OFFICE FOR URBANIZATION

Compound Vulnerabilities

THE CASE OF CAPE ANN:
Study 2
Net Zero Housing

2022

Harvard University
Graduate School of Design

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Harvard University Graduate School of Design
The Harvard University Graduate School of Design is dedicated to the education and development of design professionals in architecture, landscape architecture, urban planning, and urban design. With a commitment to design excellence that demands the skillful manipulation of form and technology and draws inspiration from a broad range of social, environmental, and cultural issues, the Harvard GSD provides leadership for shaping the built environment of the twenty-first century.

Office for Urbanization
The Harvard Graduate School of Design's Office for Urbanization draws upon the School's history of design innovation to address societal and cultural conditions associated with contemporary urbanization. It develops speculative and projective urban scenarios through sponsored design research projects.

Cape Ann
The Case of Cape Ann: Compound Vulnerabilities is led by Kira Clingen and Charles Waldheim with essential contributions by Celina Abba, Christopher Ball, Aziz Barbar, Fabiana Casale, Charlie Gaillard, Raveena John, Slide Kelly, Angela Moreno-Long, Nono Martinez Alonso, and Arty Vartanyan. The project is advised by Jill Desimini, Gareth Doherty, Rosetta Elkin, Andrew Fox, Jerold Kayden, Jesse Keenan, David Moreno Mateos, Rick Peiser, Chris Reed, Maggie Tsang, and Amy Whitesides. The project is informed by collaborations with the Harvard GSD Critical Landscapes Design Lab, the Woods Hole Group, NOAA, and Limnotech, and is made possible by the generous support of the Cape Ann Climate Coalition, the Gloucester Meetinghouse Foundation, Manchester-by-the-Sea, and the City of Gloucester.

Methodology
Scenario planning is a method of long-term strategic planning that creates representations of multiple, plausible futures used to inform decision-making in the present. While complementary to probabilistic models that forecast future vulnerabilities, scenario-based planning shifts emphasis from statistical probability to ways of thinking about the future.

The goal of scenario planning is not to predict the most likely outcome but to reveal biases and blind spots in complex and non-linear situations. Scenario planning is particularly effective in grappling with climate change, which is beyond the control of a single individual, institution, or community and entails high degrees of uncertainty. For this reason, scenario planning is among the primary methodologies used by the Intergovernmental Panel on Climate Change (IPCC) and other leading institutions focused on climate change. These scenarios approach the effects of climate change and adaptation measures at a regional scale, and also address issues that are relevant to each municipality. By reframing the issue of climate adaptation on Cape Ann through one possible outcome among many, this work is intended to support stakeholders as they make decisions in the present.

