NZN: Net Zero Neighborhood

A Major Qualifying Project Report
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Abstract

In this project, we developed a design matrix for achieving "net zero" emissions for a neighborhood in the city of Worcester. This mid-scale approach is an opportunity for utilization of sustainable technologies at large scale and resource sharing at community level. The Net Zero Neighborhood (NZN) concept integrates FEW-systems to reduce energy use and offset any energy requirements that cannot be met by independent design strategies. A design matrix for the NZN was developed to investigate the various design strategies for a sustainable city. A neighborhood in Worcester MA is used as a case study to evaluate the impacts of this approach. A series of Neighborhood models was created in REVIT and Green Building Studio to analyze the extent of the NZN strategies on existing and new development urban projects. Considering the walls of each building from masonry or CLT panels to the internal systems for HVAC, each building was designed to perform as energy efficient as possible. With the right systematic approach and updates to be made, our findings with our neighborhood show that it is possible for all neighborhoods and buildings to near or achieve net-zero emissions.

Acknowledgements

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Chapter 1: Introduction

The United States accounts for about 20% of world energy consumption and within the U.S., buildings are responsible for about 40% of the nation’s energy consumption and greenhouse gas emissions (DOE EIA 2010). Determining a way to reduce energy consumption in existing buildings is an important step in developing “smart cities”. Energy reduction has many potential benefits, including the reduction of greenhouse emissions, increase in the security of our limited natural resources, more job opportunities, and a decrease in the repercussions from rising energy prices.

Because buildings account for such a substantial portion of energy consumption and Green House Gas (GHG) emissions, it is imperative that a unified long-term goal should be set amongst the stakeholders in the building market to give the best chance of a large-scale impact. “The goal of net-zero energy (NZE), while it may be a long-term goal, also has implications for near- and mid-term actions. A successful approach to net-zero means addressing energy use as a long-term process of continuous improvement for both new and existing buildings.” (Abi Kallushi et al.,) The process begins with short term steps to reduce energy use in existing buildings at every opportunity and to “provide technology-friendly infrastructure in new and renovated buildings that can accommodate future technologies more easily and at lower costs.”(Abi Kallushi et al.,).

While improving the energy performance of individual buildings is an important step towards net-zero, a comprehensive, long-term transformation to net-zero energy requires looking beyond the individual building footprint and considering net-zero at a neighborhood or community scale. This is important for several reasons. At an individual building level, it may not be cost effective or feasible for every building to meet NZE. However, a neighborhood system allows the ability for load diversity, heat sharing, and other resource sharing systems to be implemented. Additionally, a larger area would potentially include nearby renewable energy resources that could be utilized in different renewable energy systems.

Achieving net-zero energy at the neighborhood level enables designers and developers to consider and implement mass engagement of all possible resources native to the location. While each building individually reduces its footprint, the neighborhood as a whole thrives off of each building coexisting as one grand scheme towards the ideal future of developments.

Chapter 2: Background

2.1: Net Zero

2.1.1: Goal of "Net Zero"

"Net zero" can be defined in many different ways, whether it's net-zero energy cost, emissions, source energy, or site energy. Net-zero energy indicates that renewable energy will be used to offset any energy requirements that cannot be met by other efficient strategies (Managan, 2012), and to create climate-neutral buildings (Sartori, Napolitano, & Voss, 2012). A net-zero emissions building is classified as a building that produces an equivalent amount of renewable, emissions-free energy as it consumes from energy sources that produce emissions (Kallushi, 118). As the Building Technologies Program of the US Department of Energy (DOE) set the strategic goal for economical net-zero buildings in 2020 for residential and 2025 for commercial, there is increased attention to the topic of net-zero energy building (None, 2008). The Environmental Protection Agency (EPA) definition of the source energy captures a complete assessment of the building energy consumption by incorporating all production efficiencies, delivery, and transmission losses in addition to the site energy per year. Depending on planning goals, designers benchmark buildings based on site and source EUI (Energy Use Intensity) as performance metrics. Based on the U.S. national median reference of the Star Portfolio Manager, median site EUI ranges from 36.8 KBtu/ft^2 in worship facilities to 384 KBtu/ft^2 in fast food restaurants (Star, 2014). These medians are more dramatic if we consider the source EUI and can be as high as 1,015.3 KBtu/ft^2. In other words, net-zero source energy is considerably more difficult to achieve due to the fact that energy used in production, deliveries to the building, and transmission losses are also taken into consideration for the building (Star, 2014).

2.1.2: Defining Net Zero in the NZN

In any "net zero" definition, most efforts invest in improving the efficiency of energy production, the performance of HVAC systems, the efficiency of the construction, and human behaviors. Although other aspects such as water, food, and mixed-use development play important roles in the design process, these aspects usually are planned for separately. For example, in LEED buildings strategy and practice, standards are distributed into different categories such as water efficiency and energy (LEED, 2018), and there are limited attempts to cross-relate them. Considering the interface between the water and food systems with energy provides diverse possibilities, some effortlessly marketable for reducing emissions while improving the energy performance of buildings. Therefore, in the NZN model, we define "net zero" as net-zero emissions and examine these interfaces for integrating the food, energy, and water (FEW) systems that contribute to the production of emissions.

2.2: From Buildings to Communities: Re-Defining Net-Zero

A variety of definitions have been offered for NZE buildings and, more recently, NZE communities. As noted earlier, in general a net-zero energy building is one that maximizes energy efficiency and then uses on-site power to meet the remaining energy needs. Similarly, an NZE community consumes no more energy than it is able to produce through renewables located in the community's perimeter or in surrounding non-urban areas (Carlisle et al. 2009). An NZE community also aims at reducing energy use across the entire infrastructure of the community: buildings, transportation, water, and more. The success of both NZE buildings and NZE communities depends on an integrated design approach and attention to energy performance over the full life-cycle, past design, construction, commissioning and the certificate-of-occupancy to tie in efficient operation and effective feedback on energy performance to operators, occupants, and owners (Harris et al. 2011).

A definition for a net-zero energy community is more complex than for an NZE building because the spatial scale of a community encompasses energy used not only for buildings but also for industry, vehicles, and community-based infrastructure. Pursuing a net-zero goal for communities does present more opportunities for renewables. However, accounting for a much larger set of systems and components that make up the entire community also presents new challenges.

2.2.1: Net-Zero Community Components and Approaches

In the next section we address several components of a net-zero community including short-term and long-term goals, development approach, integrated design, and stakeholder's involvement.

1) Short-term vs. Long-term Goals → A successful net-zero community is most likely to be achieved through an integrated set of short-term goals, which work towards the longer-term goal of net-zero. The goals and strategy will vary on a case-by-case basis depending on the ratio of new and existing buildings. While the ultimate long-term goal is for the community to consume only as much energy as it produces on site (or in adjacent open spaces), the range of actions over time to get to that goal are complex. An approach that focuses on maximizing energy efficiency first should also pay attention to preserving existing buildings and infrastructure where it makes sense and improving their energy performance through retrofits – given the energy embodied in existing buildings and the energy required for demolition, as well as aesthetic, cultural, and historic values. A recent NBI report identifies both net-zero energy buildings and buildings that are "zero energy-capable, which are energy efficient enough to be zero energy, but have not taken the final step of on-site renewable generation." (NBI 2012a) This concept of "net-zero readiness" can be adopted for NZE communities as well, through careful use of planning, zoning, and development permitting requirements.

2) Preservation and Redevelopment → While much of the recent attention to net-zero energy neighborhoods or communities has focused on residential single-family development, we believe than even larger potential lies with mixed-use communities such as military bases, university or health care campuses, or perhaps urban redevelopment zones and suburban planned-communities. For obvious reasons, new construction makes it easier to build in net-zero (and net-zero capable) features, but at least some of the same opportunities may be present in redevelopment of older neighborhoods – especially because older neighborhoods, designed before exclusive-use zoning was the norm, are more likely to have mixed building uses and buildings that were originally designed in the pre-air conditioning period with good solar orientation, daylighting, high ceilings, and other climate sensitive "passive" features.

3) Integrated Design → In early 2011, the Commercial Buildings Consortium (CBC, a public private consortium of 500 member organizations, led by DOE), released two major reports: "Next Generation Technologies Barriers and Industry Recommendations" and an "Analysis of Cost and Non-cost Barriers and Policy Solutions." While the reports focus on individual commercial buildings and their path to net-zero, a number of the recommendations can be applied at the community scale. These reports found that achieving low- and net-zero energy performance depends less on individual technologies than on well-executed integrated design and integrated community systems-level analysis. The role of integrated design becomes even more crucial in the case of net-zero communities, as there are many more components to consider. The key is to consider the entire community as an integrated system rather than addressing each of the components of the community separately.

4) Involving Users → The users in NZE communities - residents, those who work on site, or those who visit to buy goods and services on site - directly impact energy use. The success of net-zero communities will provide incentives for community cohesion and buy-in from users, in which owners and tenants are conscious and supportive of the goal of net-zero. Residents and users of NZE communities are also likely independent to a certain degree , thus making this goal more achievable. Community involvement will be fostered through feedback and education. An open communication framework among utilities, businesses, schools, households, etc. could be the first step to building a community of NZE supporters and contributors. The concept of “net-zero” thus goes beyond just buildings and infrastructure to become part of the lifestyle of those who live, work, shop, and recreate in the community.

2.2.2: Characteristics of Successful Net-Zero Communities

Emerging examples of NZE communities share a number of attributes including scale, timeline, financial criteria, ownership, and construction type, which all yield profiles of sites that make good candidates for net-zero communities.

1) Scale → The strategy for achieving an NZE community may differ depending on the scale, which can range from only a few buildings to a large campus complex or redevelopment district. For designers attempting to achieve NZE status on each of these scales, there are numerous challenges (and opportunities). For smaller groups of buildings representing a smaller mix of uses, the developer may benefit from building types and uses with very low energy consumption and ample roof or ground space for renewable energy installations, which makes meeting NZE goals more manageable. However, these smaller clusters also provide fewer opportunities to achieve the advantages of system scale and load diversity available in larger NZE communities. For larger groups of buildings, whether on an existing campus or a new planned development, achieving net-zero goals is more challenging by their sheer scale and the need to achieve and sustain major reductions in energy use in a larger number and range of building types. However, larger sites also allow power generation to be located in areas that might not otherwise be available in a smaller site. Thus, a college campus or military base might have the option of locating a solar PV installation (or a solid waste CHP unit) in an otherwise underutilized area unavailable to a smaller development.

2) Financial Criteria and Time Frame → The financial resources or requirements of NZE developers have a direct impact on the feasibility and success of these developments. Compared to conventional construction, NZE communities may have higher up-front development costs due to both building-level efficiency measures and infrastructure investments, including on-site generation capacity. Although these attributes convey significant value in the long-term by lowering operating costs, it may be challenging to find buyers and lenders who are prepared to attribute full value to long-term cost savings. For conventional real estate development structured around immediate sale or short-term asset holds, the economics of NZE-type assets can be very challenging under current property valuation practices. Consequently, successful financing of an NZE community at present requires a client who intends to have a long-term ownership or financial involvement. Government or institutional clients, corporate headquarters, or "buy and hold" investors are therefore ideal clients for NZE developers and owners.

