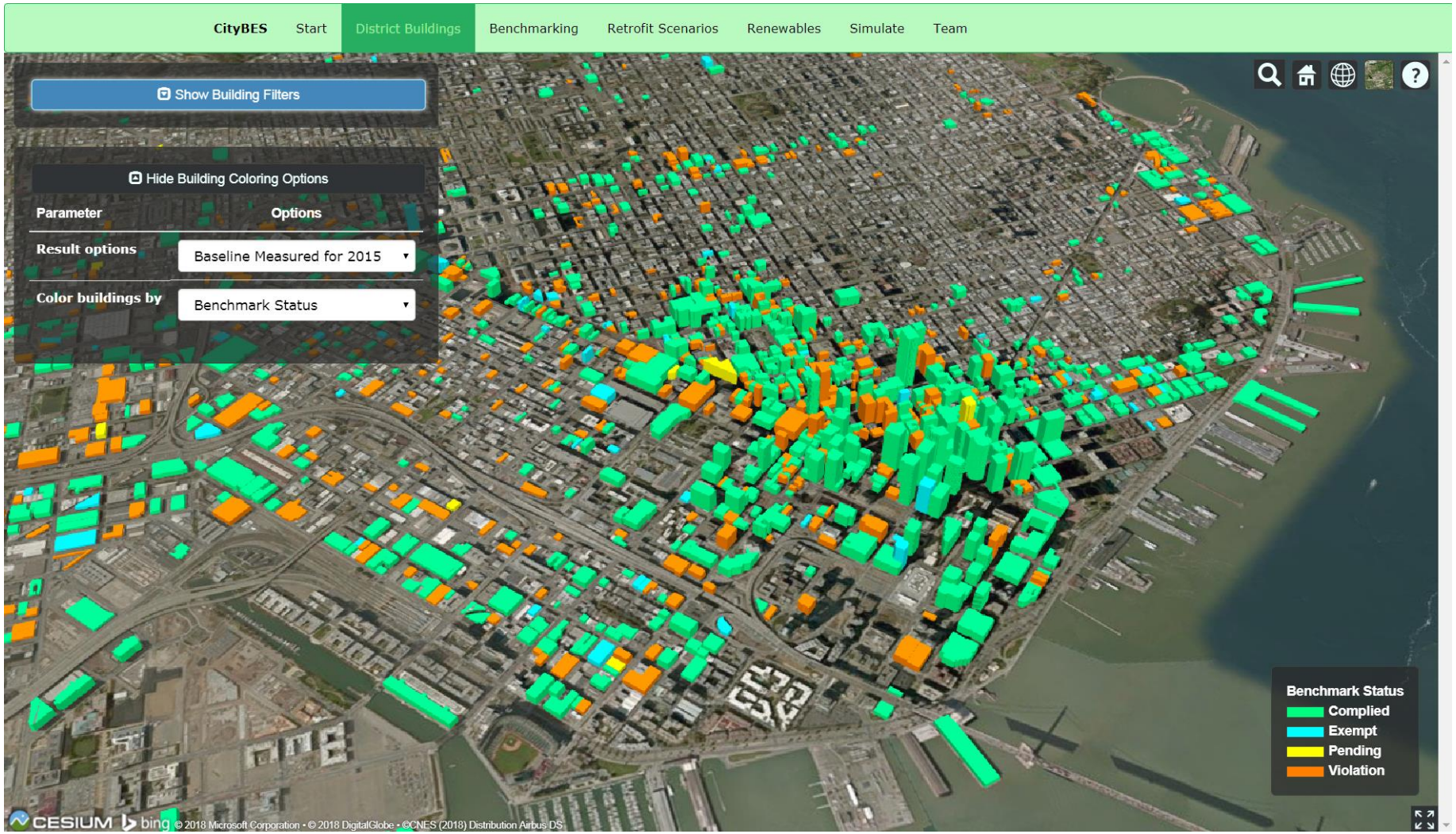
Integrating City Data in Open Standards



CityBES Architecture and Use Cases

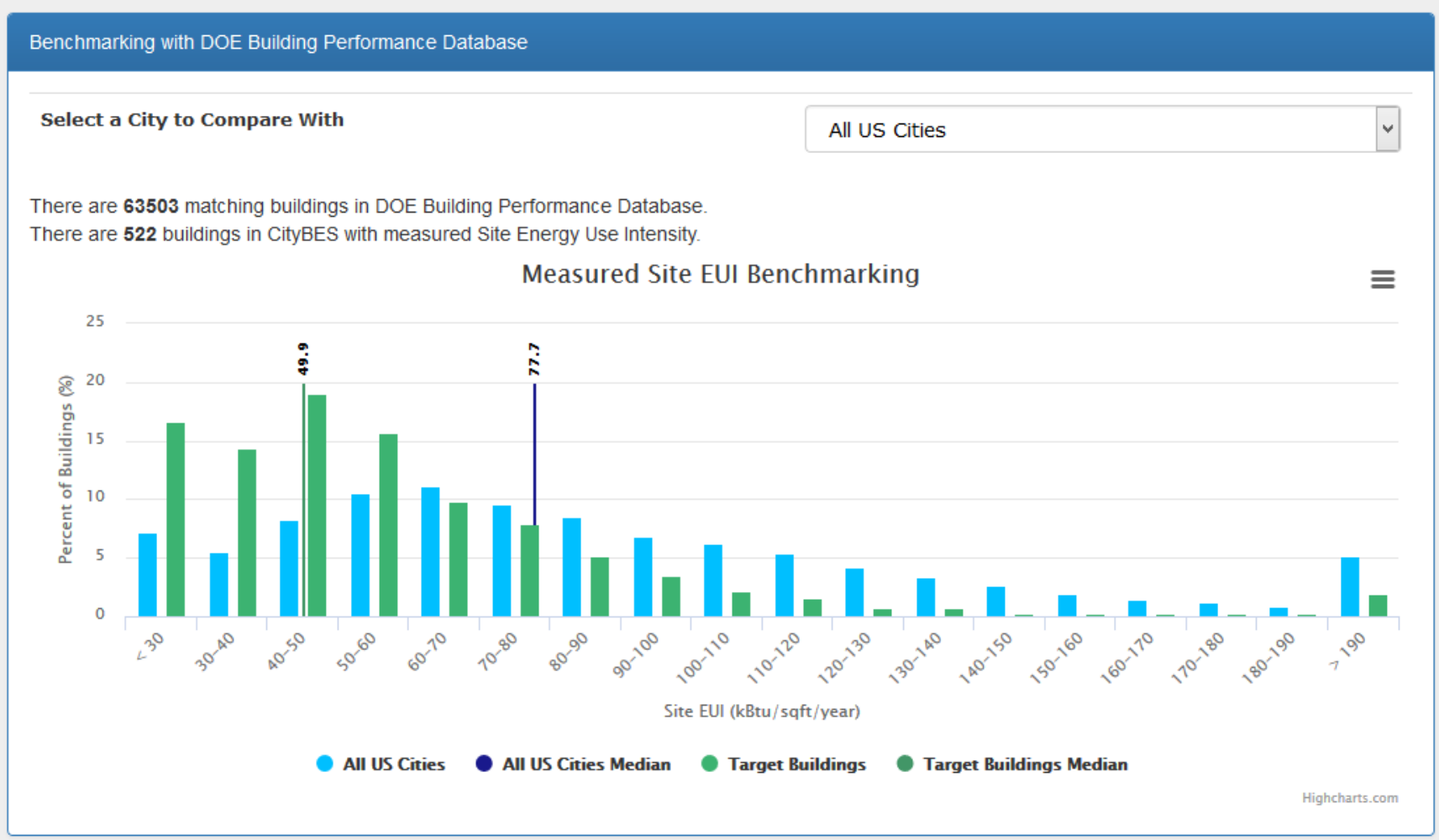


Visualize Building Energy from City Ordinance



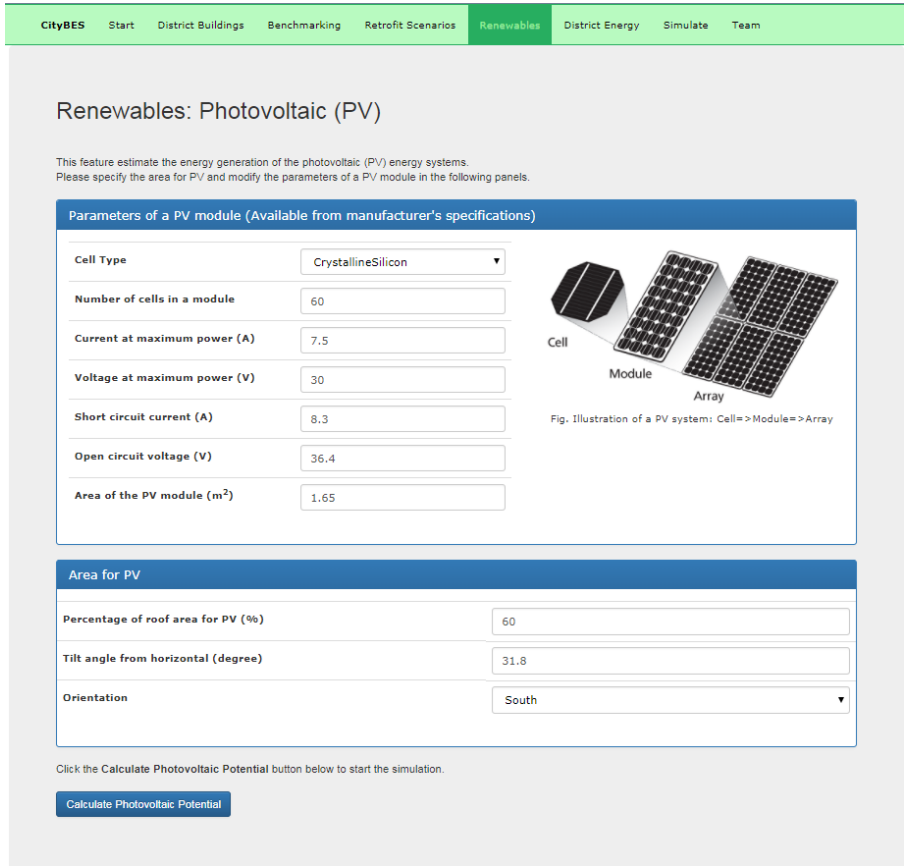
