From Zero Energy Buildings to Zero Energy Districts

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ABSTRACT

Some U.S. cities are planning advanced districts that have goals for zero energy, water, waste, and/or greenhouse gas emissions. From an energy perspective, zero energy districts present unique opportunities to cost-effectively achieve high levels of energy efficiency and renewable energy penetration across a collection of buildings that may be infeasible at the individual building scale. These high levels of performance are accomplished through district energy systems that harness renewable and wasted energy at large scales and flexible building loads that coordinate with variable renewable energy supply. Unfortunately, stakeholders face a lack of documented processes, tools, and best practices to assist them in achieving zero energy districts.

The National Renewable Energy Laboratory (NREL) is partnering on two new district projects in Denver: the National Western Center and the Sun Valley Neighborhood. We are working closely with project stakeholders in their zero energy master planning efforts to develop the resources needed to resolve barriers and create replicable processes to support future zero energy district efforts across the United States. Initial results of these efforts include the identification and description of key zero energy district design principles (maximizing building efficiency, solar potential, renewable thermal energy, and load control), economic drivers, and master planning principles. The work has also resulted in NREL making initial enhancements to the U.S. Department of Energy's open source building energy modeling platform (OpenStudio and EnergyPlus) with the long-term goal of supporting the design and optimization of energy districts.

Background

Urban Energy Consumption and Population Growth

At the twenty-first session of the Conference of the Parties in Paris, the United States joined 194 nations in agreeing to make significant reductions in greenhouse gas emissions. The U.S. Environmental Protection Agency's Clean Power Plan, although currently delayed in the courts, is aimed at achieving emissions reductions in the electric power sector. In the United States, buildings are responsible for approximately 40% of U.S. carbon emissions and consume approximately 75% of grid electricity. Studies have shown that, despite considerable strides that have been made since the 1970s in reducing U.S. building energy consumption, a great deal of potential remains for further efficiency improvements. In addition to the opportunity to reduce emissions by making buildings more energy-efficient, buildings can be designed and operated to enable higher penetrations of renewable energy. For example, the large impact buildings have on the electric grid provides a promising opportunity to tailor load profiles so that they enable a high penetration of carbon-free variable renewable sources such as wind and solar photovoltaics (PV).

Also, building systems can be designed and controlled to make use of renewable and waste-heat thermal sources. Thus, the design of efficient buildings that support the broader energy system plays a major role in addressing climate change both by reducing the amount of energy that must be produced and allowing fossil fuel sources of electricity to be replaced by renewable sources.

Nowhere is the need for energy-conscious building design more apparent than in the growth of cities, which already are responsible for 70% of the world's fossil fuel emissions. The world's population is rapidly shifting to urban areas. Over 54% of the world's population lives in urban areas, and that figure is expected to increase to 66% by 2050 (UN 2014). Overall population growth and rapid urbanization around the world is both a challenge and opportunity for efforts to address climate change; the overall demand for energy will increase, but there is an opportunity to minimize the impact by promoting energy-conscious building and urban design in cities. The need for climate-friendly cities is recognized by mayors around the world. Four hundred and sixty-one cities worldwide have signed onto the Compact of Mayors, an agreement to measure and reduce greenhouse gas emissions.[1] In the United States, over 1,000 mayors have signed the Mayors' Climate Protection Agreement (ConfM 2016).

Not only are many cities growing rapidly, but many cities are also changing in character. For decades, many people have lived in the suburbs in the United States. However, there is a growing tendency, especially among millennials, to choose to live in walkable, urban communities where everything is nearby. Thus, "vertical cities" that combine homes, retail, entertainment, recreation, and workplaces into one community are becoming more common. The Demand Institute states that "communities that can offer the best of urban living … with the best of suburban living … will thrive in the coming decade…" (DI 2015). A Nielson Company report states that "the concept of "urban burbs" is becoming more popular in redevelopment as suburban communities make changes to create more urban environments…" (Nielson 2014). These changes provide new opportunities for reducing and shaping a city's energy use.

Zero Energy Buildings

Zero energy buildings represent the state of the art for energy performance at the individual building level. Different definitions have been used for zero energy buildings. According to the U.S. Department of Energy's (DOE) recent report, *A Common Definition of Zero Energy Buildings*, a zero energy building is "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (DOE 2015). An example of such a building is the Research Support Facility (RSF) at NREL, which as of this writing, is the largest zero energy office building in the United States. Constructed in 2010, the RSF was an early example of zero energy building, and lessons learned have been widely documented (DOE 2011, Pless and Torcellini 2012, Scheib 2014). Key to accomplishing zero energy at the RSF was using a performance-based acquisition process that required a design-build team to meet a specific energy design goal, specifically an annual energy use of 35,000 British thermal units (Btu) per square foot per year.

In recent years, zero energy buildings have gained considerable traction in the market. NREL has provided input for the design of over 50 new zero energy commercial buildings. The International Living Future Institute has established a Net Zero Energy Building Certification (ILFI 2016). DOE has established the DOE Zero Energy Ready Home Program for new homes (DOE 2016a). Finally, the California Long-term Energy Efficiency Strategic Plan (CPUC 2011)

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[1] http://www.compactofmayors.org/

includes the goals that all new residential construction will be zero net energy by 2020 and all new commercial construction will be zero net energy by 2030; these goals demonstrate the growing market adoption of zero energy buildings.