3) Ownership → Single ownership of the community's buildings and infrastructure can also contribute to the feasibility of an NZE development. By working on the same construction schedule and calculating building energy loads in aggregate, decision-makers and designers are better able to allocate and balance energy loads efficiently throughout the site—a process that would be more challenging if spread among different actors. The sale or lease of buildings within a site subsequent to construction may dilute the unified decision-making ability of a single developer or owner. However, operating covenants or other arrangements for unified management of the community's infrastructure can help assure effective energy management over the long term. Nonetheless, single ownership – by a government agency, university, or health care organization (etc.) makes achieving and maintaining NZE status much easier.

4) Construction Type → When creating entirely new communities, designers have an ideal opportunity to achieve NZE status. For renovation of existing buildings and neighborhood renewal the challenge is greater, as some opportunities to optimize energy efficiency are no longer available or practical (e.g. building orientation, massing, and solar exposure). Major renovation offers the best chance to improve energy performance in existing buildings, but it is difficult to do so while preserving other desirable building attributes, including historic and architectural features.

2.3: FEW Framework

The NZN is designed to provide assessments to optimize strategies for net-zero emission urban projects by simulating different combinations of sustainable strategies. Technologies across food, energy, and water systems can catalyze each other to achieve higher benefit than each would individually. Additionally, the benefit of these systems needs to be accounted for at the neighborhood level to capture the holistic capabilities of FEW connections that work cohesively towards a net-zero goal.

Constructing net-zero energy buildings, whether the goal is the site or source EUI, can be remarkably challenging and extremely expensive especially for high energy intensive buildings such as hospitals or supermarkets, while clustering buildings into groups can increase the possibility of achieving the net-zero goal within a reasonable cost range.

In the NZN framework, Food, Energy, Water are categorized into three separate models; each is broken down into multiple sub-features (Figure 1, 2, and 3). For example, in the Energy model, combined heating & cooling, renewable energy, energy efficient buildings, and local resources serve as four sub-features. Depending on project specifications and goals, sub-features may include single or multi-level sustainable design strategies. In the Energy model (Figure 2), the combined heating & cooling sub-feature breaks down into the multi-level design strategies of passive systems and district heating & cooling. These multi-level design strategies break down even further to cover more specific design strategies such as heat island effects or biomass-fired district heating plants. Other sub-features, such as local resources, only consist of one-level strategies like mixed-used development and diverse employment opportunities.

One of the main design aspects of the NZN is creating an integrated interface for FEW systems. Although the NZN framework consists of separate models, they interact with one another at the sustainable design strategies level. The environmental effects of these sustainable design strategies were analyzed using a holistic approach. This method leads to the creation of a comprehensive repository of possible planning and design strategies for minimizing resource consumption and reducing environmental impacts. For instance, in the Food model, the district composting design strategy has more contribution to the overall sustainability picture than just the Food system. Therefore, this strategy interacts with other NZN design strategies in the Energy and Water models (Figure 1).

The relations amongst the Food, Energy and Water systems help to foster a comprehensive approach to the challenges of reducing emissions and resource consumption within a community. This can be illustrated through relations such as the connectedness of food systems and energy systems. For example, the food systems of rooftop gardens, vertical farming, edible walls/balconies, greenhouses and district composting can help reduce energy concerns by reducing heat gain, improving the ventilation of a building, reducing heat island effect, promoting mixed use of buildings, creating new employment opportunities, and reducing transportation. In terms of relatedness of food systems and water systems, the food systems of nutrient cycling, district composting, rooftop gardens, vertical farming, edible walls/balconies and greenhouses can be supplied by the water systems of the community through collection via permeable surfaces, recollection for irrigation, grey water reuse and biosolids compost. Furthermore, energy and water systems are related through...

The NZN design has the flexibility to cope with the high levels of complexity in urban systems and diverse projects requirements. As an example, if a designer does not plan to incorporate the wastewater into the Water model (Figure 3), they could disable this sub-feature without affecting the overall design. Users can also add new sub-features and design strategies to the framework, given proper interrelation and correlation coefficients to other features are provided. As the NZN assists designers and planners for developing a net-zero emissions urban project, flexibility in features can also work as feedback systems for updating and upgrading the existing framework. Project-specific models can communicate with an online central database and provide the opportunity for future investigation in the suggested configuration. Similar to Energy Star Portfolio Manager used for evaluating LEED design strategies in building performance (Scofield, 2013), the NZN framework will incorporate a sensing and measuring platform so that different design combinations can be monitored and evaluated within a year of implementation.