https://citybes.lbl.gov/?sf_ecbo=1

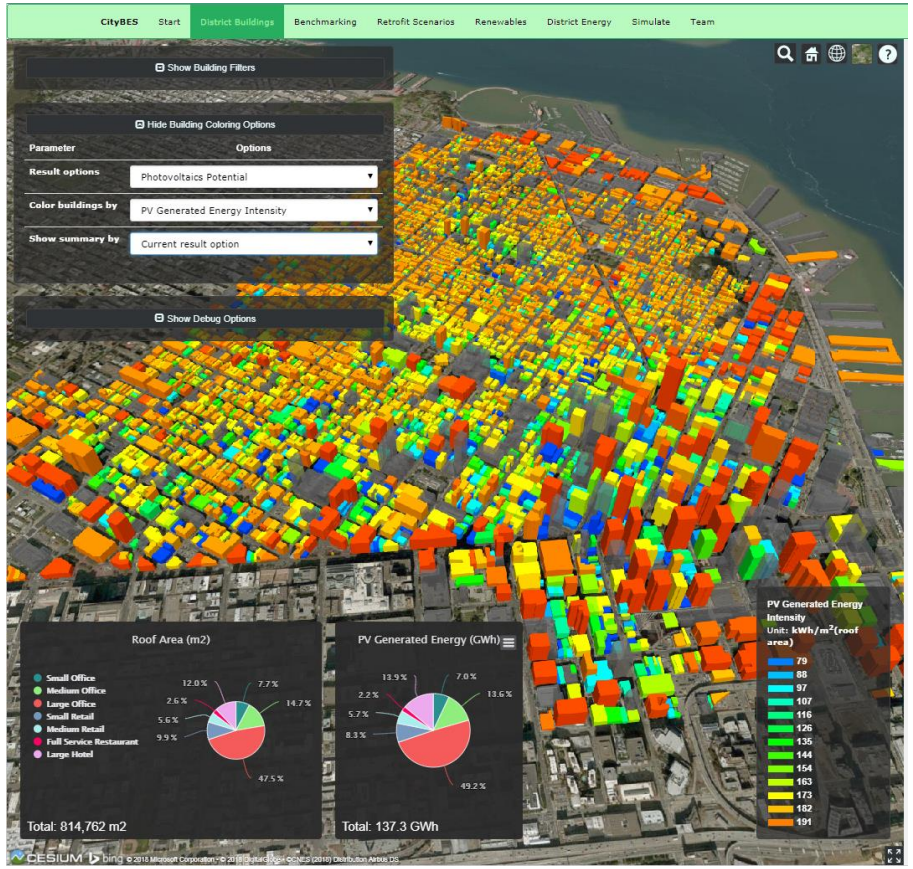
Benchmark Performance of City Buildings



Comparing site EUI of 522 office buildings in San Francisco with 63503 office buildings in the BPD.