Zero Energy at Larger Scales

The concept of zero energy is not restricted to individual buildings. Early definitions for zero energy buildings were developed by Torcellini et al. (2006). In 2009, Carlisle et al. (2009) adapted these definitions and to develop definitions for zero energy communities. DOE (2015) has since formalized source-energy based definitions for zero energy campuses, portfolios, and communities. The DOE campus definition, for example, "*allows for the building sites on a campus to be aggregated so that the combined on-site renewable energy could offset the combined building energy from the buildings on the campus*."

There are several potential advantages to approaching zero energy at larger scales. In some cases, especially for buildings that have more than few stories and/or high-intensity process loads, achieving zero energy within the building footprint or site may be very difficult. Aggregating such buildings with other buildings and community renewable energy sources may make it possible to reach zero energy. Also, approaching zero energy at a larger scale can create the opportunity for district energy systems that exploit load diversity between buildings and access renewable energy sources in ways that may be impractical for individual buildings. For example, if a large retail commercial building requires cooling while an adjacent residential multi-family building requires heating, energy can be shared through a district system to reduce the overall energy consumption and total equipment capacity.

From an economic perspective, economies of scale may be achieved through the design, acquisition, operation, and maintenance of energy systems across many buildings. The loads of many buildings can be aggregated and controlled to create new revenue streams related to grid services. Finally, approaching zero energy at larger scale creates opportunities for innovative energy service business models, rate structures, financing, and utility incentive programs.

Zero Energy Districts

Cities are beginning to recognize the potential that high-performance buildings and master-planned development have to help reach energy and carbon reduction goals. A recent survey of 17 U.S. cities identified "building certifications & best practices" and "walkable, complete, mixed-use community planning" as two of the top-three most common energy-related actions the surveyed cities are taking (Aznar et al. 2015). In their May 2015 article titled *Building the Cities of the Future with Green Districts*, analysts from McKinsey & Company (Bouton et al. 2015) examine "green districts." They define a green district as "a densely populated and geographically cohesive area that is located within a city and employs technologies and design elements to reduce resource use and pollution." Bouton et al. (2015) state that interest in green districts is growing. They point to the Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND) rating system and a similar rating system in the Middle East.[2] They also recognize that EcoDistricts launched the Target

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[2] http://estidama.upc.gov.ae/pearl-rating-system-v10.aspx

Cities Program as Clinton Global Initiative Commitment, which aims to "amplify and accelerate district-scale community regeneration and create replicable models for next-generation urban revitalization" for 11 projects in nine North American cities.[3]

EcoDistricts argues that "the district is the optimal scale to accelerate sustainability—small enough to innovate quickly and big enough to have a meaningful impact" (EcoDistricts 2014). The U.S. President's Council of Advisors on Science and Technology describes "urban development districts" as "living laboratories from which fundamental knowledge about urban processes and practical implementation practices can be learned, adapted, and generalized to other districts…" (PCAST 2016).

To achieve the large energy and carbon reductions that are needed, cities must move from green districts to zero energy districts over time. There have been some efforts to achieve zero energy at a community scale for specific projects. One of the first attempts in the United States at a zero energy district is the FortZED project in Ft. Collins, Colorado, which utilizes renewable energy coming from within a 50-mile radius of the city. The goal of the project, begun in 2007 and still in development, has been to transform the downtown area of Fort Collins and the main campus of Colorado State University into a zero energy district. As another example, the University of California, Davis has pursued a zero energy community in the West Village development (Dakin and German 2014). Additionally, there is much to learn from European cities that have generally been more aggressive than U.S. cities in pursuing energy solutions that involve district energy systems (for example, see Chittum 2014 and the District Energy Initiative[4]).

Initially, it will be more feasible for districts to attain zero energy when the vast majority of the buildings and infrastructure in the district are being newly constructed (e.g., a greenfield development or a complete redevelopment). In the longer term, approaches must also be developed to retrofit districts with primarily existing buildings and infrastructure into zero energy districts. This paper focuses on new construction zero energy districts, but many principles and tools presented here could be extended and applied to retrofit zero energy districts in the future.

National Western and Sun Valley District Energy Projects

Denver, Colorado is now pursuing several high-performance energy district projects. NREL is engaging in two of these projects—the National Western Center and the Sun Valley EcoDistrict—to develop the resources needed to resolve barriers and create replicable processes to support future zero energy district efforts across the United States. This work is currently supported through an internally funded initiative at NREL.

The 270-acre National Western Center (NWC), which is located north of downtown Denver, will be an expansion of the site used for the National Western Stock Show's annual 16-day event. The 10-year development plan includes a new 10,000-seat arena, an exposition center, a local food market, small urban farms and gardens, and buildings for Colorado State University to conduct outreach, research, and education on science, technology, engineering and math (STEM) subjects, sustainability, and the arts. The NWC project is positioned to pursue high performance. First, zero energy goals were included in the initial master plan (NWC 2014), which has been a key driving factor for the continued pursuit of zero energy in the project. Also,

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[3] https://ecodistricts.org/target-cities/about-target-cities/

[4] http://districtenergyinitiative.org/

the NWC has a variety of thermal resources that could potentially be accessed through district energy systems. Among other options, the NWC is examining wastewater heat recovery and district ground source heat pumps. To achieve high levels of energy efficiency, the NWC is considering adopting NREL's performance-based procurement approaches for their buildings and district infrastructure.