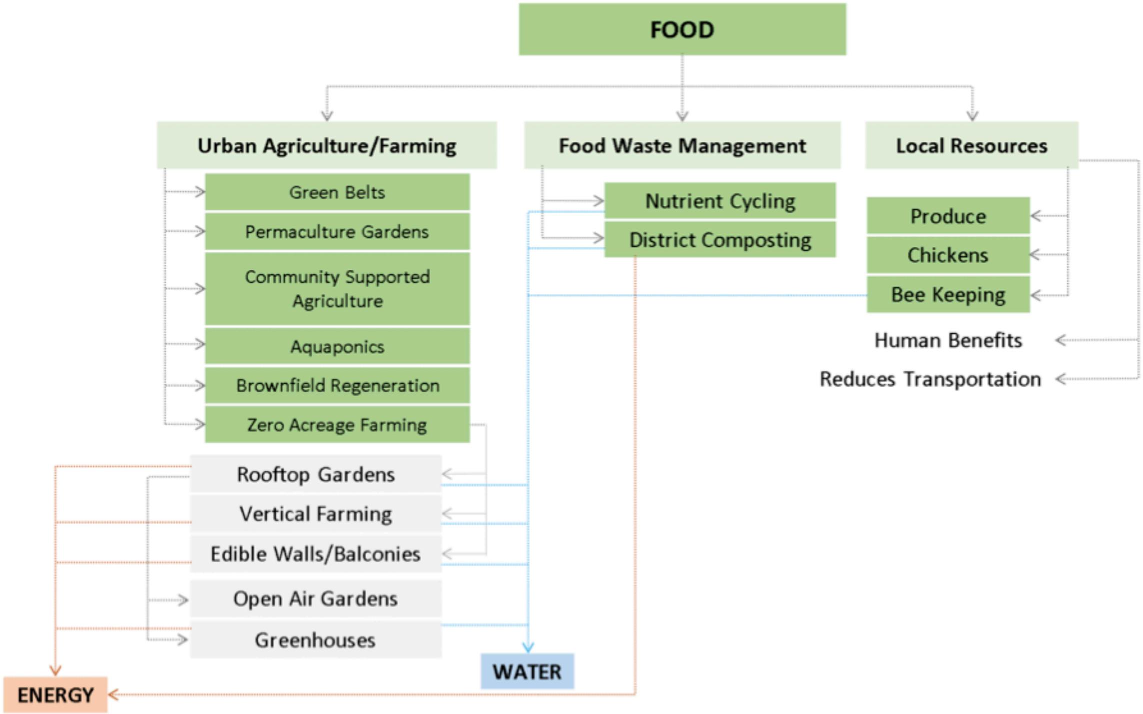


Figure 1: NZN Food Model

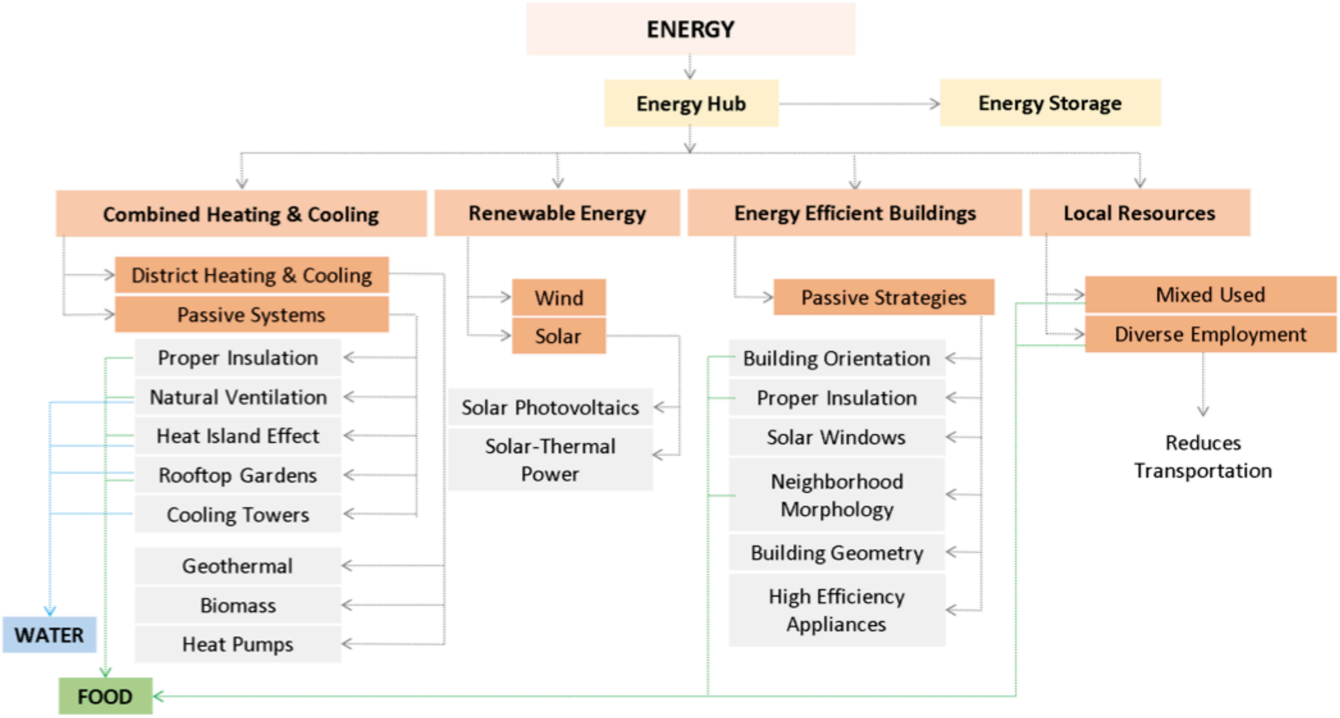


Figure 2: NZN Energy Model

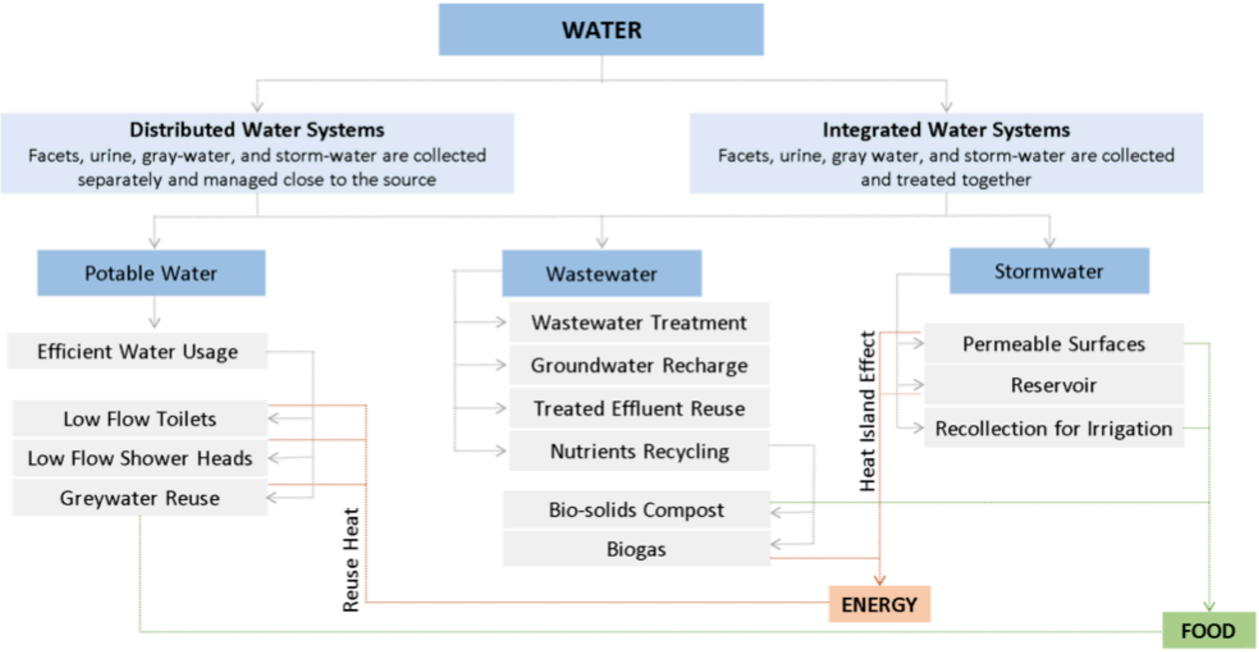


Figure 3: NZN Water Model

2.4: Case Studies

2.4.1: West Five

Using SMART and net-zero technologies, this net-zero community in West London, Ontario is currently being developed based on the success of the net-zero building, Sifton Centre. The Sifton Centre is equipped with solar rooftops and facades, occupancy sensors that coordinate heating and cooling, automatic tinting glass windows, green roofs, low-flow plumbing fixtures and a 24,000 litre rainwater tank used for flushing toilets (Williams, 2018). The net-zero community is defined by its mixed-use buildings, net zero commercial buildings, and pedestrian walkability with ample green space. Townhouses, senior housing, an apartment building, a pet facility and solar parkade to supply energy to these buildings are under development (Williams, 2018). West 5 is designed and built with the latest technologies to promote sustainability and urban living. The community has features such as electric vehicle charging stations, solar streetlights, weekend farmers markets, indoor bicycle storage, and rainwater harvesting. Through its net-zero design West 5 has offset 105,000kg of GHG, and saving more than 4 million kWh in one year (Sifton, 2019).

2.4.2: Geos Neighborhood

Located in Arvado, Colorado, the energy needs of the Geos Neighborhood are met by solar panels and geothermal energy thanks to a unique passive solar checkerboard housing orientation. The intentional placement of homes, their window sizes and window overhangs, reduce energy use while providing a walkable community with a community garden, senior housing, fruit tree co-ops, retail space and corner stores. Notable systems also include heat recovery ventilators and storm water recycling. Passive house techniques are utilized to maximize air tightness and paired with mechanical ventilation equipped with a heat exchanger to enhance air quality. When designing homes affordability is a key component to the design; therefore, economic factors are considered such as the viability of using the lower cost of installing a PV panel to offset the cost of expensive wall insulation. The building envelopes of the buildings are constructed by Structural Insulated Panels (SIPs), reducing air leaks to 4% in comparison to the average 35% to 50% of a home built to code. These envelopes are so airtight and insulated that the homes demand only 20% of heating and cooling measures of a traditional home. Additionally, windows within the home are triple-pane fiberglass. In the winter months, south facing windows allow maximum solar heat whereas west and east facing windows reflect solar heat in the summer months and are shaded by nearby trees. Minimum heating requirements of the buildings are met by geothermal heat pushed through multiple connected buildings with 3” duct work or mini-split air source heat pump systems. On colder days electric strip heaters are used, this is only 20% of yearly heating hours and can be powered by one solar PV panel. Water and landscape are also incorporated in the design of the Geo neighborhood through street tree rain gardens, greens, squares, permeable paving and localized rain gardens. These features irrigate local plantings, orchards, and gardens. Neighborhood design also includes community gardens, composting areas, walkable schools, recreation centers and gathering spaces (Geos Neighborhood, 2019).

2.5: Conclusion

As technology has significantly improved with respect to building energy performance and the ability to harness as much as renewable energy as possible, new developments have the ability to incorporate the various strategies that many of the pioneers of net-zero design have used. Despite a general trend used in many of the case studies such as utilizing as much solar energy and green space as possible, designing buildings and neighborhoods to be net-zero is very flexible in terms of which features are incorporated. Considering the relationship and connection with the FEW framework and any site, each design has the ability to be very unique. For buildings and neighborhoods to be successful, it is integral for the unity of food, water, and energy to be considered as one system composed of 3 subsystems that are interconnected.

Chapter 3: Methodology

In this project, we proposed the feasibility of achieving the goal of “net zero” for neighborhoods, specifically neighborhoods in Worcester, MA. In order to achieve this goal, we developed the following research objectives:

1. Update current FEW framework to match the needs of our project
2. Select an existing neighborhood in Worcester and develop a baseline energy model
3. Design a Net-Zero Neighborhood model as an alternative for the selected Worcester neighborhood
4. Investigate the energy performance of the new Net-Zero Neighborhood to the existing neighborhood
5. Determine the best building material in terms of NZN and structural requirements.

In this section, we describe the methods utilized to accomplish each of the four objectives.

3.1: Objective 1: FEW Framework Updates

In order for the FEW framework to be a useful tool in the development of our project, it was necessary to adjust the model for the specific parameters of our project.

3.1.1: Research

The updating of the FEW framework first started with a sizable amount of research. To begin with we started by looking at all the design strategies in the existing FEW models to determine whether they would be applicable to our project. For example, in the Food model, local sourcing of chickens would not be applicable to our project as the raising of chickens in the City of Worcester is not allowed. Another example would be the heat island effect from the Energy model, as this would not be a factor in our project since we are only focusing on an area within the city. With this information we were able to rule out all the features that would not be incorporated in our Net-Zero Neighborhood. Additionally, new sustainable design strategies were added to the existing FEW models. For example, in the Energy model strategies like CO2 Recycling (CHP system) and Structural Insulated Panels (SIP) were researched and added; they were placed under “heating and cooling” and “energy efficient buildings” sub-features respectively.

3.1.2: Case Studies

In addition, we investigated several case studies to explore new and relevant sustainable design strategies for us to research and incorporate into the existing FEW models. In addition, by finding case studies with similar environmental conditions (type of area, climate, available resources, etc.) we were able to narrow down design strategies even further by identifying those that worked best in similar conditions. Finally, the case studies also provided a great guide for us as to which sustainable design elements work most cohesively and which were actually incompatible with each other (Figure 4). For these reasons, we felt it was necessary and extremely helpful to add a key to the FEW models representing the different cases we studied and linking them to their respective design strategies of focus.

3.1.3: FEW Framework Update Results

Figures 4 through 8 are the updated FEW based on our research. Since our project is focused in a city environment, we felt it was necessary to add two more models, Infrastructure and Society, to the original three.