Evaluate Photovoltaic Potential

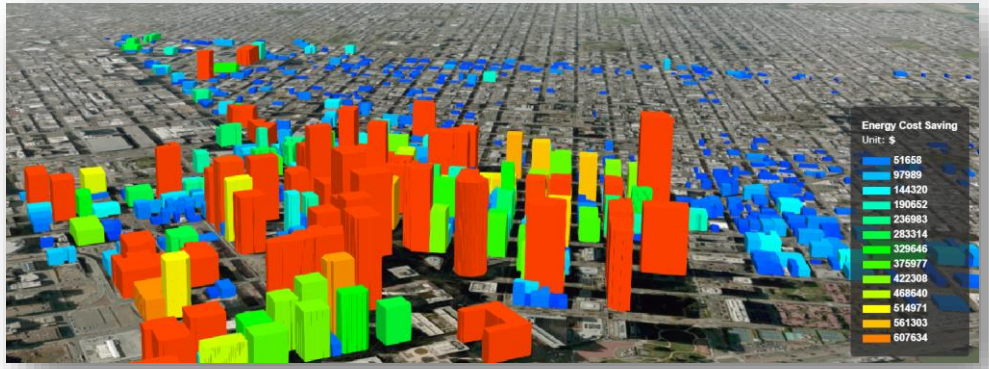


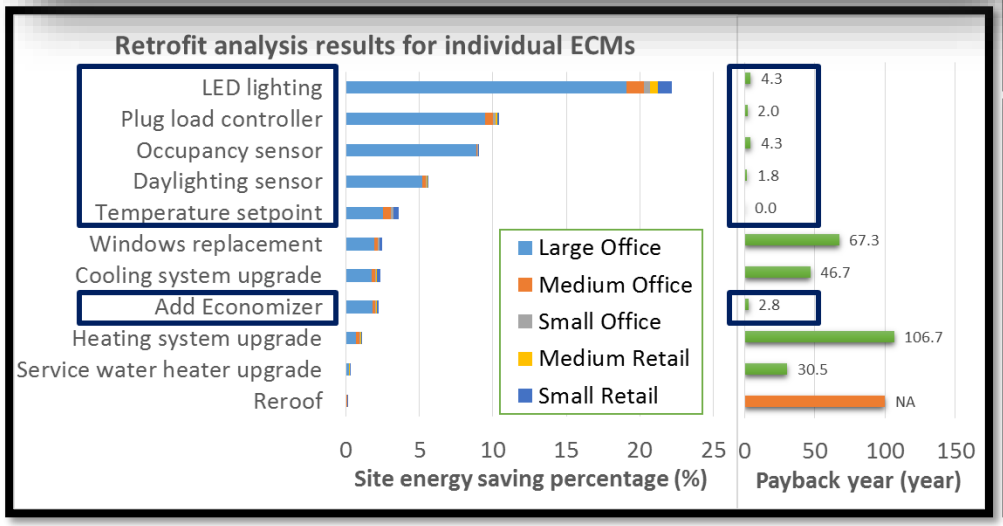


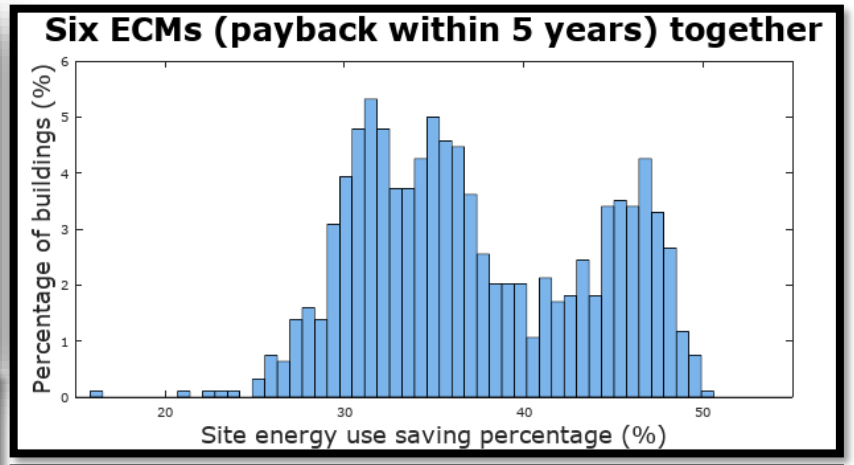
Evaluate the photovoltaic potential of 8,665 buildings in Northeast San Francisco

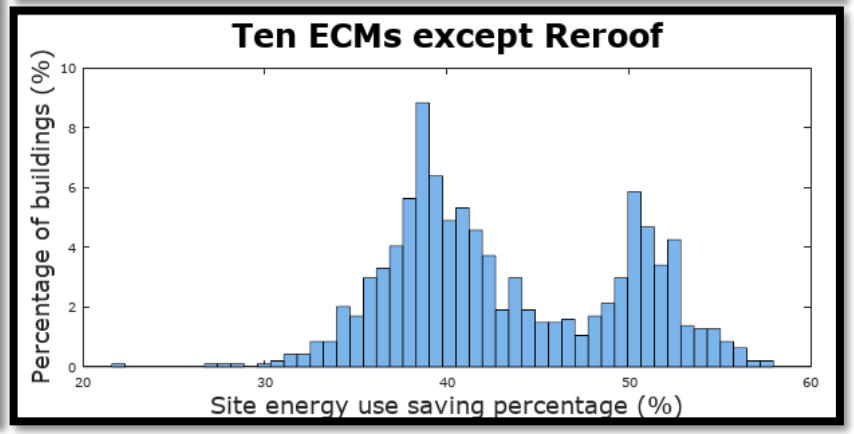
Evaluate building retrofits at large scale:

940 office and retail buildings in Northeast San Francisco



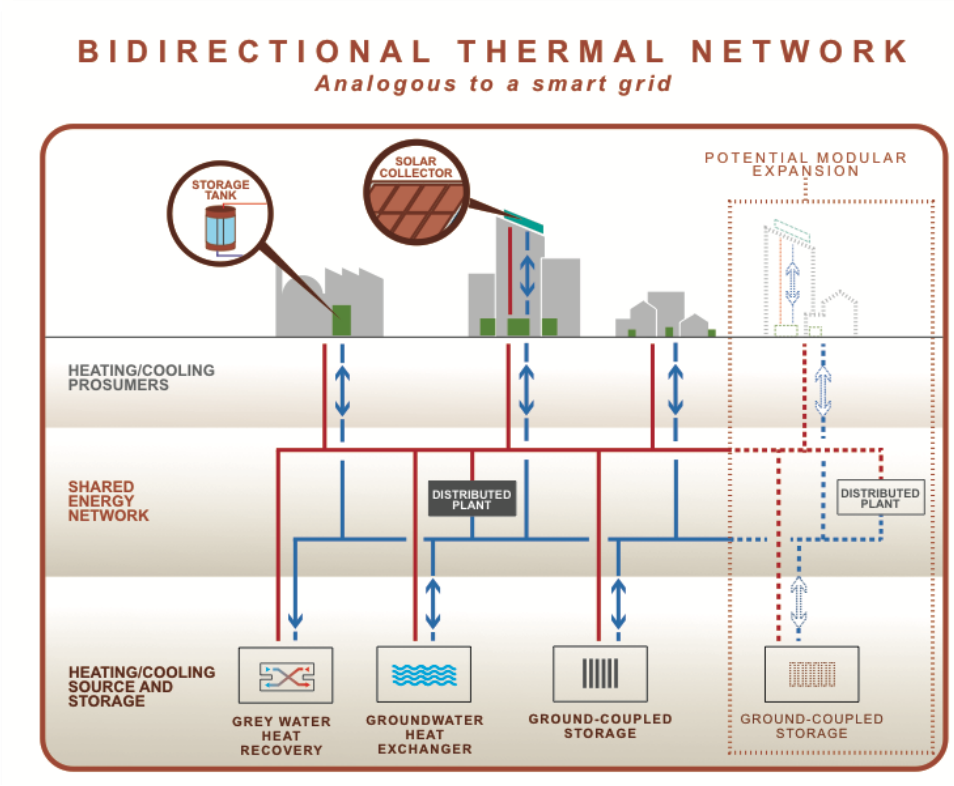






Bidirectional District Thermal Systems

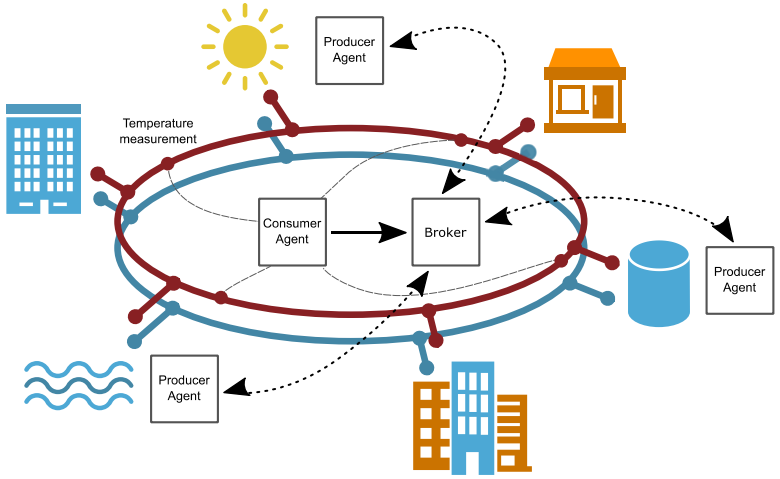
Enable sharing of waste and excess energy among buildings.
Enable staged build-out through distributed architecture.