The 80-acre Sun Valley neighborhood, which is located south of Denver's professional football stadium and a new stop on the W light-rail line, is Denver's lowest-income community. The Denver Housing Authority controls approximately 40 acres in Sun Valley and is examining rebuilding its facilities at much higher efficiency levels and three times the density, which would be divided roughly as one-third each public, low-income, and market-rate housing. High-efficiency buildings, district thermal energy, and solar PV are some of the options being considered to help Sun Valley achieve zero energy. Sun Valley is one of 11 EcoDistricts Target Cities projects across North America (EcoDistricts 2016).

One important aspect of Sun Valley is the opportunity to achieve zero energy for a low income community and its residents. The Denver Housing Authority has held open meetings with Sun Valley residents to gather feedback and understand their needs. This project could lead to a replicable approach that housing authorities across the country could employ to transform similar neighborhoods into high-performance districts that create better living conditions and opportunities for residents.

Zero Energy District Design Principles, Economic Drivers, and Master Planning Principles

Many best practices for the design and construction of zero energy buildings can be extended to zero energy districts. As a result of a) our involvement in the design of zero energy buildings, b) the creation of the NREL research campus with high-efficiency buildings, district energy systems, and renewable energy production, and c) the early planning of Denver district energy projects, we have begun to define a set of core zero energy district design principles, economic drivers, and master planning principles. We see these principles as strategies and concepts that should be considered for all zero energy districts. However, we recognize that not all districts may be able to successfully implement these principles because of project-specific constraints and challenges, as well as a current lack of technical resources and design tools for zero energy districts. As we will describe in the final section of this paper, we are working to enhance the open source DOE building energy modeling platform by creating new capabilities specifically designed to help implement and explore these principles and concepts.

Design Principles. Table 1 outlines four core design principles for new zero energy districts: maximize building efficiency, maximize solar potential, maximize renewable thermal energy, and maximize load control.

Maximizing building energy efficiency starts with the building envelopes. Proper building orientation and optimum ratios of window area to floor space for a given climate can provide direct gain for passive solar heating in the winter and maximize daylighting, thus reducing lighting and cooling loads. High-efficiency windows and high levels of wall and roof insulation minimize heating and cooling loads. Locating wall insulation external to thermal mass can support the use of nighttime ventilation to pre-cool buildings in appropriate climates. A high level of airtightness coupled with heat recovery ventilation minimizes infiltration loads while maintaining healthy indoor air quality.

To minimize "miscellaneous electric loads," best-in-class products should be carefully selected, robust control strategies should be developed, and ongoing monitoring should be performed to verify performance and identify necessary behavioral interventions (see Lobato et al. 2011). High-efficiency light-emitting diode (LED) lighting that is properly adjusted to occupancy and balanced with available daylighting, as well as judicious use of task lighting minimize electric lighting loads.

A wide variety of potential approaches exists for district thermal systems. Given the loads and site-specific opportunities and limitations, the most promising potential approaches should be evaluated and compared on technical and economic bases. For example, one approach could be to combine centralized district heating and cooling plants with a heat pump loop system (similar to the systems often found in stand-alone zero energy building projects). This combined district heat pump loop system utilizes low, or ambient temperature water distribution where heating/cooling is upgraded in each building by heat pumps. This configuration offers the potential value of optimal heat recovery from multiple sources while minimizing the district piping costs. Another key advantage of this approach is that low-temperature heat sources in ambient loop district systems can be well-matched to low-temperature heat loads such as those for radiant heating systems. Among many factors, the technical and economic evaluation of these systems must consider the energy use and costs associated with district system piping and pumping (e.g., such systems may not be optimal for districts with low building and energy load densities).

To maximize the potential for solar electricity, buildings must be designed and arranged to maximize solar access. Building heights and roofs must be designed to maximize solar access, and buildings should be arranged within the district to minimize rooftop shading. The district must also be designed to provide district solar spaces, such as parking lots with electric vehicle charging stations that are sheltered by solar energy generating canopies.

In addition to maximizing building energy efficiency, solar potential, and renewable thermal energy, it is important to control building and district system energy demands to accommodate the variable supplies of renewable energy (e.g., PV and wind) and to support the district's interaction with the electric grid. Demand response measures to control the timing of major loads such as heat pump compressors and water heating can match demand to supply. The use of district thermal energy allows for the utilization of cost-effective district thermal or electrical storage to further control load profiles.

Ultimately, these principles are interrelated and must be maximized together using analysis approaches and tools that account for tradeoffs between each principle. For example, increasing building enclosure efficiency can affect the feasibility of certain district thermal systems. To arrive at a final solution, an iterative design process is required that considers all systems and their interactions, as well as associated costs and value streams.

Combined, these principles can help minimize carbon emissions. If the goal for a district is zero carbon emissions,[5] the district could be comprised of all-electric buildings, with all the electricity provided by renewable sources, primarily PV but also wind-generated electricity if appropriate. The percentage of renewable electricity that will be generated within the footprint of the district will depend on the population density and the energy efficiency of the district. Thus, high levels of efficiency are critical to minimize the amount of renewable electricity that must be imported from off-site PV or wind installations. Other renewable energy sources, such as biomass and geothermal energy could also play a role zero emissions districts.