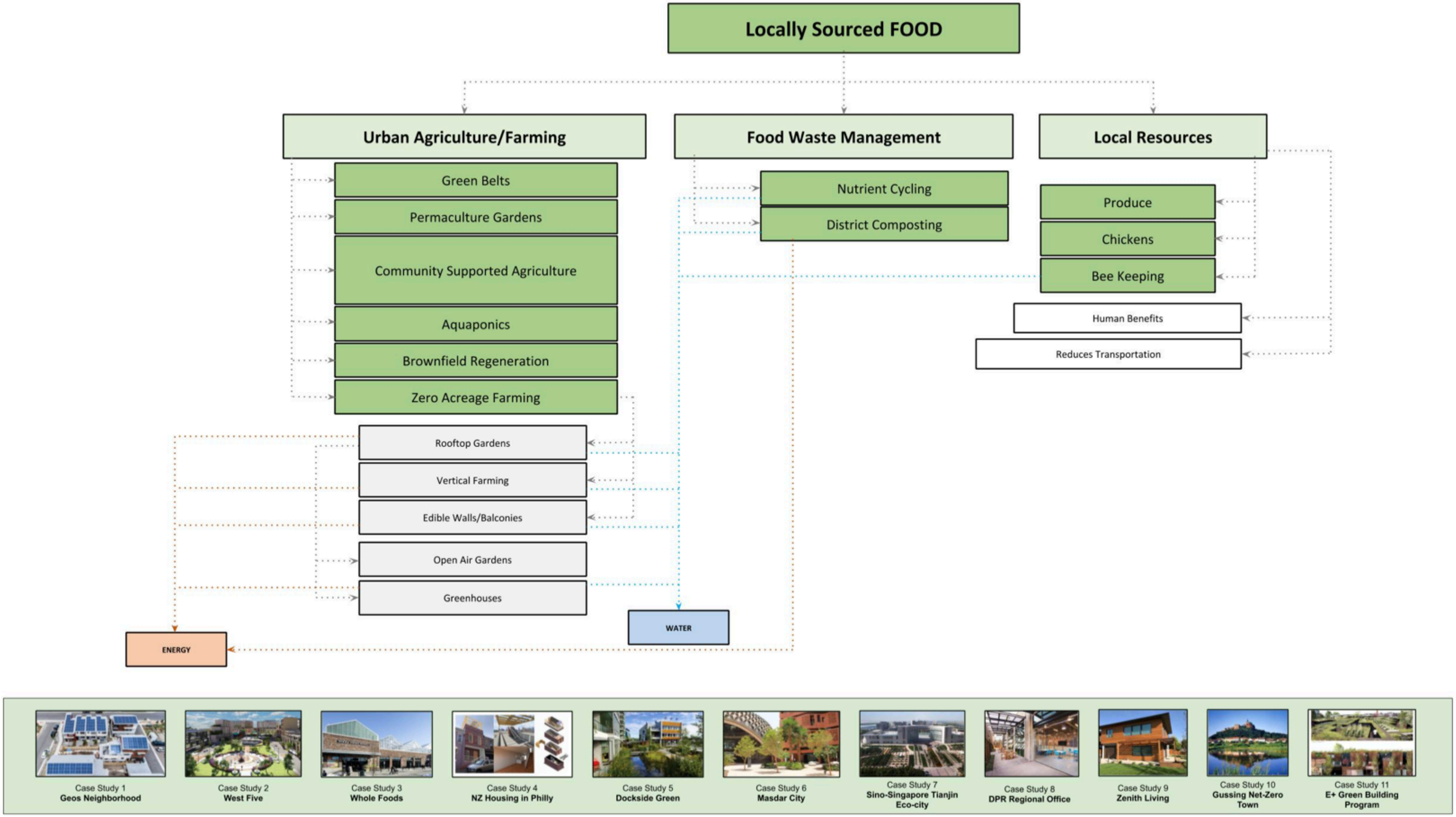


Figure 4: NZN Food Model

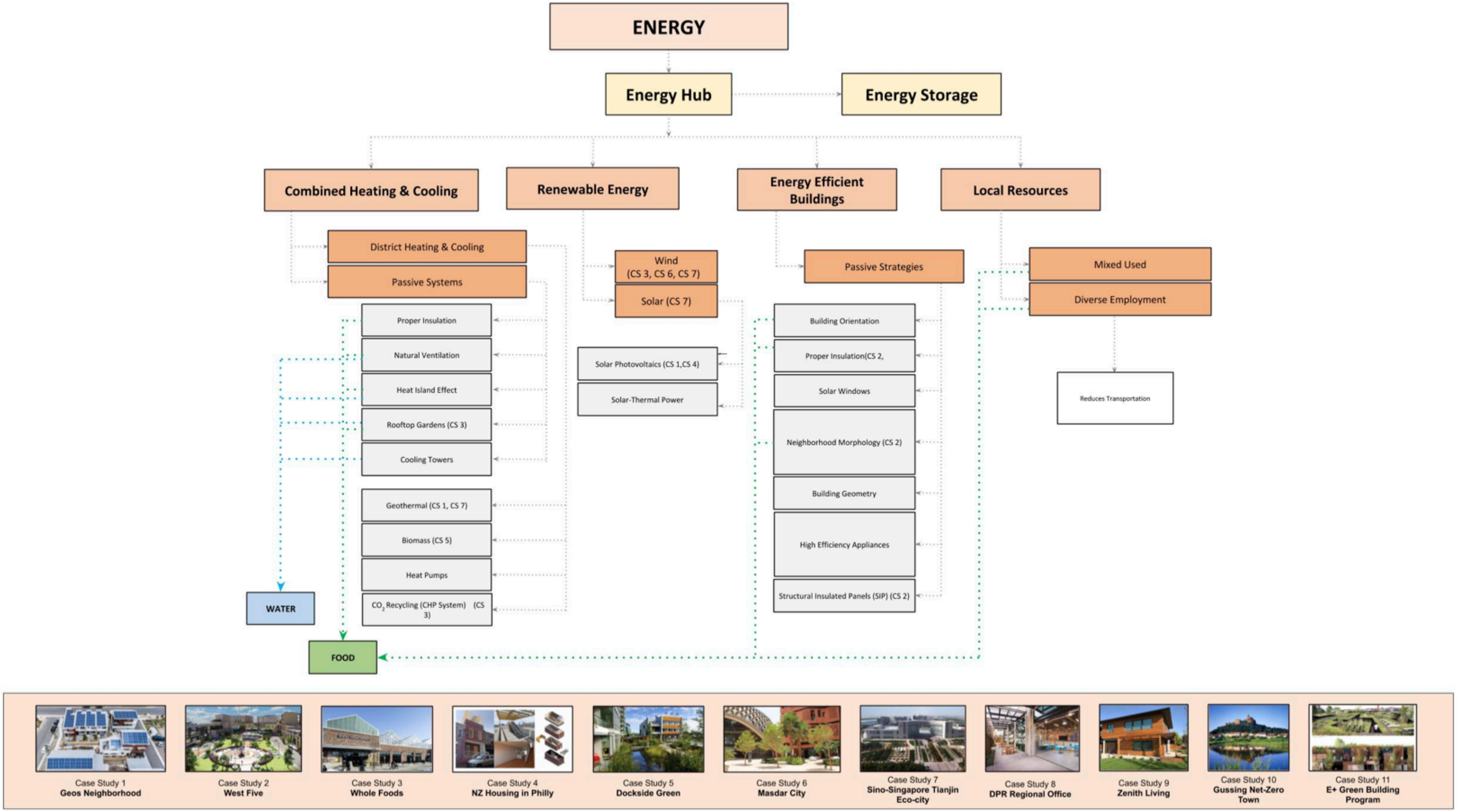


Figure 5: NZN Energy Model

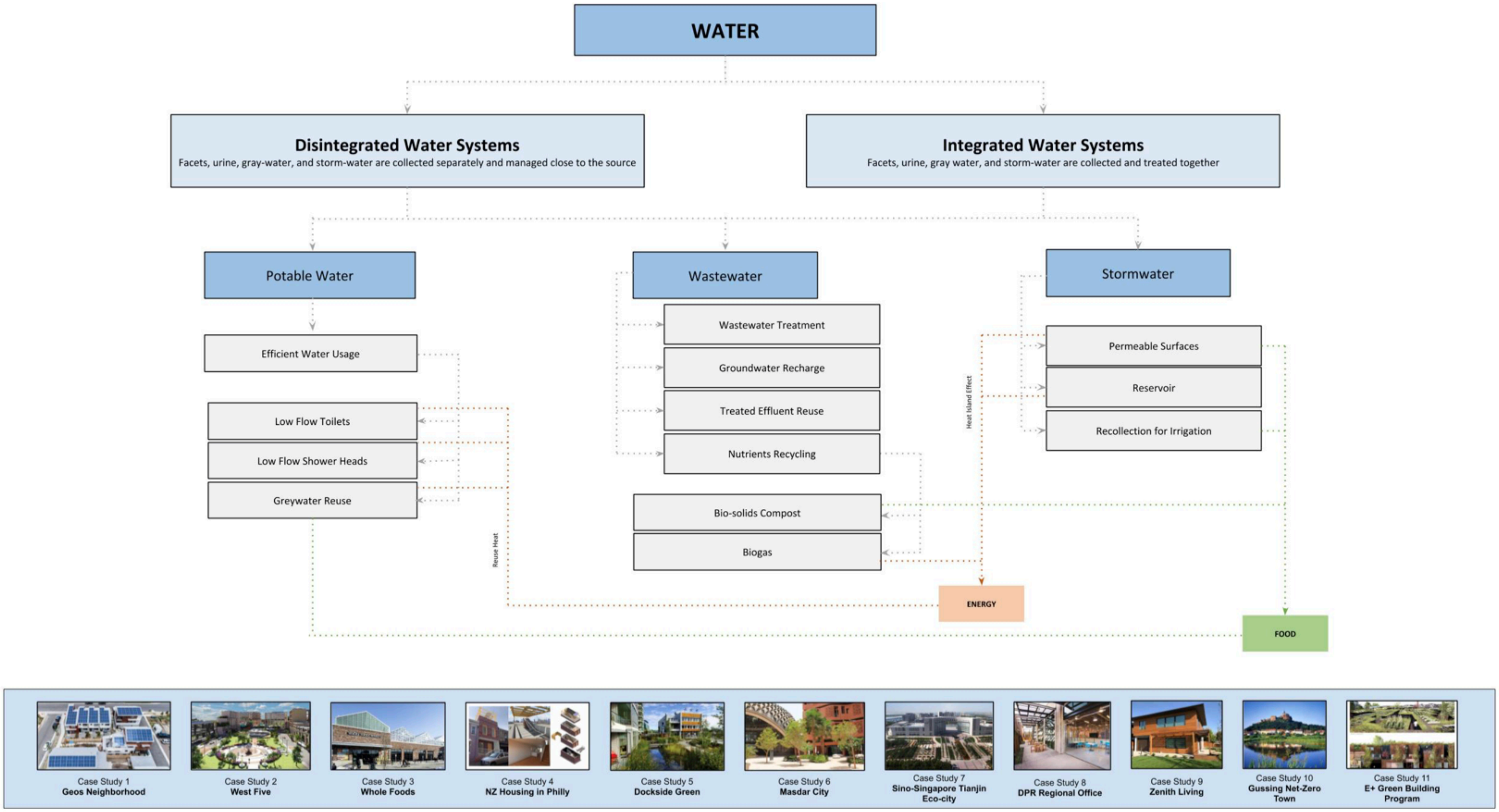


Figure 6: NZN Water Model

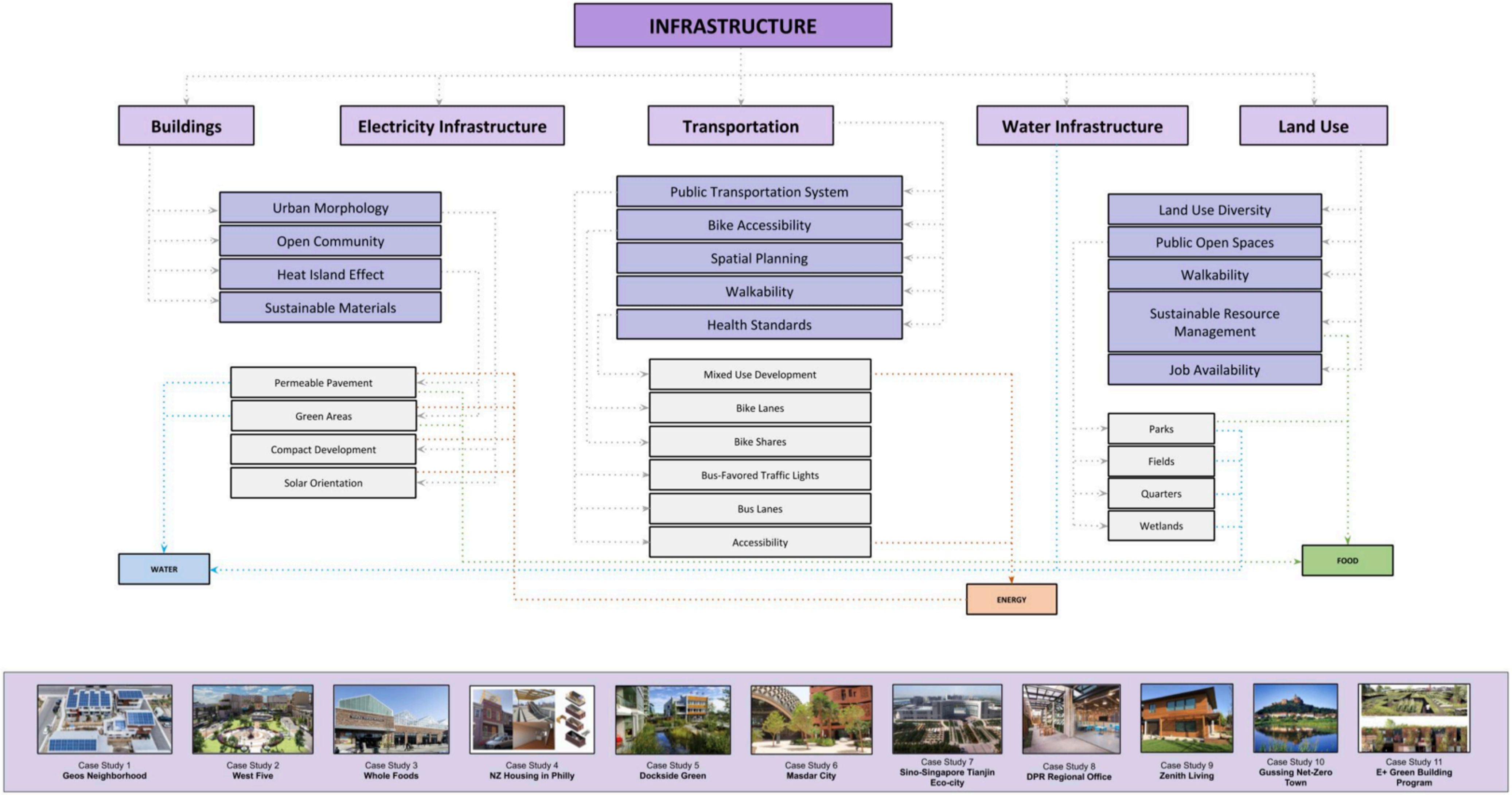


Figure 7: NZN Infrastructure Model

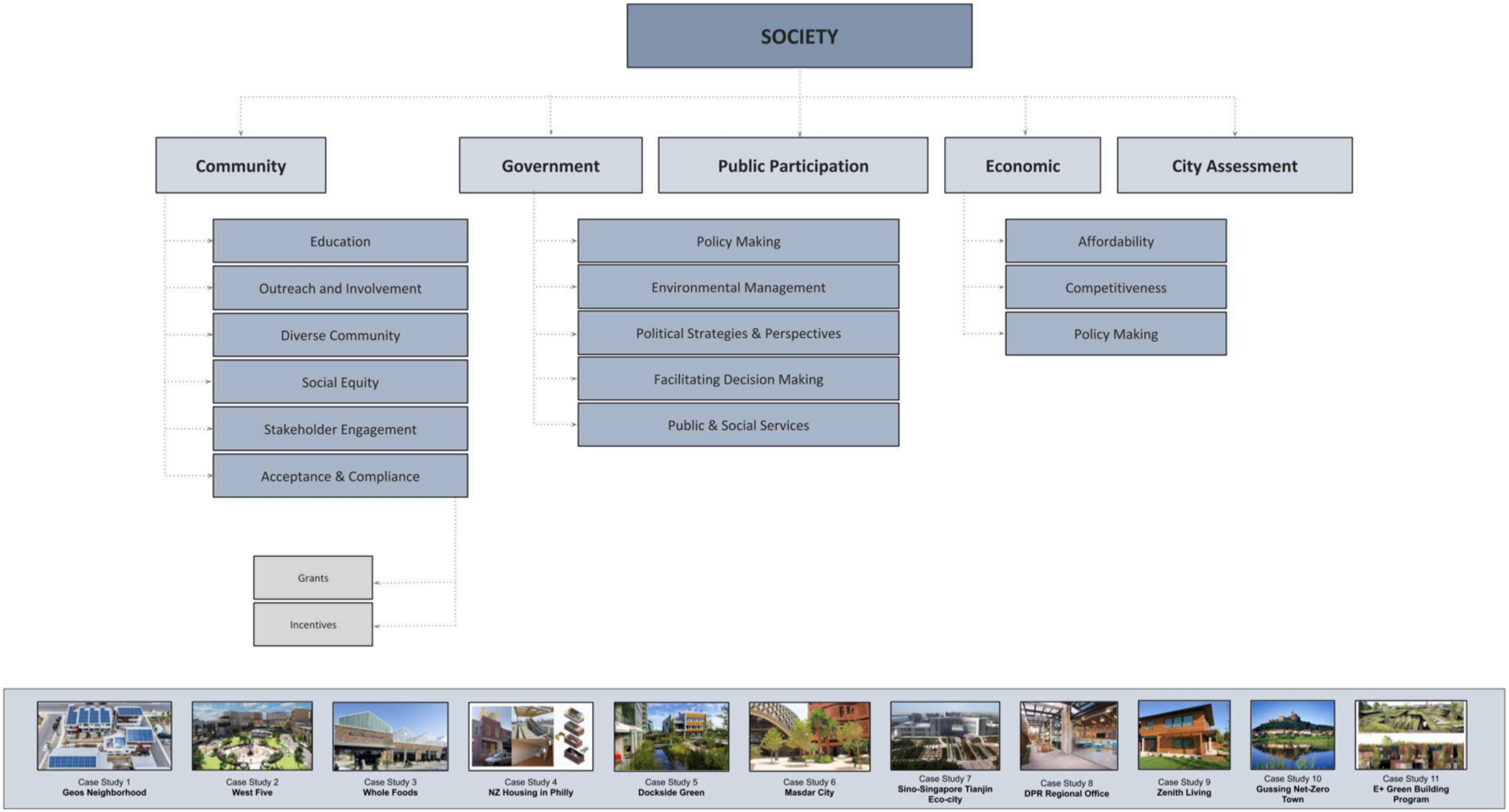


Figure 8: NZN Society Model

3.2: Objective 2: Developing a Baseline

Our second objective was to develop a baseline neighborhood model. As with any project, having a baseline point to reference is very important and can be extremely beneficial. A baseline acts as a starting point against which you can show that your project has delivered tangible improvement. For this project, an existing neighborhood in Worcester, MA was selected to act as our baseline.

3.2.1: Neighborhood Selection

For this project, there were no guidelines given for the neighborhood we were to select as a baseline. Because of this, we decided to reference work previously done on this project, as discussed in the background, for size, building type, and general location/zoning. With this information we were able to select a neighborhood in the Canal District of about 404,490 sq.ft. as shown in the map below.

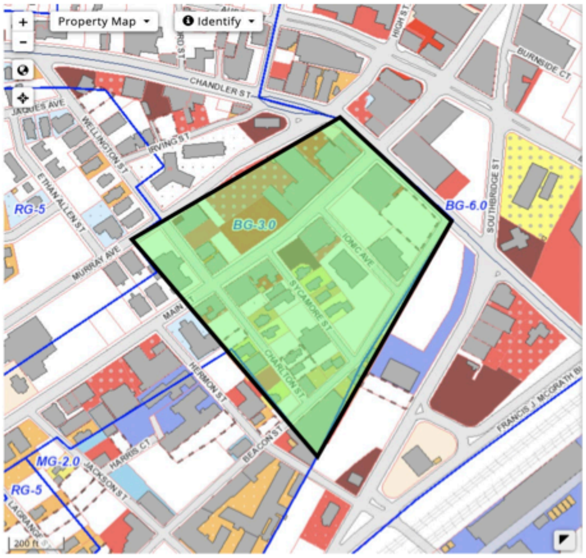


Figure 9: Highlighted Neighborhood

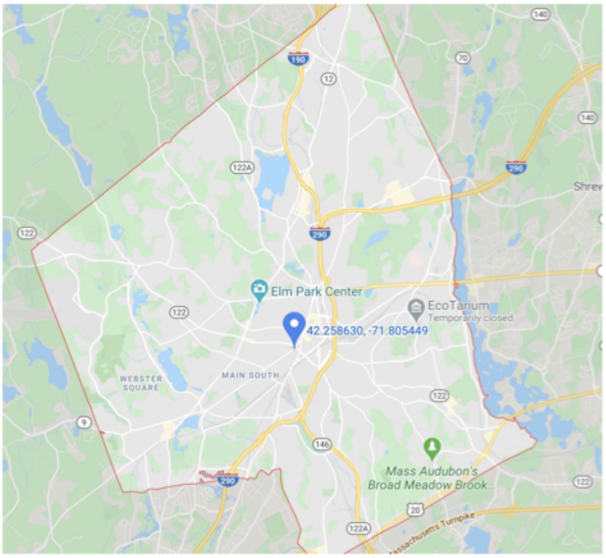


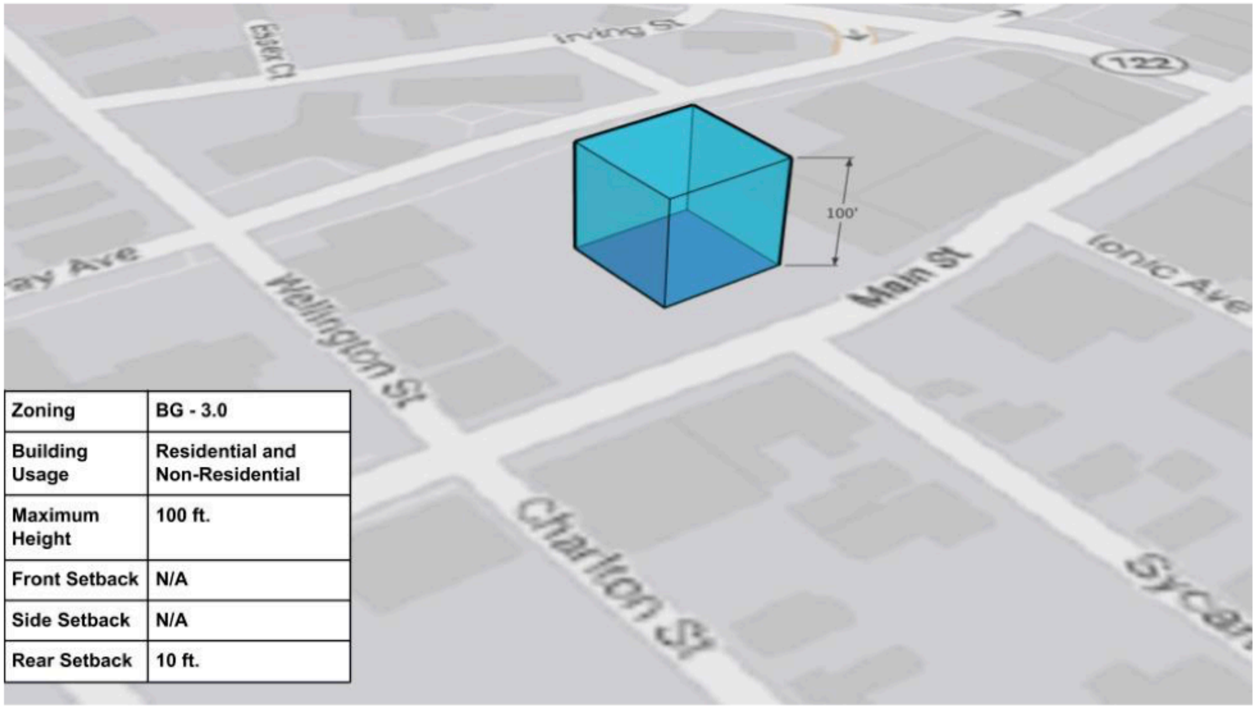
Figure 10: Zoomed Out Neighborhood Location

3.2.2: Gathering of Neighborhood Data/Information