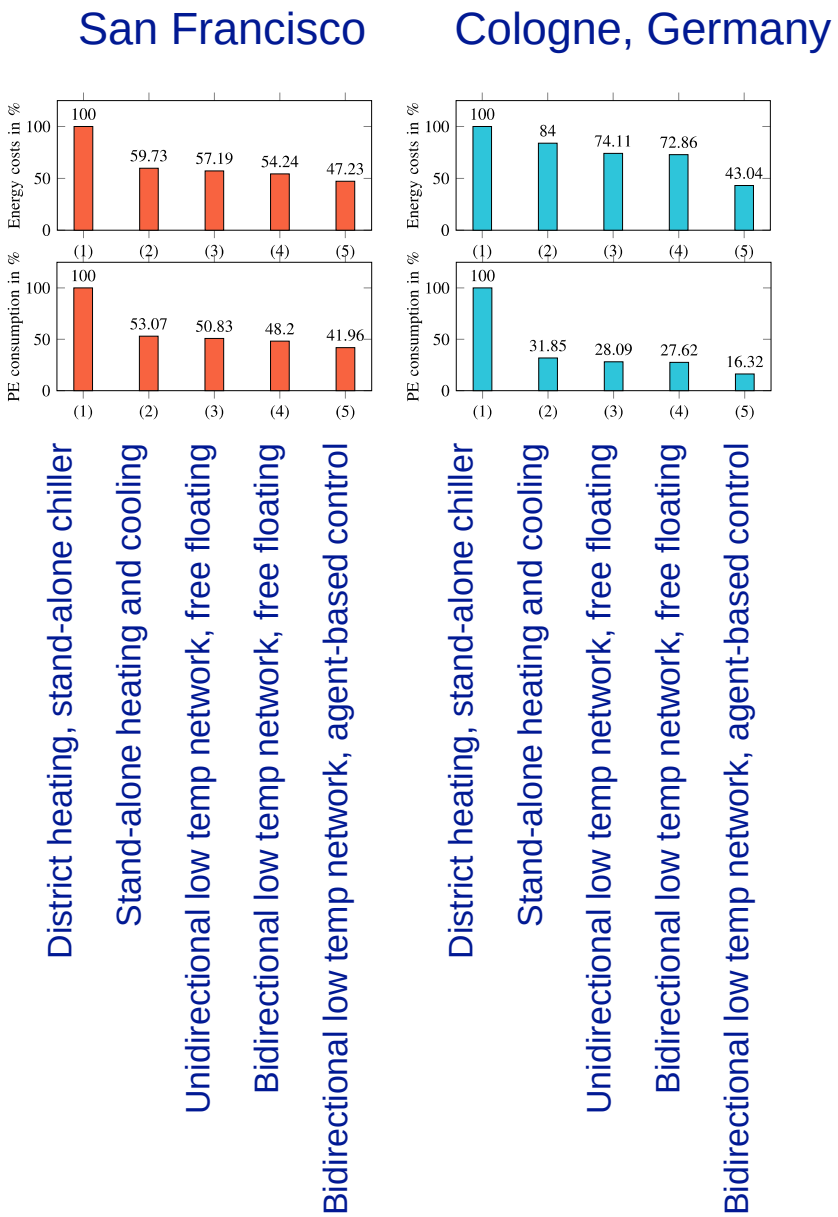


Operating bidirectional system at Zug, Switzerland

Michael Wetter, LBNL

Demonstrated substantial cost and energy reductions for bi-directional DHC





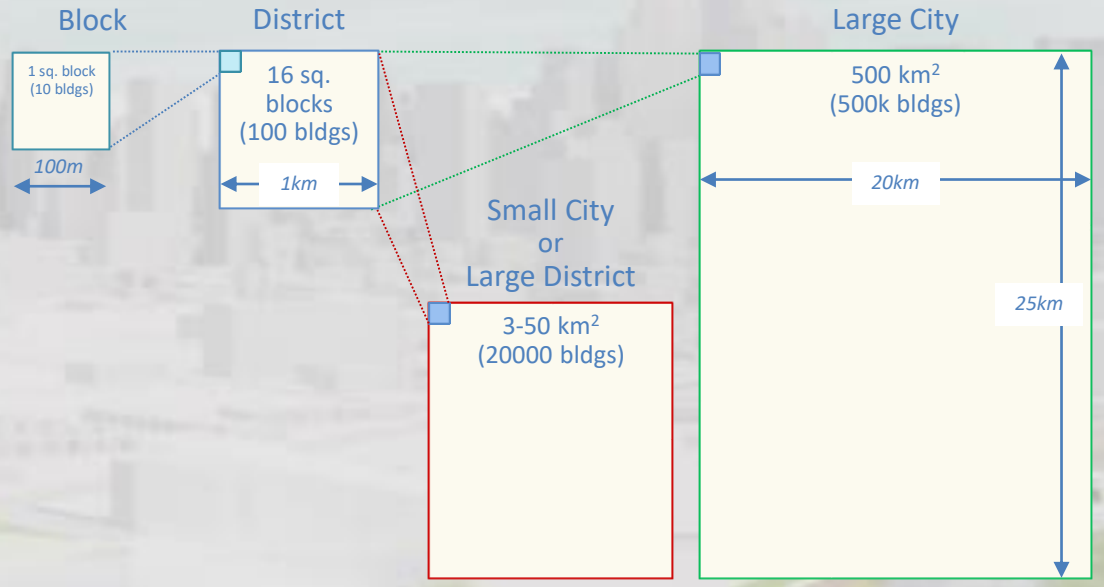
Methodology

- annual simulation using Modelica
- agent-based control
- dynamically computed energy and water flow distribution
- full flow friction simulation for pump energy

Michael Wetter, LBNL

Multiscale Coupled Urban Systems - Background

- **Current State**: Use of simple, single-sector models (e.g., transportation), independently run. Design changes take weeks to evaluate, relying on these independent models and on heuristics. Significant effort to import real-world geometries and convert to model input grids. No ensemble or optimization capabilities.
- **Required State**: Evaluate urban designs & changes in hours or days, guided more holistically using coupled models, supporting more rigorous designs, *reducing risk though evaluation and optimization of many more options (ensembles) than current state allows.*
- **Stakeholders**: Urban planners, designers, policymakers, engineering firms, utilities. *Working with Chicago Department of Planning and Development to target the 760-acre (3 km^2) North Branch Framework redevelopment as a test case.*



Four urban scales for coupled models:

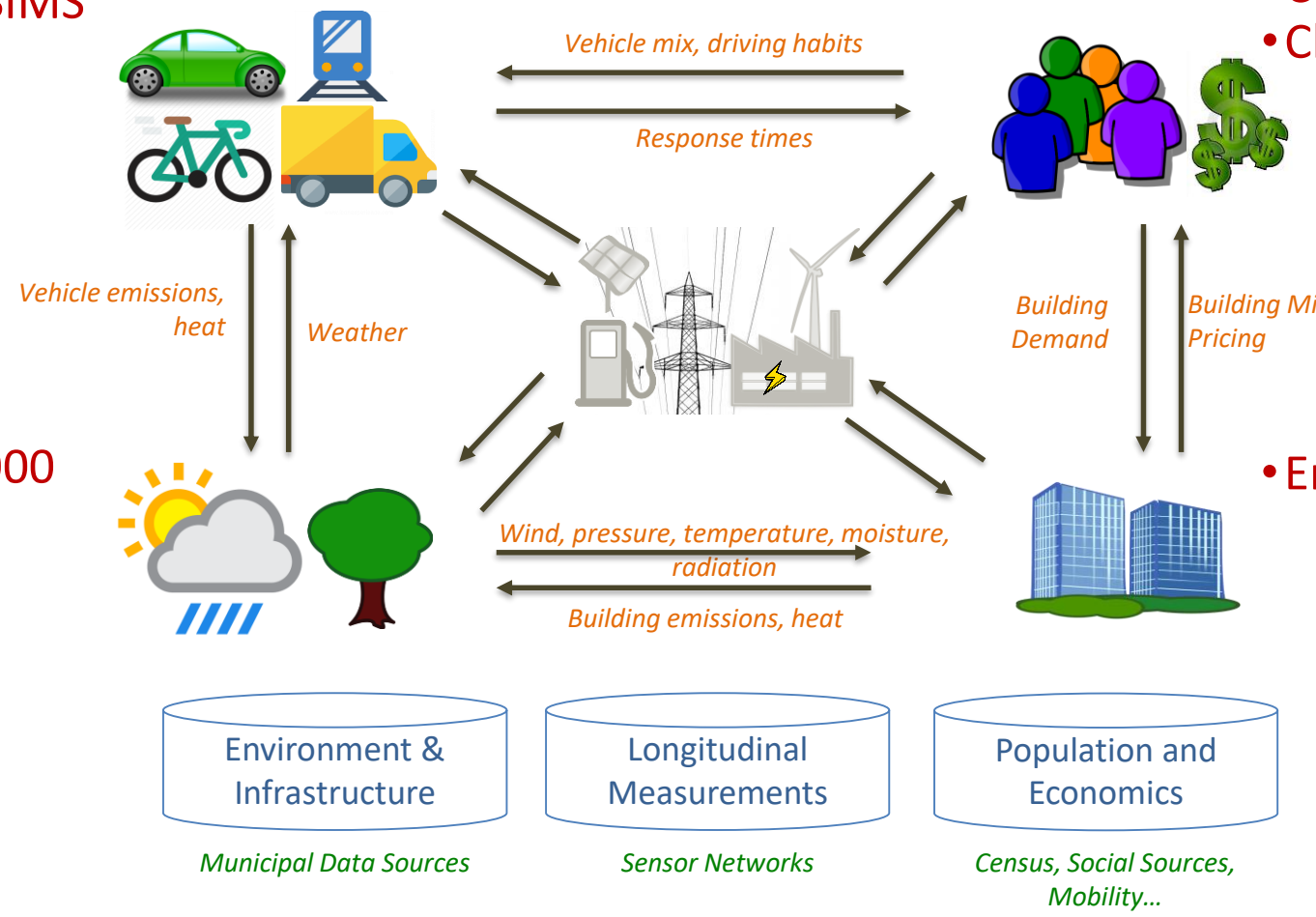
- *100 sqm (block, ~ 10 buildings);*
- *1 km^2 (district, ~100 buildings);*
- *3-50 km^2 (small city or large district, ~ 20000 buildings);*
- *500 km^2 (city, ~ 100-500k buildings).*