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[5] A goal of zero carbon emissions is very different from a goal of zero energy (see Torcellini et al. 2006).

Table 1. Zero energy district design principles

Design Principle	**Design Sub-Principle**
Maximize Building Efficiency	Orientation: Maximize natural daylighting, passive solar design
	Enclosure: Employ efficiencies currently being implemented in Zero Energy Building industry (e.g., DOE Zero Energy Ready Program[6]; 50% Advanced Energy Design Guides[7])
	Miscellaneous Electric Loads: Carefully select best-in-class products; develop robust control strategies; verify with ongoing monitoring to minimize miscellaneous electric loads (see Lobato et al. 2011)
	Lighting: 100% LED, controls for occupancy and daylighting variability
	HVAC: Employ district-connected systems that maximize thermal energy recovery opportunities from low-grade heat sources across the district (e.g., ambient temperature district loops with building-scale heat pumps)
Maximize Solar Potential	Arrange buildings in districts to prevent building-to-building shading (e.g., shorter buildings oriented south, ideally)
	Orient buildings and roof slopes for maximum solar access
	Minimize other buildings systems that require roof space (e.g., target 75% plus solar thermal/PV coverage of total roof area)
	Reserve all parking lots and garages to be shaded parking with PV
	Improve potential for off-grid resiliency, maximize rooftop solar access
Maximize Renewable Thermal Energy	Evaluate potential for renewable thermal energy systems and waste heat recovery (e.g., ground-source district heat pump systems, industrial waste heat recovery, and wastewater heat recovery)
Maximize Load Control	Establish controls for building and district system energy demands to accommodate the variable renewable energy supplies (e.g., PV and wind) and support the district's interaction with the electric grid.

Economic Drivers. Key economic drivers when considering energy systems at a district scale include economies of scale, diversity of loads, and access to waste heat sources. Cost and energy savings can be achieved by procuring and operating systems at larger scales. Examples include:

- The larger the PV project is, the lower the cost per watt installed will be. In general, systems greater than 250 kilowatts (kW) are less expensive than smaller

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[6] See DOE 2016a.
[7] See DOE 2016b.

projects (Barbose et al. 2015). Multiple smaller systems that are part of a larger contract and project can still get some of the economies of scale for PV.
- Larger ground source heat pump systems can provide heating at a lower cost than several smaller systems because pump costs do not scale linearly with pump size (Jensen and Dowlatabadi 2012).
- In some cases, eliminating natural gas infrastructure from the district (i.e., going to all-electric) can save on piping, meters, and associated costs. The cost savings can help pay for other low energy district systems.
- Centralizing energy systems to limit the number and types of systems can potentially reduce operation and maintenance costs in the district.

If buildings are connected through a district system and have diverse load profiles (e.g., some buildings are heating while others are cooling or some buildings peak during day while others peak during evenings), the capacity of the district system required to meet aggregate load may be smaller than the sum of the capacities of separate systems designed to serve individual buildings. Because equipment costs generally scale with capacity, load diversity can help reduce initial capital costs.

Aggregating and controlling loads can create new revenue streams related to ancillary grid services, such as peak demand reduction and frequency regulation. Revenue streams such as this could attract a central entity, such as an energy service provider, to manage the district energy systems and performance to meet the zero energy goals.

Finally, waste heat sources from nearby industrial facilities may be available at little cost. The challenge in these cases is the cost associated with the infrastructure that accesses and transports the heat to the buildings in the district.

Energy Master Planning Principles. The energy master planning team for a district plays the critical role of helping translate design principles and economic drivers into practice. Table 2 outlines some initial zero energy district energy master planning principles that can help ensure zero energy concepts propagate throughout the overall master planning process and then translate into the design process.

Including and clearly defining[8] zero energy goals in the overall district master plan is an important step to help ensure zero energy remains a priority throughout the development of a district and that decisions in all areas must consider energy implications. In addition to this initial step, the energy master planning team can help ensure energy concepts remain visible by advocating that energy systems are accurately represented in the master planning documents and architectural renderings of buildings and the district. The physical size and location of PV arrays, district geothermal wells, and district central utility plants, for example, should be represented in master plans so that they are not an afterthought in district programming. The size of PV arrays required to reach zero energy, both on building rooftops and in other district spaces, may be surprising to those who are unfamiliar with zero energy projects. Accurately representing such arrays in renderings of buildings can help set expectations and demonstrate that aesthetically pleasing designs with high levels of PV are possible.

The energy master panning team can help coordinate energy recovery by advocating for the location and density of buildings, as well as the location of district systems. For example, the team can help identify buildings that have complementary energy load profiles (e.g.,

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[8] For example, utilizing DOE’s standardized definitions (DOE 2015).

simultaneous heating and cooling during periods of the year) and advocate that they are located such that energy can be transferred through a district thermal system.