Once the neighborhood was selected, we focused on collecting data and information about the neighborhood. This information was essential in creating a baseline model for our selected neighborhood. With this information, we could input the data into an energy simulation, in order to have an accurate understanding (with supporting graphics) of the current FEW usages in the selected area. These data points were collected by researching neighborhood history and FEW data for the existing buildings.

3.2.2A.: Building and Neighborhood History

For our baseline it was vital to get as much information about the neighborhood as possible. Using the *International Building Code* and *City of Worcester Zoning Ordinance*, we were able to compile data on the general space, for example, permissible uses, setbacks, building height limits, etc. This type of information would be used later on in the new Net-Zero Neighborhood NZN design. Also, with the help of Worcester's Geographic Information System database, we found the specifics of a majority of the properties/lots within the defined neighborhood. This information included what was on the lot (building, vacant, condemned, parking, etc.), who owned the property, and occupant density. If there was a building on the property these databases provided further information as to what type for building it was (residential, commercial, mixed, industrial, etc.), square footage, number of stories, building materials, type of HVAC system, and more. This information was especially important to have for this project as we would be attempting to recreate the existing neighborhood as a model in Revit.



Zoning	BG - 3.0
Building Usage	Residential and Non-Residential
Maximum Height	100 ft.
Front Setback	N/A
Side Setback	N/A
Rear Setback	10 ft.