Layered on these scales is agent based modeling for social/economic/transportation at:

- *scales of 3M and 10M agents*

Four Models to Evaluate Data Flow and Interconnections

- TRANSIMS
- NEK5000
- WRF



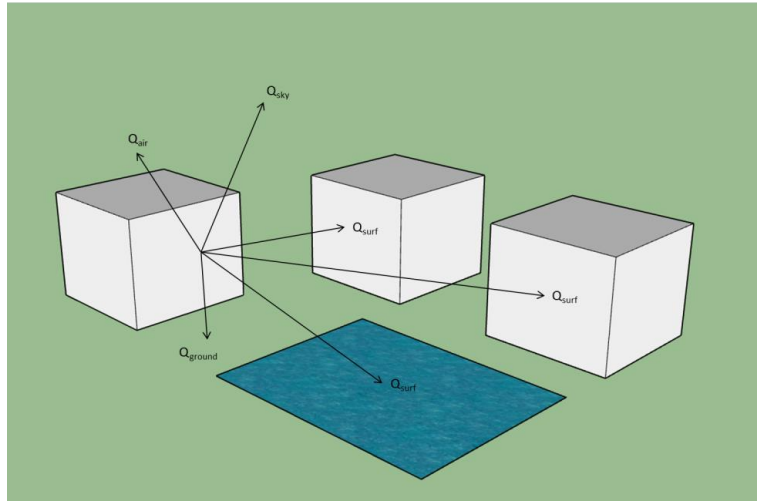
- CommuterSIM
- ChiSIM
- EnergyPlus

- How will competing district-scale designs, zoning, and transportation changes impact energy use? Water supply requirements? Storm and sewer networks? Microclimate? Traffic congestion? Job growth?
- How will distributed energy storage impact generation and distribution requirements?
- How will green infrastructure (roofs, new parks, etc.) or district-scale building configurations impact urban airflow?
- What is the impact of adding dedicated transit lanes?
- How would energy use change if human behavior with regards to decisions about commute options and commute times are altered?

Model Urban Buildings with EnergyPlus

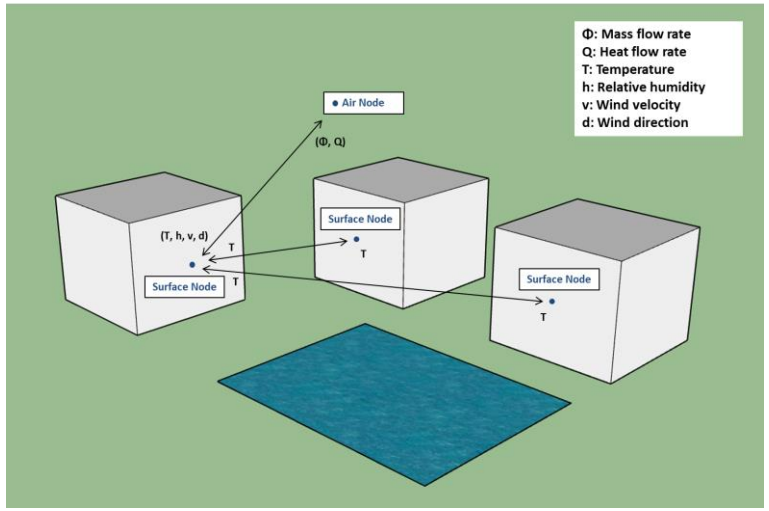
- Consider the radiant heat exchange effect between buildings;
- Consider the heat and mass flow interaction among building models and urban atmosphere models;
- Calculate heat emissions from buildings to ambient environment.

Building ↔ Building



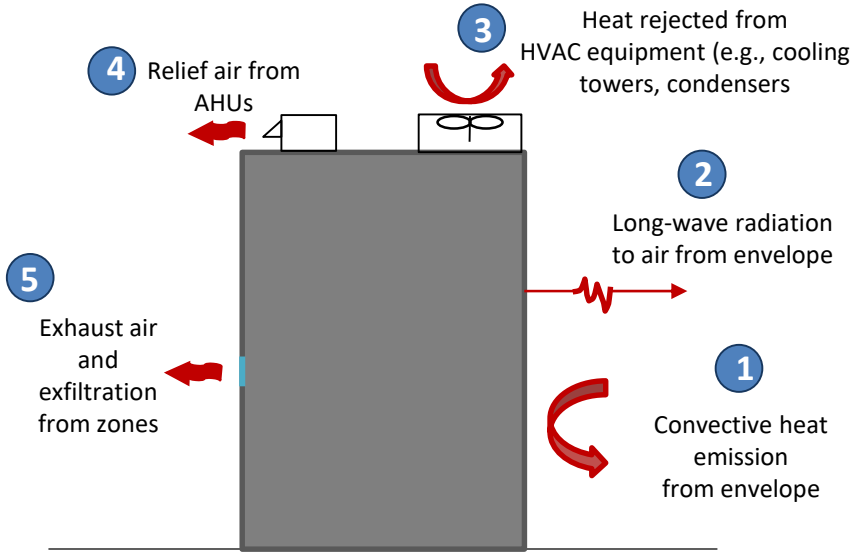
Interaction among building energy models and urban atmosphere