Once the energy master planning team has arrived at a final plan for reaching zero energy at the district scale, it can support the procurement of district infrastructure and buildings by producing zero energy design guidelines for the district. As an example, the final energy master plan could specify the parameters of district thermal system to which buildings will be required to connect (e.g., the temperatures and flow rates of the district thermal loops) and the energy use intensity requirements for each building. This information can feed into a performance-based design-build process similar to the one used for the zero energy RSF at NREL (see Background). The approaches described by Herk and Beggs (2016) for implementing DOE Zero Energy Ready Home requirements on a community scale could be adapted and applied for residential buildings, with additional considerations related to district energy systems.

Table 2. Zero energy master planning principles

Define Zero Energy Goals	Include and clearly define zero energy goals in the district master plan
Accurately Represent Energy Systems	Represent the physical size and location of PV arrays, district geothermal wells, and district system central utility plants in the master plans and renderings
Identify Complementary Loads and Coordinate Energy Recovery	Identify potential complementary heating and cooling scenarios across buildings within district and coordinate energy recovery through building locations, density, and district thermal system design
Produce Energy Design Guidelines	Produce zero energy design guidelines for the district to support procurement of district infrastructure and buildings (e.g., through performance-based design-build process)

Zero Energy District Design and Modeling

Background

Traditionally, district energy modeling has been done in a top-down fashion. High-level models and spreadsheets are used to develop overall goals as well as performance goals for individual buildings. Building engineers then use the performance goals to develop designs for individual buildings, potentially using detailed energy modeling software to guide their decisions. This approach meets some of the key design principles identified above. With the high-level spreadsheets, planners are able to establish and track zero energy goals for the district master plan. Detailed energy modeling for individual buildings allows for maximizing building efficiency. However, the traditional approach misses some other key design principles. Modeling buildings in isolation does not allow maximizing solar potential by reducing building-to-building shading. Nor does it not allow maximizing renewable district thermal energy by examining simultaneous heating and cooling between buildings.

As computing power increases and building energy modeling software becomes more sophisticated, a new set of tools for performing bottom-up urban building energy modeling (UBEM) is emerging. A comprehensive review of the state of the art in UBEM tools is given in Reinhart and Davila (2016). UBEM tools combine energy models for many individual buildings into a unified district or city-level model. Such combined models can allow building-to-building shading and simultaneous heating and cooling to be evaluated. A district-level model can also allow buildings and district systems to be shown in a unified view, which is important for setting size and location expectations in district master planning.

UBEM tools vary widely in their capabilities and functionalities. Some tools, such as the Energy Atlas Berlin (Kaden and Kolbe 2013), use very simple regression-based energy models for individual buildings. These models are useful for predicting energy use of buildings typical of the data set that was used to develop the regression model. Other tools, such as the proprietary LakeSim tool (Bergerson et al. 2015) that was developed to support the 600-acre Chicago Lakeside Development Project on the south side of Chicago, use more complex energy models. These models are able to model more high-performance options on a physical basis.

Currently, DOE's open source building energy modeling platform is primarily designed for analysis of individual buildings. OpenStudio is a suite of free and open source software applications that facilitates building energy analysis using DOE's EnergyPlus calculation engine. The OpenStudio application example interface allows the user to open and edit the features of individual buildings, one at a time. As a result, use of DOE's modeling platform in UBEM tools has been somewhat limited. One of the first UBEM tools to use DOE's flagship EnergyPlus simulation engine (Crawley et al. 2000) at the individual building level was umi (Reinhart et al. 2013). umi uses EnergyPlus at the building level to examine strategies for maximizing building efficiency. umi runs on the Rhinoceros CAD software for which a license must be purchased.

URBANopt

To better support the effective design of zero energy districts across the United States, NREL is enhancing DOE's open source building energy modeling platform to create an open source urban modeling platform called URBANopt. As seen in Figure 1, the URBANopt platform uses the OpenStudio platform (Guglielmetti et al. 2011) to perform detailed energy modeling at the individual building level using EnergyPlus. OpenStudio is a software middleware layer that fits between URBANopt and EnergyPlus. The OpenStudio layer has several key features that make it more attractive to work with than working with EnergyPlus directly. The first key feature of OpenStudio is its application programming interface (API). The API allows other software to load and manipulate OpenStudio models directly in memory rather than having to read and write EnergyPlus simulation input files. The API allows other software developers to easily extend the capabilities of OpenStudio. The primary way this occurs is through the development of OpenStudio Measures (Hale et al. 2012), which are scripts that modify an OpenStudio model using the OpenStudio API. OpenStudio Measures can accept user inputs that modify their operation, and the user inputs may be varied to perform custom parametric analyses. OpenStudio Measures can be easily shared with the energy modeling community through the Building Component Library (Fleming et al. 2012). The URBANopt workflow being developed, shown in Figure 1, relies heavily on the concept of OpenStudio Measures. This is significant because it allows the system to be easily customized by users who can either get new OpenStudio Measures from the Building Component Library or create their own.