Figure 11: Neighborhood Zoning Model

3.2.2B.: FEW Information

In addition to building history and property information, it was also important to collect statistics on FEW from the existing neighborhood and FEW systems that were already in place, if any. In looking for this information it was clear that finding specific food, energy, and water usage per building was not going to be available to us. From this we adjusted to researching on a broader scope and looked at average FEW information for the City of Worcester instead. The statistics we were able to collect from this research included average energy usage, average fuel usage, and average water/sewage usage of residential, commercial, and industrial type buildings.

3.2.3: Building of Baseline Model in Revit

Finally, with all this information, we were able to form our baseline model. Using the building/property information collected, we modeled the neighborhood in Revit, a building design software. In addition, for energy analysis we exported the REVIT model into the Gbxml and utilized Green Building Studio. This add-in allowed us to quantify the design strategies and produce an energy simulation/analysis for our specific neighborhood area. With this, our baseline model was completed.

3.3: Objective 3: Designing an NZN Model

To design an NZN Model, we developed roadmaps for our site and each building as a framework for the entire model.

3.3.1: A Systematic Concept

The process of designing a building can be very complex and the process of designing a whole neighborhood is even more so. In designing a net-zero neighborhood, there were many requirements that needed to be met and guidelines from case studies that we wanted to follow. Initially, it was a must to consider the use of each building designed. Incorporating net-zero features that best fit the use of each building was an integral component of design to reduce the complexity of each building. With the ability to grasp an understanding of the best methodology to design individual buildings, expanding our scope to the neighborhood level became a far simpler task. At the neighborhood level, the underlying task was to distinguish which features we could best utilize from our site that allow the individual buildings to coexist as a whole optimally. This process was very similar to assembling a puzzle where we have all of the correct pieces but have to establish where each one fits.

3.3.2: Building Design Process

For our neighborhood, we determined we would need 32 buildings of 10,958 sq.ft., each containing at least 10 units in order to meet the demands of the existing neighborhood and also to meet NZN recommended ratios. Based on the NZN design strategies, we developed a matrix of building forms. We quickly realized designing 32 unique but cohesive buildings would be nearly impossible, but we also wanted to avoid having repeat buildings. To do this, a building design convention was formed.

Figure 12: Building Design Matrix

Underlying all features and finishes on a building is just a basic shape or a few. These shapes could be anything, a square, a rectangle, or maybe even a cylinder; for the facades, we designed a series of balconies, windows, and green walls. Depending on the orientation of a given facade, different facade elements would be selected. For example, we would have a window, solar panel, or green wall for the southern wall facade to allow for the most sunlight to be captured. Additionally, different roofs were developed to incorporate more net-zero concepts into the building shape, also keeping in mind the orientation for maximum sunlight. These roof options included features like solar panel gardens, greenhouses, variation in slopes for water collection and reuse, and various combinations of the previously mentioned elements. Finally, the grounds surrounding the building was also an element that was considered for net-zero design opportunities such as gardening or walkways. By taking the basic shape and size of our choosing and strategically adding various features and elements, we could make numerous net-zero building designs that could all live within the same neighborhood cohesively. Figure ## is the developed matrix.

For this project we decided to design four different building typologies to develop our NZN neighborhood. The designs are as follows:

Figure 13: Building Model 1

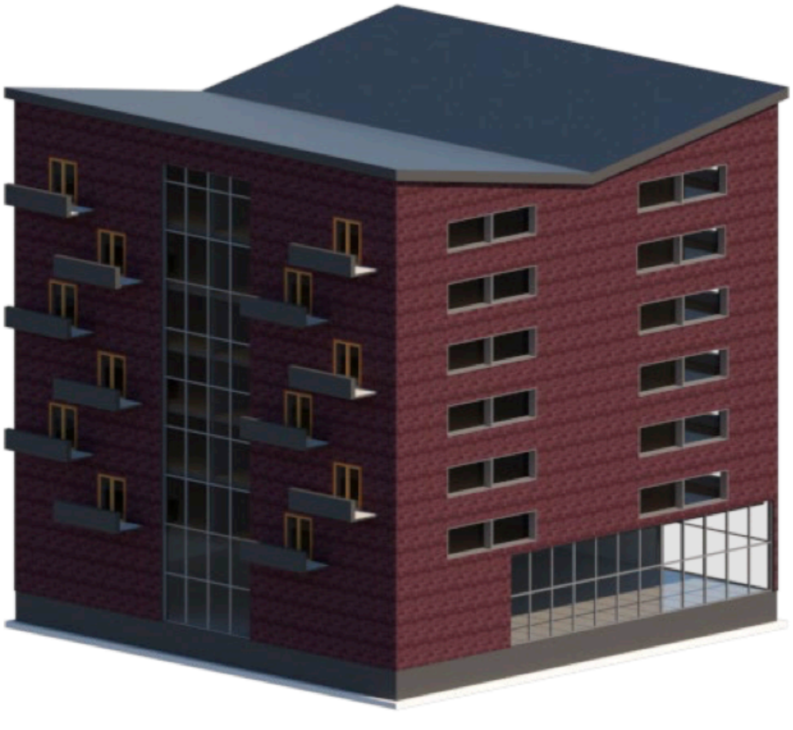


Figure 14: Building Model 2

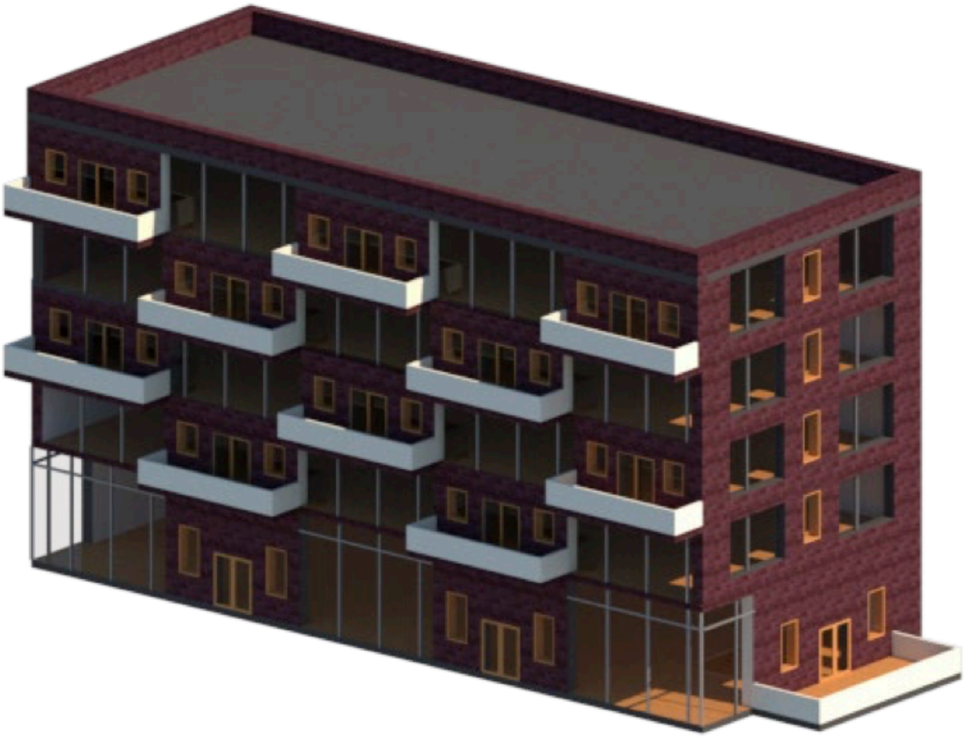


Figure 15: Building Model 3

Figure 16: Building Model 4

3.3.3: Site Design Process

To ensure the design for each building is utilized to its maximum potential, we took on a similar approach regarding the site. It was a must to continue with the needed dwellings for the site that would best suit the existing conditions as well as maintain similar usages for each building. For the site to achieve net-zero, reconfiguring the buildings, providing a means of navigation, and implementing as much green space as possible was necessary. If we decided to not alter the configuration of the site and to update the buildings that exist with the new features of the different facades, roofs, balconies, etc., the buildings would perform far from optimally.

The major considerations for redesigning the site were as follows: shading, natural ventilation, sun exposure, means accessibility in and out of the site, and incorporating green space where fit. To determine the best fit conditions for the site for natural ventilation, sun exposure, and shading, modeling and simulation was used within SketchUp and Revit. Considering that our site is located in the northeast, we designed for the winter as it is essential to utilize natural lighting and heating to limit the mass amount of energy that would be necessary for heating. With that being said, it was also necessary to consider the energy that would be used for cooling throughout the warmer months of the year, which reinforced the design considerations we previously established for the winter months. As a summary of our findings through modeling and simulation for the site, we were able to distinguish the best window to wall ratio which was approximately 35%, the appropriate distance between buildings to prevent shading at peak sun hours, and ideal hours of sun exposure each face of the building will receive throughout the day. These results can be viewed in the following figure.