Atmosphere → Building



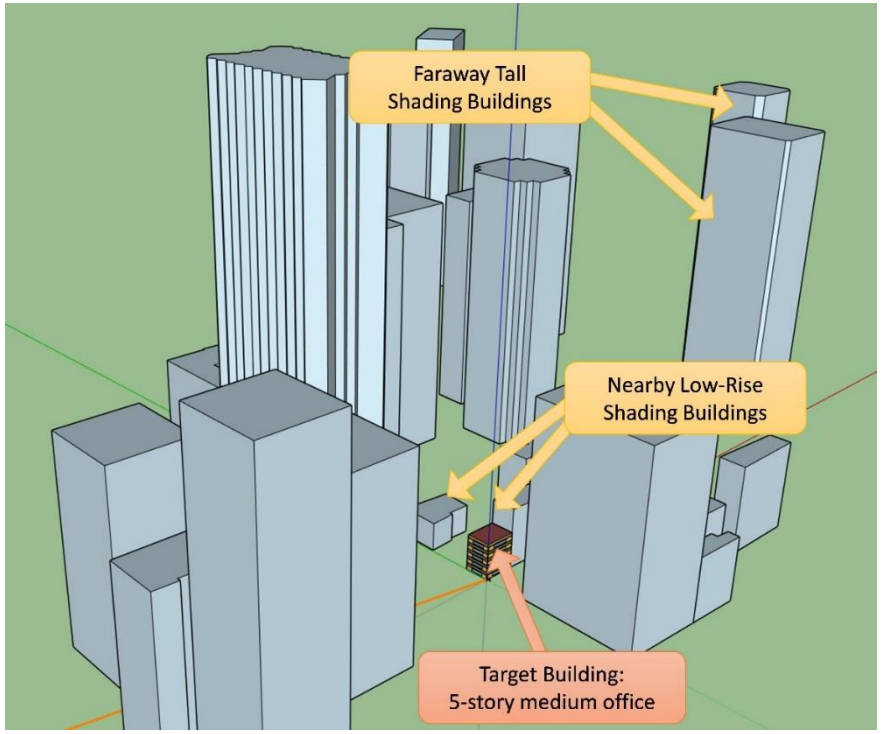
Interaction among building energy models and urban atmosphere

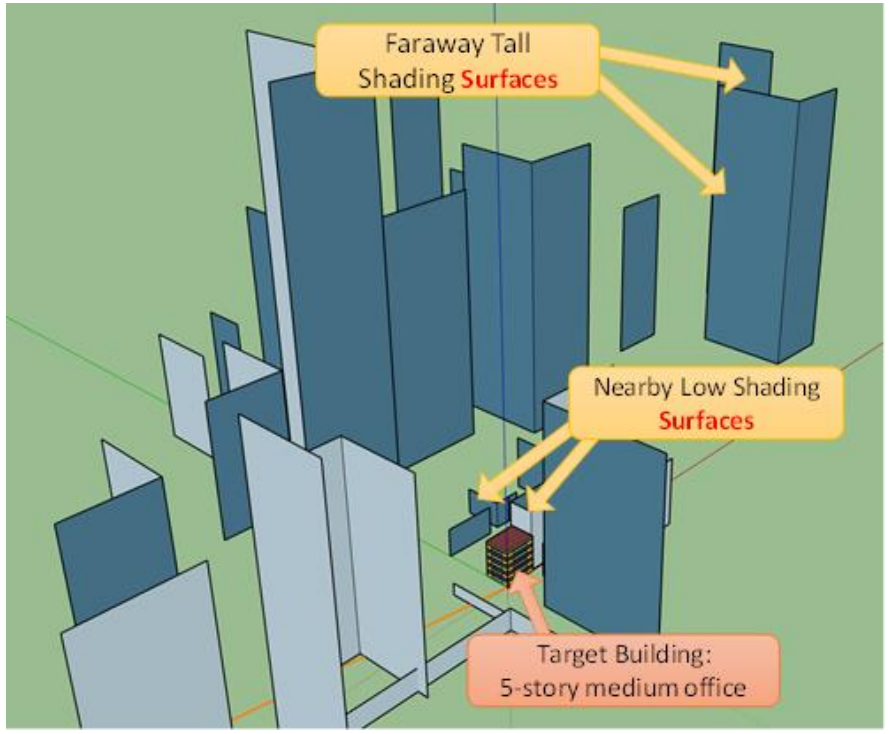
Building → Atmosphere



Heat emissions from buildings

Inter-Building Effect: Shading





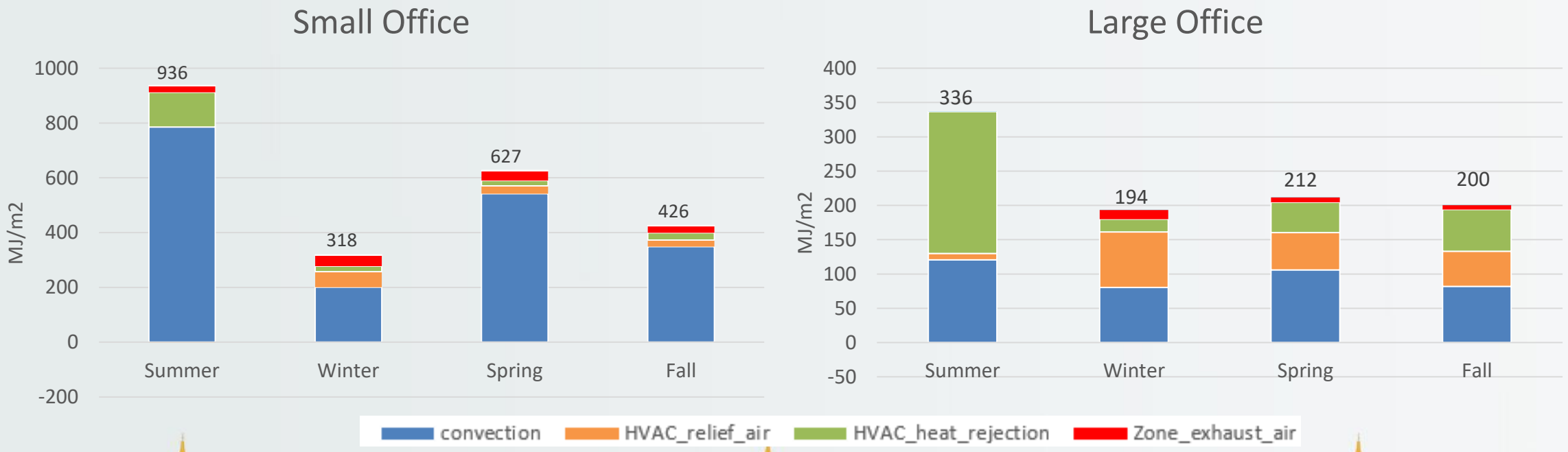
Simplify Coordinates of Far away Buildings