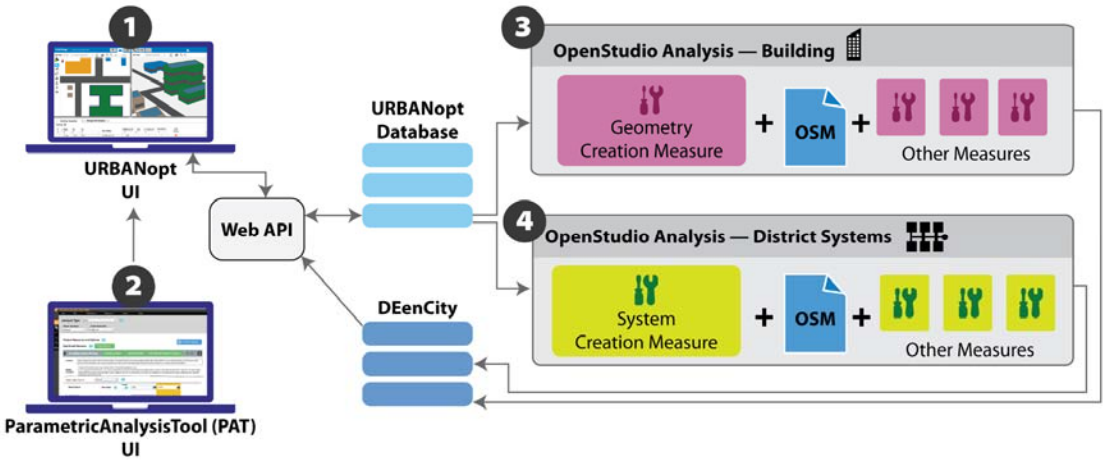


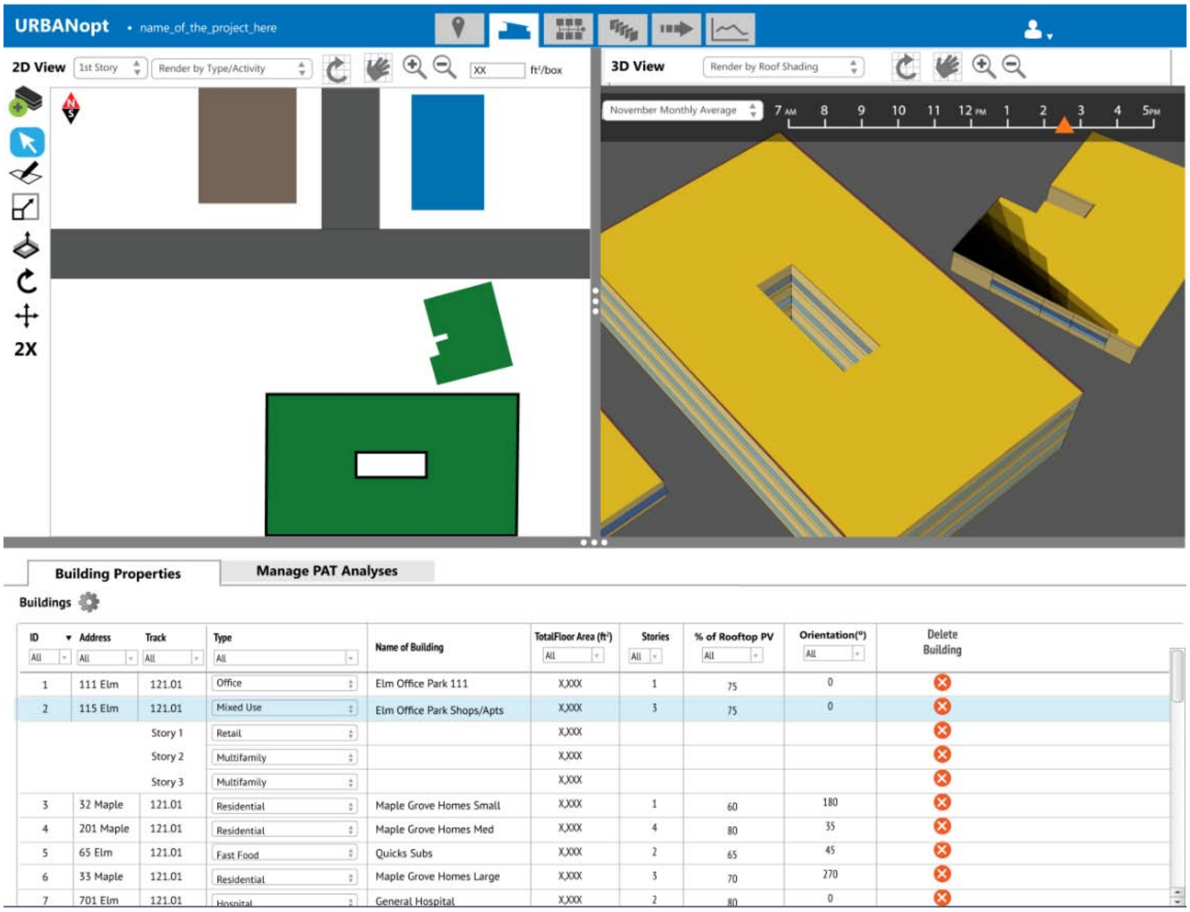
Figure 1. URBANopt workflow

An example user interface (UI) is under development at NREL to a) help guide the development of the URBANopt platform and b) provide an example that shows developers how to access and use the URBANopt platform (Item 1 in Figure 1). As is OpenStudio, the underlying URBANopt platform will be open source and can be used independently of the example URBANopt UI. This means software developers can use the URBANopt platform in whole or in part for their own custom applications.