Study 2: Net Zero Housing

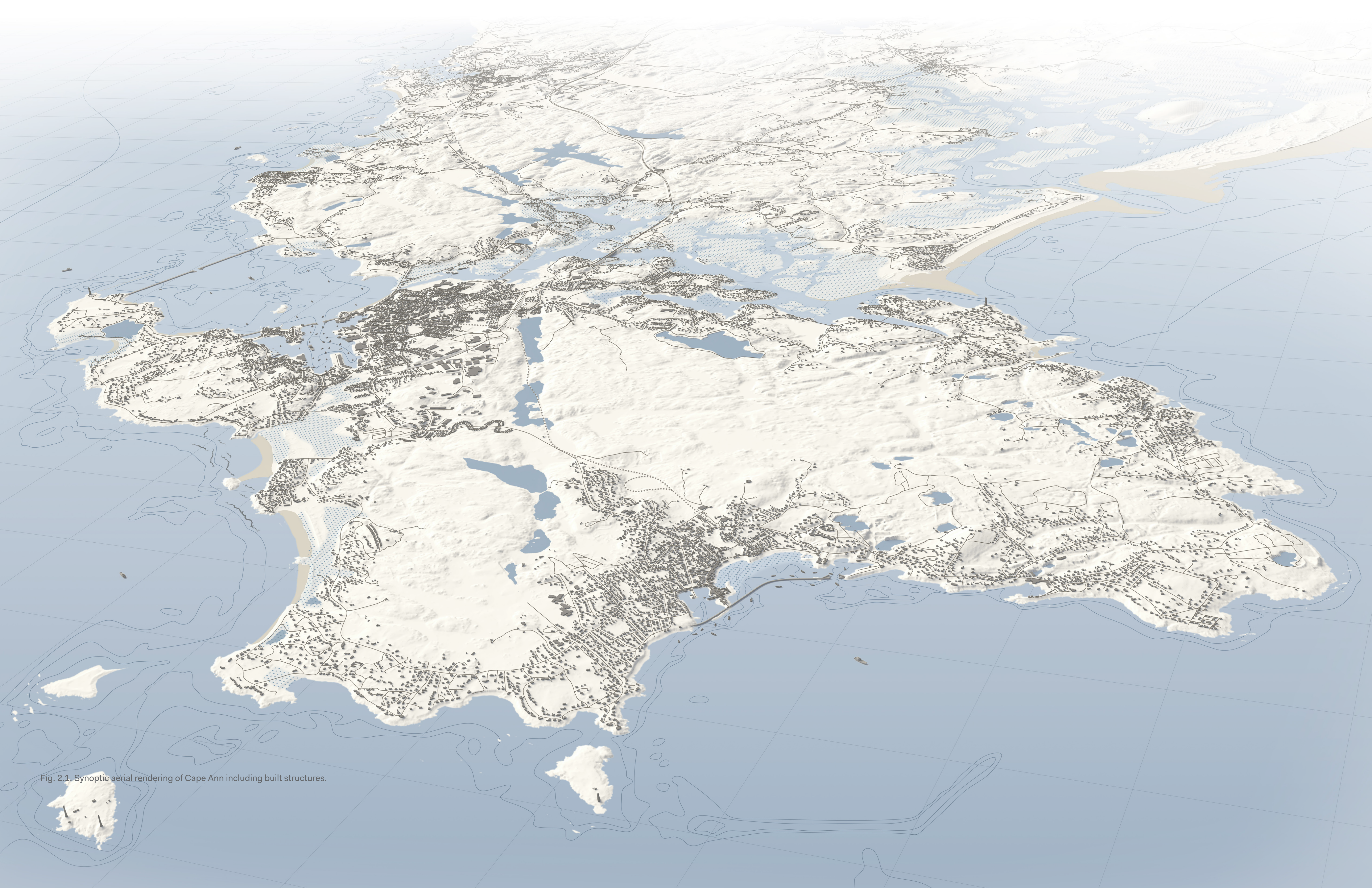


Fig. 2.1. Synoptic aerial rendering of Cape Ann including built structures.

Net Zero Housing

As a region, Cape Ann faces significant demand for diversified housing options to increase social equity. Additional housing types can accommodate the broad variety of lifestyle preferences of Cape Ann residents, including seniors, younger residents, families, artists, and workers.

Study 2: Net Zero Housing, projects a range of housing options across Cape Ann that are accessible to a wider range of residents, and proposes net-zero building strategies including passive orientation, renewable energy production, and innovative construction methods.

The shift to net zero construction is critical because New England is largely dependent on natural gas for power generation and heating. These resources rely on aging infrastructure. ISO New England has estimated that there could be fuel shortages and electrical system reliability issues by 2024 due to regional fuel security concerns. It is therefore important that the Cape Ann region increase its energy independence.

Cape Ann, and Gloucester in particular, have already experimented with green infrastructure. The wind turbines at Blackburn Industrial Park, for example, are a landmark on Cape Ann.

To continue to increase resilience, individual buildings should be outfitted with solar panels. There are 20,361 buildings across Cape Ann that are suitable for solar power installation. These buildings have annual solar radiation greater than 800 kWh and greater than square meters of rooftop space for solar installations. If every suitable rooftop on Cape Ann was outfitted with solar panels, residents could generate 516,206 MWh of electricity per year. This is greater than the 324,609 MWh of electricity used across Cape Ann annually.