Advanced Pre-scan Algorithms

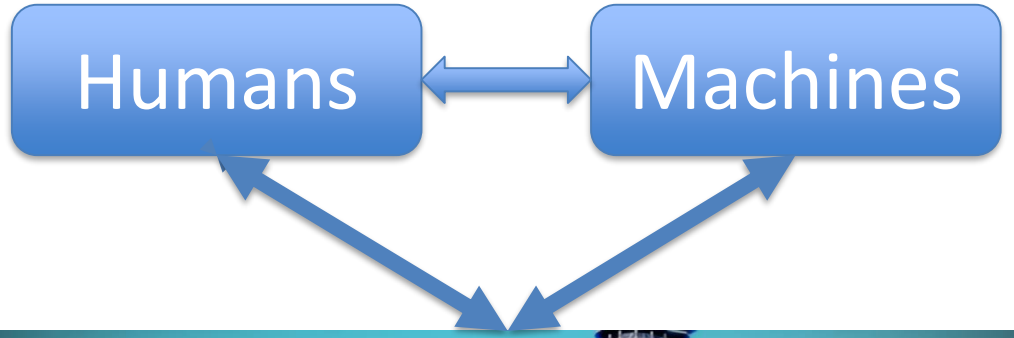
Heat Emissions from Buildings

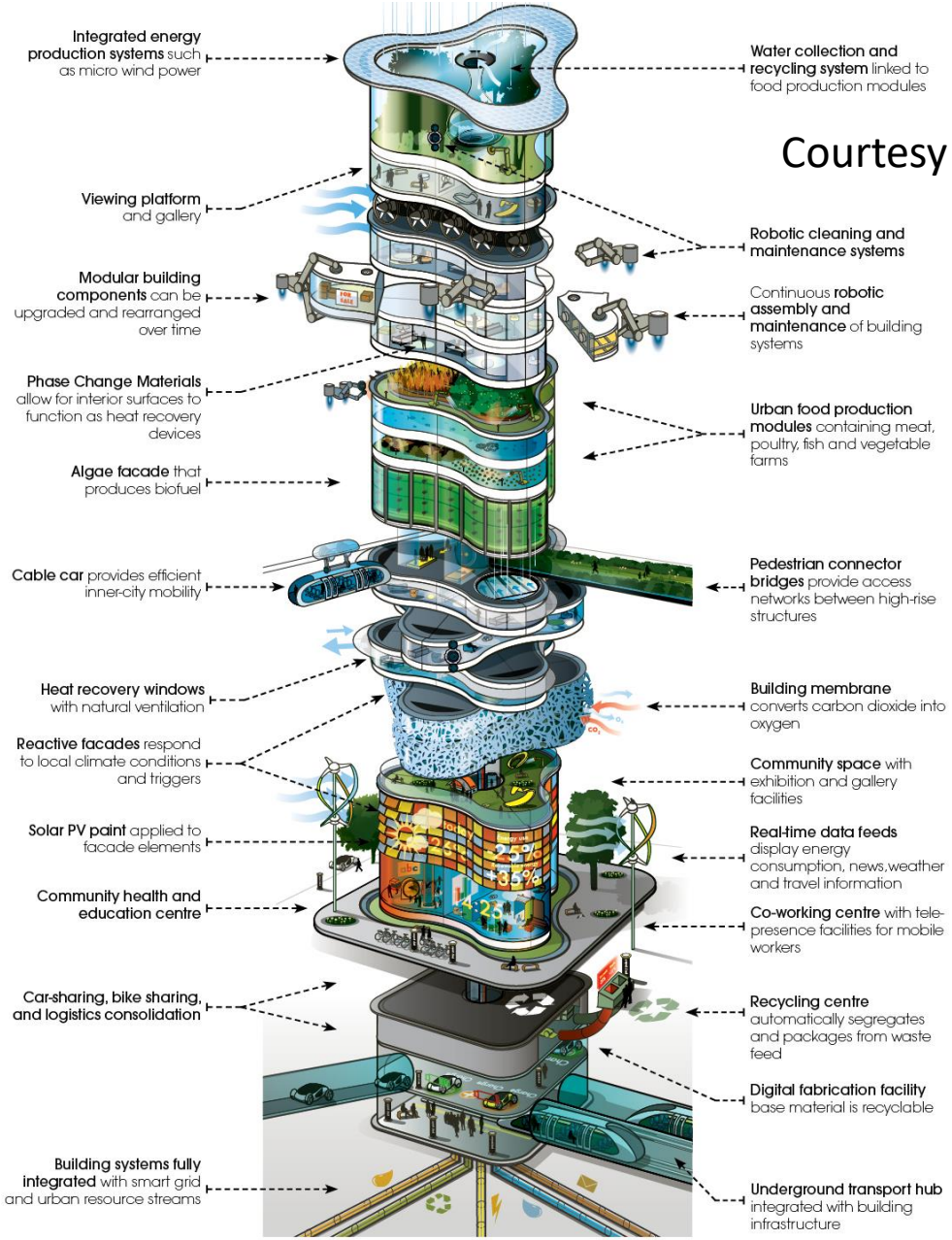
Annual heat emissions from two prototype office buildings in Chicago

	Small Office	Large Office
Annual net heat emission (MJ/m2)	2307	942
Annual site energy consumption (MJ/m2)	621	551
Ratio of heat emission to energy consumption	3.7	1.7



Envisioning Future Cities: How much we need to know?





Courtesy Arup

Publications

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2. T. Hong, X. Luo. Modeling building energy performance in urban context, **ASHRAE BPAC** / SimBuild, September 2018.
3. Y. Chen, T. Hong, M.A. Piette. Automatic Generation and Simulation of Urban Building Energy Models Based on City Datasets for City-Scale Building Retrofit Analysis. **Applied Energy**, 2017.
4. R.Z. Pass, M. Wetter, M.A. Piette. A thermodynamic analysis of a novel bidirectional district heating and cooling network, **Energy**, 2017.
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10. Y. Chen, T. Hong, M.A. Piette. City-Scale Building Retrofit Analysis: A Case Study using CityBES. IBPSA Building Simulation Conference, San Francisco, August 2017.
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14. T Hong, Y Chen, MA Piette, X Luo. Modeling City Building Stock for Large-Scale Energy Efficiency Improvements using CityBES. ACEEE Summer Study, 2018.

Acknowledgments

- The work is funded by Lawrence Berkeley National Laboratory through the Laboratory Directed Research and Development (LDRD) Program.
- This work was also supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
- The Exascale Computing Project is sponsored by U.S. Department of Energy Office of Science.
- LBNL team: Xuan Luo, Wanni Zhang, Mary Ann Piette, Yixing Chen (former LBNL)
- City of San Francisco, Department of the Environment and Department of Technology, provides the building datasets and support in the development of the San Francisco CityGML city models.

Thank You

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