The planned URBANopt UI is being designed to demonstrate how the URBANopt platform can be used to investigate zero energy district design principles. The final version of the planned UI will allow users to define several projects that may be shared between several users. The UI will allow users to define the overall location of the district and assign weather conditions and utility rates. The UI will also allow users to quickly add prototypical buildings to a 2-D site map, as well as draw custom footprints and assign floor-by-floor building types to support mixed-use buildings. The designer can input the overall location of the district, graphically lay out the streets, place parking lots, and create floor space targets for different building types (e.g., multi-family residences, single-family residences, offices, retail space, and supermarkets). Building properties can be easily seen and edited in a single grid view. Building properties can include their size, type, energy efficiency levels compared to code, rooftop PV, and building energy storage. A 3-D view can be used to evaluate building-to-building shading and solar access, as demonstrated in the preliminary UI conceptual view shown in Figure 2.

District systems will be explicitly laid out on the 2-D map, ensuring that space for these systems is preserved in the final plans. Several types of district systems will be supported, including community-scale PV, central heating and cooling plants, ground source heat pumps and ambient loops, and community energy storage (battery and thermal). Properties of district systems will be easily viewed and edited in a grid view.

The user will be able to use the OpenStudio Parametric Analysis Tool (PAT) to develop a series of design alternatives that may be considered for buildings or district systems (e.g., minimum-code buildings with individual HVAC systems versus high efficiency buildings with district energy systems). Each design alternative will be composed of a series of OpenStudio Measures that are chained together to create a detailed building energy model for simulation. The user will be able to test these design alternatives locally using PAT and once they are satisfied, they can upload them using the URBANopt UI. Once the user has uploaded design alternatives from PAT, they can use the URBANopt UI to develop scenarios by assigning specific design alternatives to each building and district system.



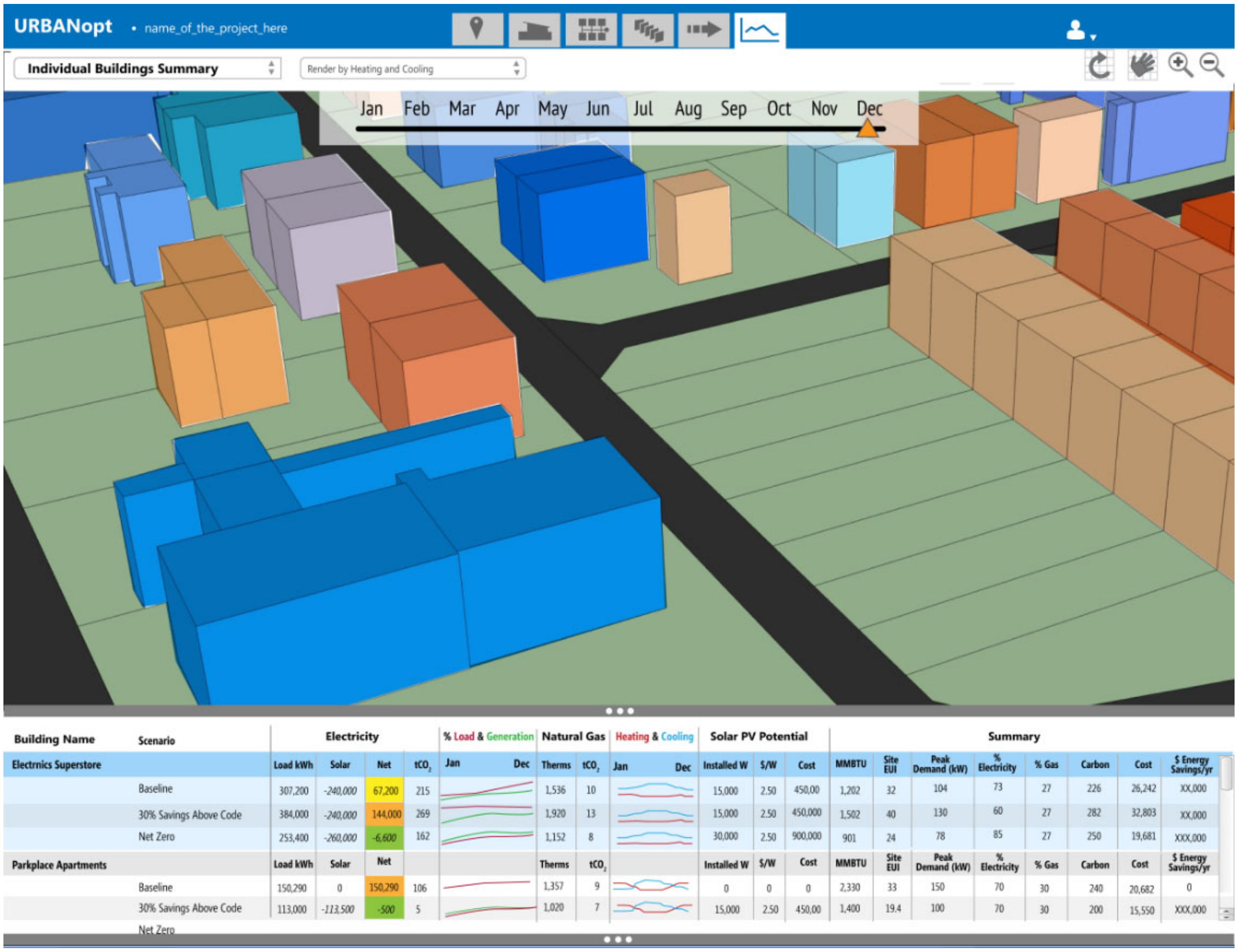
ID	Address	Track	Type	Name of Building	TotalFloor Area (ft²)	Stories	% of Rooftop PV	Orientation(°)	Delete Building
All	All	All	All		All	All	All	All	
1	111 Elm	121.01	Office	Elm Office Park 111	X,XXX	1	75	0	⊗
2	115 Elm	121.01	Mixed Use	Elm Office Park Shops/Apts	X,XXX	3	75	0	⊗
		Story 1	Retail		X,XXX				⊗
		Story 2	Multifamily		X,XXX				⊗
		Story 3	Multifamily		X,XXX				⊗
3	32 Maple	121.01	Residential	Maple Grove Homes Small	X,XXX	1	60	180	⊗
4	201 Maple	121.01	Residential	Maple Grove Homes Med	X,XXX	4	80	35	⊗
5	65 Elm	121.01	Fast Food	Quicks Subs	X,XXX	2	65	45	⊗
6	33 Maple	121.01	Residential	Maple Grove Homes Large	X,XXX	3	70	270	⊗
7	701 Elm	121.01	Hospital	General Hospital	X,XXX	2	80	0	⊗