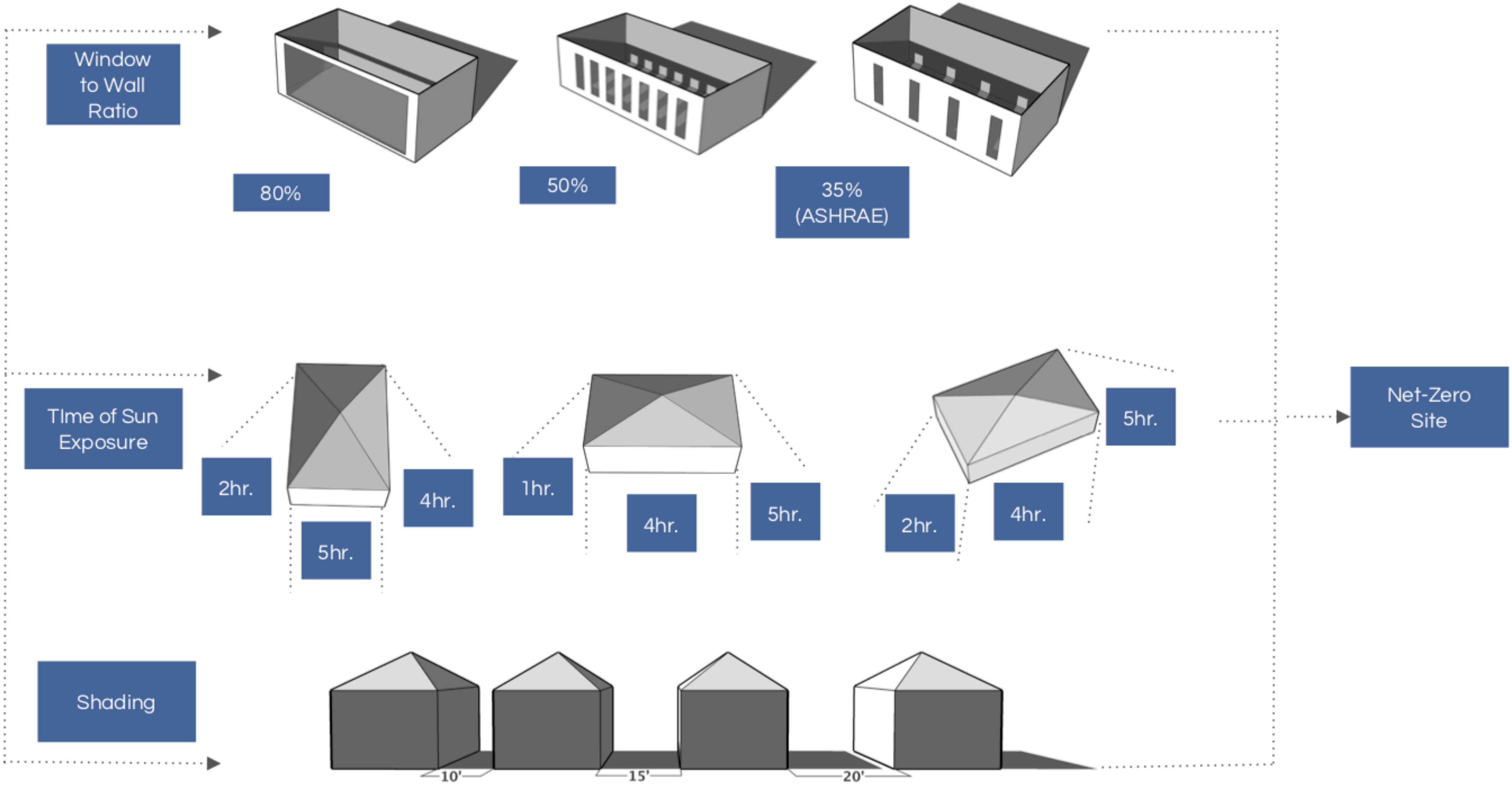


Figure 12: Building Placement Matrix

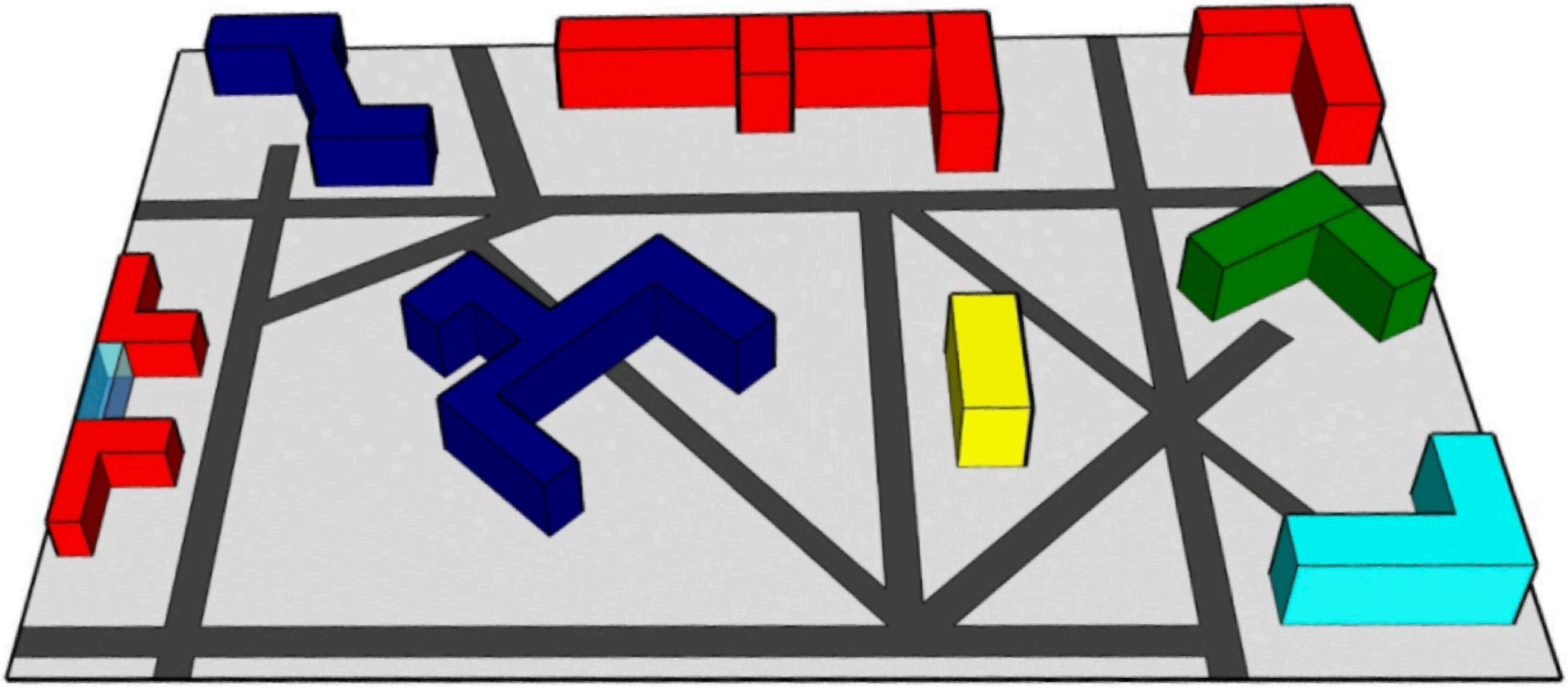


Figure 18: NZN Neighborhood Building Placement

3.3.4: A Finished Product

With consideration to each of the factors mentioned in Section 3.3.3, we were able to develop a conceptual design for our neighborhood that embraces the modular design for each building and best fits our site. While incorporating multiple means of entering and exiting the neighborhood from the main roadways that border the neighborhood, we were also able to design for easy navigation and to make transportation by automobile unnecessary within the neighborhood. The overall theme of the neighborhood is unity between the configuration of the buildings for optimal efficiency and its users.

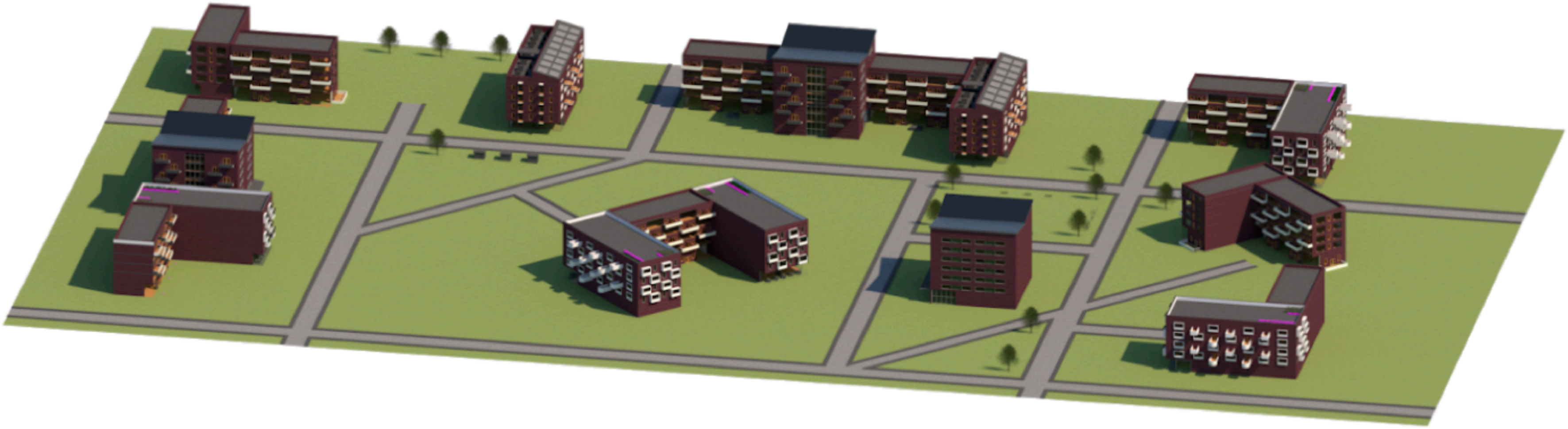


Figure 19: Final Neighborhood Rendering

3.4: Objective 4: Energy Simulation and Analysis

3.4.1: Introduction

To ensure the new neighborhood reaches improvements with respect to the existing conditions, it was a necessity to determine the baseline conditions regarding Energy Usage Intensity (EUI). The existing neighborhood EUI as well as the NZN EUI was established using energy simulation within the green building studio. This simulation and the analysis of results provide further confirmation that the changes made do indeed enhance the performance of the neighborhood as a whole.

3.4.2: Baseline Model

Working within the building modeling software Revit, the existing neighborhood was divided into groups with respect to each building's function. The groups are as follows: single family, multifamily, mixed use, retail, and educational facility. Within Revit, the construction type, building use and type, and HVAC systems were designated for each group. Using the plug-in Green Building Studio, an energy simulation was performed for each of the groups. The Green Building Studio simulation provided the EUI for each of the groups. The EUI was broken down into the specific uses of energy such as lighting, miscellaneous equipment, space cooling, vent fans, pumps aux, space heating, and hot water. The results were then compared to the national EUI values provided by RECS to ensure that our method of simulation and analysis was sufficient and accurate. In addition to determining the EUI for each building type, we calculated the EUI for the entirety of the existing neighborhood. This was completed by summing the square footage composed within each building group and multiplying that by the EUI for the corresponding group. That was then divided by the total square footage of the entire neighborhood to calculate the weighted average EUI for the neighborhood.

The energy simulation results in comparison to the national averages were fairly close with some deviation. The deviation of the results could be accounted for in the age of the buildings, as the majority of the buildings were built in the early 1900’s. Also, it could be possible that some updates to the buildings have been recently made that would alter the simulated results found to be closer to national values.

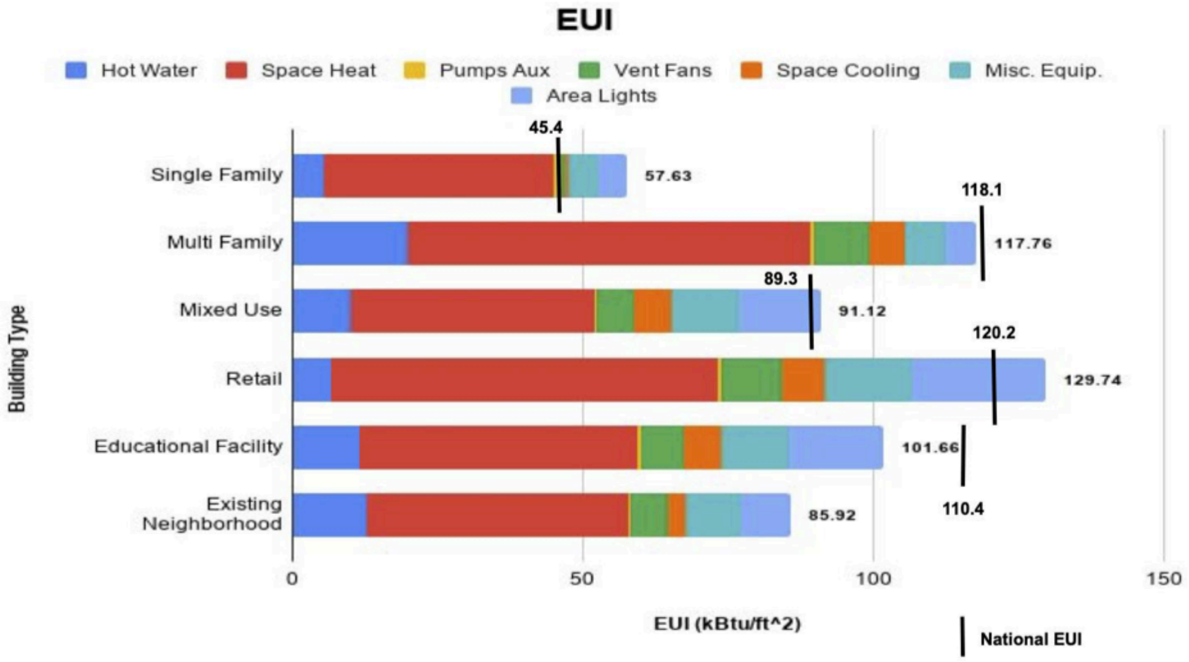


Figure 20: Baseline Energy Simulation Results

3.4.3: NZN Model

Upon completion of analyzing the existing neighborhood, we analyzed each of the new buildings in the NZN. To do so, we continued with a similar process with Revit and the plug-in Green Building Studio. For the simulation settings, changes were made to the inputs for each of the buildings with respect to the anticipated updates to our design. These updates include the facade and wall system, heating and cooling systems, PV panels, and the consideration of natural ventilation. To directly compare the EUI at a building level, we began our simulation and analysis for each building type. We then combined the simulation results for a new neighborhood using the same process as the existing neighborhood.