Case Studies

Net zero houses generate as much energy as they consume each year. The following net zero precedents from around the globe demonstrate exceptional site planning, design, and technological innovation.

Study 2: **Case Studies**

Sheridan Small Homes

TYPE
Single-Family Condominium

LOCATION
Providence, Rhode Island

COSTS
$280,000/unit

UNITS
5

SIZE
750 ft^2

CLADDING
Wood

SYSTEMS
Photovoltaics

PROJECT STATUS
Completed 2022

The Sheridan Small Homes are five affordable net zero homes deployed on a three-quarter acre site along the Woonasquatuck River Greenway, a bike path in Providence, Rhode Island. The community includes two house models, each with two bedrooms, one and a half bathrooms, and second-floor decks.

To reduce operating costs, each of the five homes maximizes solar production through the use of 320-watt PVs (each unit has twelve to eighteen panels). The PVs produce enough solar energy to match the home's annual energy consumption. Any excess solar energy produced will be sold back to the grid through the Rhode Island Renewable Energy Growth Program (REG Program). Each home is oriented to maximize solar gain through a south-facing arc. This design, coupled with slab-on-grade and south-facing windows, allows the concrete floors to act as thermal masses, storing heat during the day and radiating heat at night. In the summer, overhangs shade the highly efficient triple-paned windows, reducing heat gain. When passive ventilation is not feasible, the home uses a single mini-split duct heating and cooling system and an energy recovery ventilation (ERV) system.[1]

The houses serve as a model for community partnerships. Architect and educator Jonathan Knowles worked with a team of students at the Rhode Island School of Design to design the houses. A project team including the City of Providence, energy consultant CLEAResult, and nonprofit community developer ONE Neighborhood Builders worked with nonprofit builders Building Futures to provide apprenticeships for Rhode Islanders interested in working in construction.

The team is taking the lessons learned from the Sheridan Small Homes project and applying them as a prototype for infill sites. They may also be constructed as accessory dwelling units (ADUs).[2]

Fig. 2.2. *Unit A*. Rendering by ONE Neighborhood Builders, 2019, oneneighborhoodbuilders.org/sheridan-small-homes.

Study 2: **Case Studies**

Lanesville Outbuilding

TYPE
Accessory Dwelling Unit

LOCATION
Gloucester, USA

CONSTRUCTION
New Build

COSTS
$10,000

UNITS
1

SIZE
168 ft^2

CLADDING
Wood

PROJECT STATUS
Completed 2013

Cape Ann is already experimenting with accessory dwelling units (ADUs).

A family in Lanesville, located on the east coast of Gloucester, built a contemporary ADU on the site of a former shed in their backyard. Their property is zoned for neighborhood business (NB) in Gloucester.

The family spent a year building a sustainable and inexpensive studio out of salvaged and reclaimed materials. The structure is clad in mahogany boards, includes recycled flooring from an apartment complex in Boston, and brings in natural light through porthole windows and a skylight. The structure is oriented toward the west to take advantage of evening light.

The structure is not net-zero, and uses a portable space heater in the winter. Solar panels could be added to the roof to generate electricity for the structure.[3]

