Modeling Coupled Urban Systems: Opportunities and Challenges

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Transforming Cities

Cities drive our economy and dominate energy and environmental challenges

- 70% Energy / GHG
- 80% GDP
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

Changing urban climate

Need for city-scale and deep savings

Source: CalISO
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

- Residential
- Comm./Ind.
- Transport
CityBES.LBL.gov
Integrating City Data in Open Standards

Data (sources)
- Building Footprint (SF GSA Technology)
- Land Use (SF Planning)
- Assessor Record (SF Assessor-Recorder)
- Energy Disclosure (SF Environment)

Processing
- Building ID
- Parcel Number (APN)
- Mapping & Integration

Intermediate Results
- Master Building Dataset (CSV, GDB file)

Simplify & Standardize
- CityGML
- GeoJSON
- GDB

End products (different formats)
- CityBES (LBNL)
- BRICR (DOE)
- UrbanSim (UCB)
- ESRI Apps (ESRI)

Applications

BEDES (Building Energy Data Exchange Specification)

CityGML
CityBES Architecture and Use Cases
Visualize Building Energy from City Ordinance

https://citybes.lbl.gov/?sf_ecbo=1
Benchmark Performance of City Buildings

There are 63503 matching buildings in DOE Building Performance Database. There are 522 buildings in CityBES with measured Site Energy Use Intensity.

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
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 through 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 km²) North Branch Framework redevelopment as a test case.

Four urban scales for coupled models:
- 100 sqm (block, ~10 buildings);
- 1 km² (district, ~100 buildings);
- 3-50 km² (small city or large district, ~20000 buildings);
- 500 km² (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**
  - Vehicle mix, driving habits
  - Response times
  - Vehicle emissions, heat
  - Weather

• **NEK5000**
  - Vehicle mix, driving habits
  - Response times
  - Vehicle emissions, heat
  - Weather

• **WRF**
  - Wind, pressure, temperature, moisture, radiation
  - Building emissions, heat

• **CommuterSIM**
  - Building Demand, Pricing
  - Building Mix, Pricing

• **ChiSIM**
  - Building Mix, Pricing

• **EnergyPlus**
  - Building Demand, Pricing
  - Building Mix, Pricing

**Municipal Data Sources**
- Sensor Networks
- Census, Social Sources, Mobility...

**Environment & Infrastructure**
- Weather

**Longitudinal Measurements**
- Environment & Infrastructure

**Population and Economics**
- Building Demand, Pricing

• 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.

Interaction among building energy models and urban atmosphere:

- Building ↔ Building
- Atmosphere → Building
- Building → Atmosphere

Heat emissions from buildings:

1. Convective heat emission from envelope
2. Long-wave radiation to air from envelope
3. Heat rejected from HVAC equipment (e.g., cooling towers, condensers)
4. Relief air from AHUs
5. Exhaust air and exfiltration from zones
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

<table>
<thead>
<tr>
<th></th>
<th>Small Office</th>
<th>Large Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual net heat emission (MJ/m²)</td>
<td>2307</td>
<td>942</td>
</tr>
<tr>
<td>Annual site energy consumption (MJ/m²)</td>
<td>621</td>
<td>551</td>
</tr>
<tr>
<td>Ratio of heat emission to energy consumption</td>
<td>3.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

### Graphs

#### Small Office
- **Summer**: 936 MJ/m²
- **Winter**: 318 MJ/m²
- **Spring**: 627 MJ/m²
- **Fall**: 426 MJ/m²

#### Large Office
- **Summer**: 336 MJ/m²
- **Winter**: 194 MJ/m²
- **Spring**: 212 MJ/m²
- **Fall**: 200 MJ/m²

Legend:
- **blue**: convection
- **orange**: HVAC_relief_air
- **green**: HVAC_heat_rejection
- **red**: Zone_exhaust_air
Envisioning Future Cities: How much we need to know?


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