3.5: Objective 5: The Structural Component

3.5.1: Structural Expectations

In addition to the design of a net-zero neighborhood, our project also evaluated certain structural elements of our neighborhood. In net-zero design, a big factor that must be kept in mind is the material used in constructing a building. For the structural component of this project, we looked into the use of two different materials, masonry and cross-laminated timber (CLT). To make this comparison, lateral wind load calculations were performed to determine the necessary size and strength required of each material to support and enclose the buildings we designed. These calculations provided us with sufficient information to determine which material would be more NZN friendly.

3.5.2: Structural Alternatives

3.5.2.A: Masonry

Most commonly used in new construction during the 1970's, masonry in architecture was once a staple in society. With the advent of many new wall systems and facades, masonry has slowly begun to phase out of new construction. Despite its downfall in popularity with being used in new construction, masonry wall systems provide many advantages over many other wall systems. With brick as the exterior facade, the typical wall assembly for masonry consists of concrete masonry units (CMU) anchored and tied together with insulation in between and waterproofing. Rebar and concrete within the CMU blocks are used to add to the structural strength and stability, as masonry is not particularly strong in resisting tension from lateral loads. Structurally masonry is very strong resisting compressive loads. It can be very economical regarding transporting, material cost, and labor due to it likely coming from a local source.

To confirm masonry was a viable option structurally for our project, we needed to find an appropriate value of a lateral wind load for a masonry wall assembly. While using values that are specific to the City of Worcester, it was then possible to find values for maximum loading, cracking moment, and shear stress. It was found that 8" CMU with #4 rebar would be suitable for our buildings. Using Table 3a from TEK 14-01B and Table 9.1.9.2 from TMS 402-16, we were able to confirm that the cracking moment was larger than the moment capacity of the masonry, which ensured the masonry design would work given the loading conditions.

3.5.2.B: Cross-Laminated Timber

Cross-laminated timber (CLT) is a large-scale, prefabricated, solid engineered wood panel. A CLT panel consists of several layers of kiln-dried lumber boards that are stacked in alternating directions, bonded with structural adhesives, and pressed to form a solid, straight, rectangular panel. CLT panels consist of an odd number of layers (usually, three, five, or seven) and may be sanded or prefinished before shipping. For this project specifically, there are many advantages in using CLT over another material. To begin, CLT is lightweight yet very strong, with superior acoustic, fire, seismic, and thermal performance, making it a great material for mixed use spaces that comprise a majority of the neighborhood buildings our group designed. In terms of net-zero, as mentioned before, CLT is prefabricated making it fast and easy to install. This generates almost no waste onsite which offers design flexibility and low environmental impacts. Structurally, finished CLT panels are exceptionally stiff, strong, and stable, handling load transfer on all sides. This makes it perfect for supporting long spans in walls, floors, and roofs which is another element commonly found in our building designs.

As previously mentioned, to make a comparison between masonry and CLT, we needed to calculate the lateral wind load of a wall panel in accordance with *ASCE 7-10*. For CLT, we began by identifying the loading conditions and adjustment factors specific to the Worcester area. By applying these variables to the dimensions of our building we were able to come up with the initial estimates for loading, maximum moment, and maximum shear stress. Then, using Table A2 from the *ANSI/APA PRG 320-2018 Handbook*, we assumed a 3-ply CLT of stress grade V3 to give us the effective bending moment capacity and reference shear capacity. With these values we were then able to calculate the total load, maximum moment, and maximum shear stress. To check if the CLT size would pass under these loading conditions, the maximum moment must be less than the effective bending moment capacity.

3.5.3: Evaluation of Alternatives

Structurally, CLT and masonry were both feasible options for our design. We then had to consider factors beyond structural performance. To do this a point system was developed evaluating different factors of each material. Scoring 1 to 3, three being high or good, factors considered included energy demand, durability, ease of construction, aesthetics, and flexibility for NZN buildings.

Chapter 4: Results

4.1: Energy Analysis Results

4.1.1: Baseline Model

As shown in the previous figure, it was apparent that the existing neighborhood was far from being efficient. In many cases regarding individual building types, the baseline performed worse than most nationally. The EUI for the baseline was 85.92 kBtu/ft^2 without any renewable energy systems being utilized to help reduce the value. Our results show that space heating was the largest energy use that needed to be addressed. Despite being located in climate zone 5B where space heating is far more significant than most other locations, the value for the baseline model was significantly higher than expected. The baseline model is a clear indication that many existing neighborhoods in the case study perform inefficiently due to poor construction and lack of proper insulation. For the case of our baseline model, it is apparent that the technologies within each building and the site as a whole were not designed to reach performance-based efficiency but to be optimal for the community's needs.

4.1.2: NZN Model

With the new neighborhood, we were able to design as energy efficient as possible given the existing location and with the advent of many new building technologies. Although we were unable to achieve the status of the neighborhood to achieve net-zero status, we were able to reduce the EUI by 27.86 kBtu/ft^2. Our results display significant improvement to the existing conditions and in comparison, to the national averages, the neighborhood is far more efficient. With that being said, with the energy simulation software Green Building Studio as well as the building modeling software Revit, there were many factors that we were unable to include in the model or consider. These factors are the use of biomass, highly efficient appliances and fixtures, energy storage, and updated water systems. Additionally, the new neighborhood does not consist of any single or two-family homes. Single family and two-family homes typically have a smaller EUI as there are fewer common spaces that require energy in comparison to multifamily and mixed-use buildings.

4.1.3: Overall Results

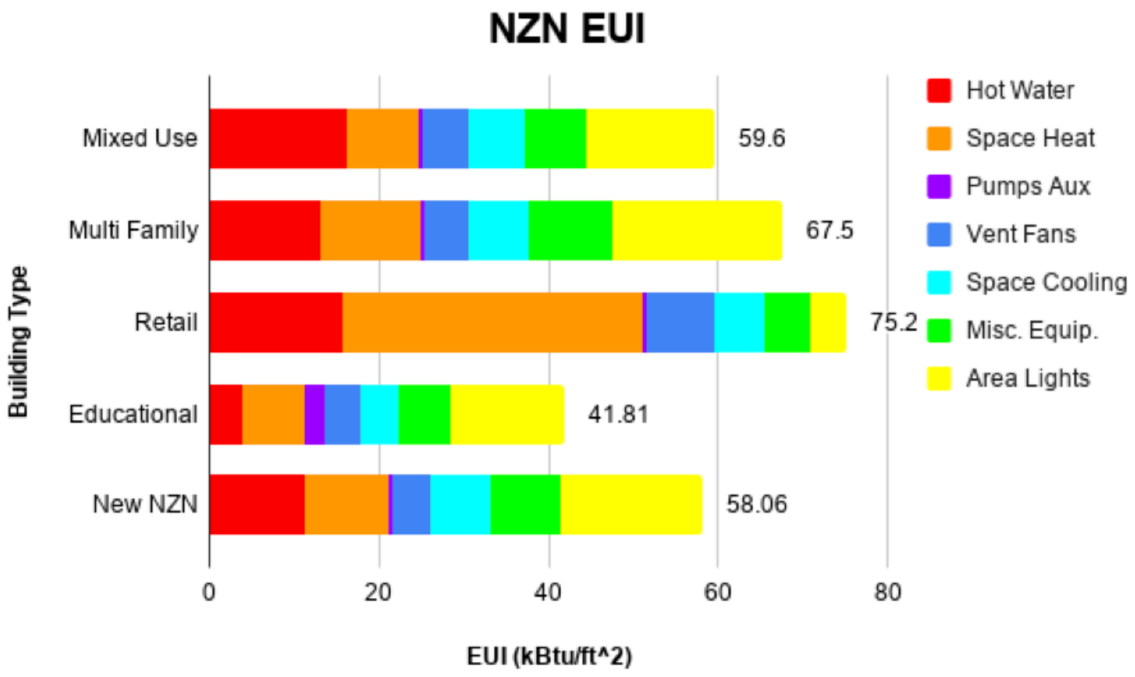


Figure 21: NZN Energy Simulation Results

4.2: Structural Results

Structurally, both CLT and masonry were both feasible options for our design. The primary factor under consideration was the thermal performance of each alternative. Our research found that the R-value (thermal resistance) of the CLT panels for our design was 6.68 as opposed to 1.11 of the masonry. Additionally, the thermal insulating ability of the CLT panels is about 10 times better in comparison to masonry. Regarding the performance of the material, our findings displayed that choosing CLT over masonry for our neighborhood was a far more sensible option. The wall panels that resisted the loading conditions were 3-ply of stress grade V3 at a total thickness of 4 ⅛".

In addition to these values, the scoring system we developed, as shown below, points toward CLT being the better choice for this project.

	CLT **(high = 3, medium = 2, low = 1)**	Masonry (high = 3, medium = 2, low = 1)
Thermal Resistance	**3**	1
Energy Demand/Insulation	**3**	1
Durability	**2**	2
Aesthetics	**3**	3
Ease of Construction	**3**	2
Flexibility	**2**	2
TOTAL:	**16**	11

Chapter 5: Conclusion and Future Works

Although our project was not a complete success, we were able to design a new neighborhood that shows significant progress and promise for creating zero emissions neighborhoods in the City of Worcester. We were able to develop adequate design framework, suggestions, and a model that can be referred to and improved upon in future projects. Achieving net-zero energy in neighborhoods is an innovative approach to society and may very well be the future of new constructions. With potentially changing our analysis and simulation methods, it is very likely that our results would reflect the design considerations and improvements we made. Although we only tested the two wall assemblies of masonry and CLT, it may be likely that with future projects and designs there may be more optimal materials to be used. Our findings concluded that CLT is a viable option for the future of construction whether it be for buildings that are aiming to achieve net-zero energy or for buildings looking for a high-performance wall system. Using CLT as well as considering the other design considerations at the neighborhood and building level can be used for many years to come as technology progresses for all new construction to be as efficient as possible.

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