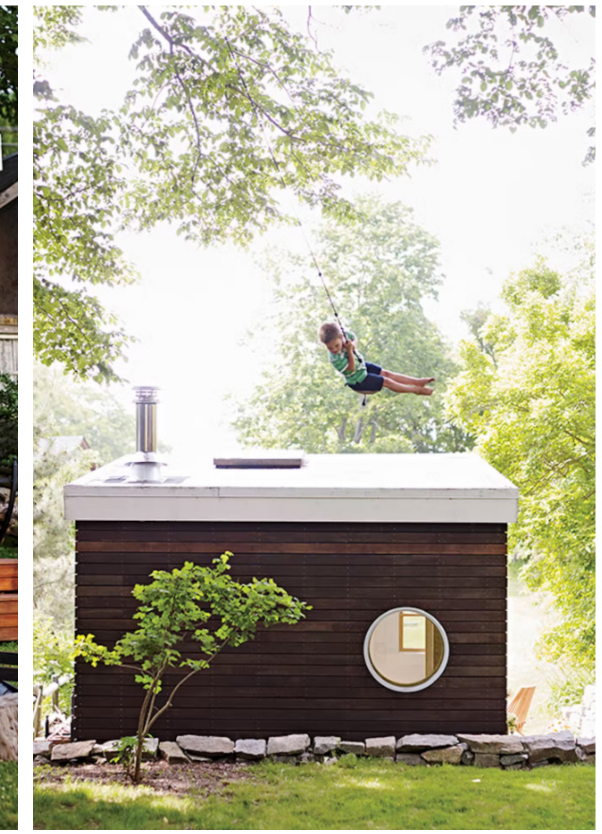


Fig. 2.3. and 2.4. *Lanesville Outbuilding by Tim and Meg Ferguson Sauder* Photographs by Christopher Churchill, 2019. www.dwell.com/article/a-family-builds-a-tiny-backyard-studio-on-an-even-tinier-budget-46d2e1f1.

Study 2: **Case Studies**

Lighthouse

TYPE
Single Family Residential

LOCATION
Watford, UK

COSTS
Not Available

UNITS
1

SIZE
1,000 ft^2

CLADDING
Wood

SYSTEMS
Photovoltaics
Wood Pellet Boiler
Solar Hot Water

PROJECT STATUS
Completed 2016

The Lighthouse was designed as a factory-built prototype intended to provide consumers with more sustainable Net Zero construction. It is an unconventionally designed home, where the sleeping and living areas are reversed. The two-bedroom home occupies 1,000 square feet over two and a half stories. By switching the living spaces to the upper floors, the bedrooms remain cooler on the ground level in the evenings. The double-height living space accommodates an open plan and helps regulate temperatures through passive ventilation. The skylights (which act as wind catchers and light funnels) provide ample daylight while providing passive cooling and ventilation. During the day, hot air flows upwards and exits; during the evening, cool air enters and settles to the lower levels.

The roof includes 495 square feet of PVs angled at 40 degrees, generating electricity for the home. The PVs produce 4.7 kWh of energy, decreasing annual heating costs to $80. Smart metering is paired with solar panels to allow more accurate energy consumption monitoring to minimize waste.The home utilizes biomass boilers to heat the home. Biomass boilers utilize organic compounds such as wood pellets to produce heat. Biomass boilers are zero-emission because the amount of carbon dioxide produced during burning is offset by the amount of carbon the material consumed during crop growth. The energy produced through the onsite PV panels significantly reduced its annual use in the Lighthouse.

To help maintain cooler indoor temperatures during the summer, phase-changing materials were used on the ceilings. These "thermal heavyweight" surfaces, such as (PCM) plasterboard, absorb room heat by changing from solid to liquid within microscopic capsules in the board. At night, this phase-changing is reversed due to the cooling of the air by the skylight/wind catcher.[4]

Fig. 2.5. *Carbon Neutral Lighthouse in the UK*. Photography by J. Green, 2008. www.jetsongreen.com/2008/02/lighthouse-uks.html.

Study 2: **Case Studies**

Passivhaus

TYPE
Multi-Family Residential

LOCATION
Darmstadt-Kranichstein, Germany

COSTS
Not Available

UNITS
4

SIZE
6,716 ft^2

CLADDING
Masonry

SYSTEMS
Super Insulation
Green Roof
Photovoltaics

PROJECT STATUS
Completed 1991

"Passive Houses" are buildings that require little to no heat consumption due to the thermal insulation and passive design strategies such as ventilation and solar gain. The world's first Passive House (Passivhaus) was built under rigorous testing in the early '90s in Kranichstein.[5] It was designed by architects Prof. Dr. Bott, Ridder, and Westermeyer and built by Dr. Wolfgang Feist.[6] Although the technology has advanced since its design and construction, there is still much to learn from this high-performance house.