Figure 2. Example URBANopt user interface providing a conceptual view of building-to-building shading

Each scenario will be run through the URBANopt UI. As simulations finish, results will be pushed to a DEnCity database (Roth et al. 2012). If simulation results are already available in the database, simulation is skipped, giving the user a faster response time. Buildings in the scenario will be simulated first. Then, building loads will be exported from DEnCity for each building in the scenario and used as input to the district system simulations, allowing simultaneous heating and cooling to be considered in the district system simulation.

Once the simulations are complete for a scenario, results can be visualized in several ways. High-level metrics will be reported, which will easily allow the user to see whether district-wide goals are being met for a given scenario. Additionally, results can be viewed spatially, allowing the user to look for potential simultaneous heating and cooling opportunities, as demonstrated in Figure 3. This section of the UI will include building demand profiles, critical loads, peak loads, and the maximum electricity exported to the grid. The UI will output data in a format that can be conveniently imported and used by utility transmission and distribution planning tools.

Engaging in the National Western Center and Sun Valley district energy projects is helping NREL identify design requirements for the URBANopt modeling platform and UI example. URBANopt will be tested and improved by conducting advanced analyses related to these real district energy projects.



Building Name	Scenario	Electricity				% Load & Generation	Natural Gas		Heating & Cooling	Solar PV Potential			Summary							
Electrnics Superstore		Load kWh	Solar	Net	tCO_2	Jan Dec	Therms	tCO_2	Jan Dec	Installed W	$/W	Cost	MMBTU	Site EUI	Peak Demand (kW)	% Electricity	% Gas	Carbon	Cost	$ Energy Savings/yr
	Baseline	307,200	-240,000	67,200	215		1,536	10		15,000	2.50	450,00	1,202	32	104	73	27	226	26,242	XX,000
	30% Savings Above Code	384,000	-240,000	144,000	269		1,920	13		15,000	2.50	450,000	1,502	40	130	60	27	282	32,803	XX,000
	Net Zero	253,400	-260,000	-6,600	162		1,152	8		30,000	2.50	900,000	901	24	78	85	27	250	19,681	XXX,000
Parkplace Apartments		Load kWh	Solar	Net			Therms	tCO_2		Installed W	$/W	Cost	MMBTU	Site EUI	Peak Demand (kW)	% Electricity	% Gas	Carbon	Cost	$ Energy Savings/yr
	Baseline	150,290	0	150,290	106		1,357	9		0	0	0	2,330	33	150	70	30	240	20,682	0
	30% Savings Above Code	113,000	-113,500	-500	5		1,020	7		15,000	2.50	450,00	1,400	19.4	100	70	30	200	15,550	XXX,000
	Net Zero																			

Figure 3. Example URBANopt user interface providing a conceptual view of simultaneous heating and cooling (heating: orange/red, cooling: blue, floating: purple)

Conclusions

Reducing urban carbon emissions is critical to mitigating the consequences of climate change. Buildings must achieve the highest levels of efficiency, run on renewable energy sources, and adjust their loads in a way that enables large-scale deployment of renewable technologies. In recent years, zero energy buildings have gained considerable traction in the market. Districts are the ideal platform to extend zero energy building concepts to the urban scale. NREL is engaging in the early stages of two new district energy projects in Denver to identify barriers and develop resources that enable the establishment and replication of zero energy districts across the United States. We have described some initial findings from our efforts related to zero energy districts, including a discussion of key design principles of maximizing building efficiency, solar potential, renewable thermal energy, and load control. We have also described economic drivers, energy master planning principles, and our efforts to develop URBANopt, which will extend DOE’s open-source building modeling platform to the zero energy district scale. In the future, these principles and tools may be extended and applied to the retrofit of districts with primarily existing buildings and infrastructure.

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