Passivhaus is a three-story housing development with four distinct and equally sized units (1,680 square feet). The continuous sloped roof is vegetated, covered in grasses, and terminates at the home's main entries, which are all located on the north side of the complex. The north façade provides each unit with glazed bright sunrooms that double as an indoor/outdoor space and act as an insulating buffer to the home.

The two fundamental principles for the design of the house (and Passive House designations today) are thermal insulation and heat recovery ventilation.[7] These principles were considered in the design and construction of the roof, exterior walls, foundation, windows, and energy systems. Within each of these building elements, airtightness is crucial. Airtightness ensures the building envelope is sealed, preventing heated air from escaping and cool air from entering.[8]

After construction, sensors monitored numerous design variables, from thermal bridging to air tightness. Thermal bridges are joints or connections where heat can transfer through due to different material temperatures. In Passive House, these moments (eaves, windows) are important to consider and design around because energy can be lost. Airtightness is crucial to meet the standards of efficiency required for Passive House and was tested through blower door tests. The blower door and continuous measurement tests demonstrating airtightness, energy consumption, and internal temperatures proved that Passivhaus met its objectives. The house consumed 19.8 kWh in its first year, which amounts to 8% energy consumption compared to a comparable dwelling. In its second operational year, it reduced its consumption to 5% energy consumption compared to comparable dwellings.

In terms of energy production, Passivhaus initially only used solar collectors to provide hot water to the home. However, decades later, in 2016, the house replaced the existing solar collectors with 280 square feet of new photovoltaic panels. These new energy-efficient PVs now produce clean solar energy for hot water and electricity. These efficient solar photovoltaics meet all of the house's needs.[9]

Fig. 2.6. *The First Passive House*. Photograph by Passive House Accelerator, 2018.

Study 2: **Case Studies**

Wohn-und Werkhaus

TYPE
Multi-Family Residential

LOCATION
Schwaikheim, Germany

COSTS
Not Available

UNITS
6+ workshop

SIZE
8,718 ft^2

CLADDING
Wood
Concrete

SYSTEMS
Photovoltaics

PROJECT STATUS
Completed 2021

Wohn-und Werkhaus by Schleicher Ragaller architects is a six-unit housing complex in Schwaikheim, Germany. The complex is designed to accommodate living and working and is outfitted with generous workshop spaces. Schwaikheim is a rural neighborhood outside Stuttgart, and the design highlights the value of critical regionalism by incorporating regional building techniques and typologies. Wohn-und Werkhaus is a gabled farmhouse clad in darkened local timber, slipping into its context seamlessly. The three-story living spaces sit on top of a concrete plinth that balances out grade variations across the site. The structure is site-specific and is constructed with reusable materials to maximize local craft and comfort.

Wohn-und Werkhaus achieved Net Zero energy and capitalized on passive design strategies. It is built with efficient windows, heating systems, and photovoltaic panels. The PVs are optimally placed on the south-facing roofs and are oriented in the east-west direction to ensure maximum solar production. By orienting the building in this manner, passive daylighting is also maximized. The building's highly efficient envelope and heat pump comply with the region's minimum usage based on the KfW energy efficiency standards.[10] These design considerations bring the housing complex's annual energy requirements to zero.

Fig. 2.7. Wohn-und Werkhaus. Photograph by Z. Braunz, 2021. www.archdaily.com/949996/housing-and-workshop-weilerstrasse-schleicher-ragaller-architects.

Study 2: **Case Studies**

The Battery-Phase 3

TYPE
Multi-Family Residential

LOCATION
Philadelphia, USA

COSTS
Not Available

UNITS
42 (3 Phases)

SIZE
500 ft^2/unit

CLADDING
Aluminum Composite Panel

SYSTEMS
Photovoltaics

PROJECT STATUS
Completed 2017

The Battery is a 42-unit development completed in three phases over 18 years in Philadelphia. It is designed as a slow development to accommodate changes within the community and across the market. Slow development facilitates flexibility in design and construction based on its context. Phase 1 was a retrofit to an existing meat-packing plant, generating eight apartments. Phase 2 was the construction of duplexes, and Phase 3 (The Battery) is the creation of 25 attainable Net Zero micro units rented at below $1500/month + utilities. The project aimed to help diversify the gentrified neighborhood that was socially and economically homogenous. By developing sustainable and affordable units, The Battery attempts to rectify inequity within the neighborhood by creating affordable housing and increasing diversity.

To meet Net Zero energy standards, The Battery constructed extensive green roofs with geothermal heating, installed highly efficient insulation, maintained airtightness, and produced 77 kW through their photovoltaic canopy. The solar canopy also acts as a shading device while meeting the building's annual energy requirements. In order to demonstrate the building's sustainable goals, the north and west façades were designed as performance indicators. White panels embedded with LED lights are connected to the complex monitoring system and glow green, yellow, and red depending on energy performance. When it glows green, the building is performing as expected, yellow indicates caution, and red indicates that tenants are not occupying their units to their energy potential. By attaching their indicators to The Battery's sensors, the building creates social consciousness surrounding energy consumption and aims to raise awareness.[11]

Fig. 2.8. *Three Lights at The Battery*. Photograph by Onion Flats Architecture, 2017. www.onionflats.com/the-battery-phase3.

Study 2: **Case Studies**

Veridian at County Farm

TYPE
Neighborhood Residential

LOCATION
Ann Arbor, USA

COSTS
Not Available

UNITS
110

SIZE
12.5 acres

CLADDING
Photovoltaics
Rainwater Harvesting

SYSTEMS
Photovoltaics

PROJECT STATUS
Projected 2025

Veridian at County Farm is a mixed-income, net zero energy neighborhood in Ann Arbor, Michigan. It sits on a 13.59-acre historic County Poor Farm (1836) property that later became a Juvenile Detention Center. When completed in 2025, Veridian will be a fully solar-powered community with no built gas lines or combustion appliances. Veridian connects to greater Ann Arbor through public transit and bike lanes, illustrating large-scale sustainable net zero development feasibility.[12]

Veridian is a community with varied housing typologies for 110 units, a grocery store, coffee shop, community greenhouse, and ample outdoor park space. Roughly 50 units developed by a non-profit parent Avalon Housing are affordable homes for those making less than 60% of the area's median income. Some of the 50 homes will provide shelter to those facing homelessness along with access to on-site programming to help with housing stability and crisis response. The six different housing typologies range from $180,000 to $900,000.[13][14]

The plan is organic and does not site every house optimally for maximum solar efficiency. However, their rooftops generate 1.5 megawatts of power, enough to achieve NZE. Maximizing efficiency came second to human inhabitation. The organic organization of the community produces better outdoor spaces for the community to gather, with a third of the site landscape designated for food production.[15]

A benefit to solar electric generation is the resilience one achieves in instances of blackouts and the hand of aging infrastructure, and increased weather events. Veridian homes are equipped with home batteries that store solar energy, efficient windows, thick insulation, and heat pump systems.[16]

Fig. 2.9. Veridian at County Farm. THRIVE Collective and Avalon Housing, 2022. www.veridian.community.

Funding Opportunities

Cape Ann should continue to seek out federal and state grant programs to explore net zero housing production. Residents should take advantage of tax rebates expiring in 2023 to assist with the installation of PV panels on private homes.

Study 2: **Funding Opportunities**

Residential Tax Incentives

Federal Residential Renewable Energy Tax Credit
Residential tax credit for solar water head, photovoltaics, biomass, geothermal heat pumps, wind power, and fuel cells using renewable fuels for up to 26% of the qualifying project costs (declining to 22% in 2023 and 0% in 2024).[17]

Massachusetts 830 CMR 62.6.1: Residential Energy Credit
Personal tax credit for Commonwealth residential property owners for $1,000 or 15% of qualifying solar and wind project costs (whichever is less).[18]

Grant Funding

Municipal Energy Technical Assistance Grants
The Green Communities Division offers a technical assistance grant program to third parties working with municipalities on the development of alternative energy initiatives.[19]

Building Resilient Infrastructure and Communities
The United States Federal Emergency Management Agency awards funds for capability- and capacity-building activities, mitigation projects, and management costs for large infrastructure projects that reduce the risk of natural hazards for a community. A municipality may apply as a subapplicant and must have an approved Hazard Mitigation Plan in place to be eligible.[20]

Other Funding

Solar Massachusetts Renewable Target (SMART) Program
The Department of Energy Resources (DOER) and investor-owned electric utilties offers a production-based incentive that is paid directly by utilities to solar electric system owners. Typical residential systems are eligible to participate for ten years and receive incentive payments monthly via checks or electronic payments.[21]

Net Metering
Customers receive credits on their utility bill from electric utility companies for excess generation during any month. These credits can be applied during times when the system is not generating electricity. Net metering credit values depend on system size and utility rates and are monitored by the state Department of Public Utilities.[22]

Solarize Massachusetts (Solarize Mass)
The Massachusetts Clean Energy Center runs a competitive solicitation process that aggregates homeowner buying power to lower installation prices of solar systems for paricipants. The program also includes a Toolkit to support communities interested in conducting community clean energy initiatives to run campaigns and explore emerging technologies. [23]

MassSave Rebates and Incentives
MassSave rebates and incentives are available to homeowners, renters, and landlords for new net zero construction, including single-family and multi-family homes as well as renovations and additions. Participants work with Home Energy Rating System (HERS) companies to enroll their homes and calculate incentives by energy savings requirements and overall performance compared to average new homes in Massachusetts.[24]

Proposed Net Zero Operations on Cape Ann

The Cape Ann region is facing an immediate affordable housing crisis along with a longer-term need to decarbonize the regional economy and built environment.

There is a lack of housing options across the Cape, especially for younger, elderly, minority, and middle- and lower-class residents. This includes commercial and waterfront industrial workers in all municipalities. This shortage will be exacerbated due to sea level rise and extreme storms, which will create additional demand for housing outside of floodplains, and away from infrastructure (including roads) that are constructed through floodplains.[25]

All new construction on Cape Ann should use net zero building technology. Municipalities should work to provide grants and subsidies to finance this construction.

Each municipality should review their zoning regulations and pass less restrictive zoning by-laws that allow for as-of-right ADU construction in all municipalities, and consider authorizing multi-family development within Transit-Oriented Development (TOD) districts near public transit hubs, including commuter rail stations and bus stops. ADU construction should be incentivized with technical assistance and financial subsidies in each municipality.

Additional development outside of the floodplain on municipal parcels can alleviate the housing shortage. These municipal parcels must be developed in areas that will not become islands on higher ground connected by road networks that are vulnerable to flooding.

Study 2: **Proposed Net Zero Operations**

Net Zero Energy Strategies

All new development on Cape Ann should be net zero construction. Municipalities should work to incentivize residential and commercial property owners to use various siting, ventilation and massing strategies.

Combing strategies, including solar orientation, natural ventilation, and thermal massing, is critical for reducing the consumption of energy and maximizing the amount of solar energy generated by each structure.

In addition to the design and construction of net zero buildings, proper use and maintenance is necessary. Municipalities can provide education through community centers and public courses on the benefits and upkeep of net zero homes.

Interventions

Existing Structure

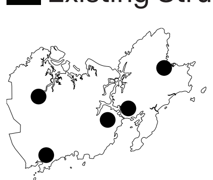
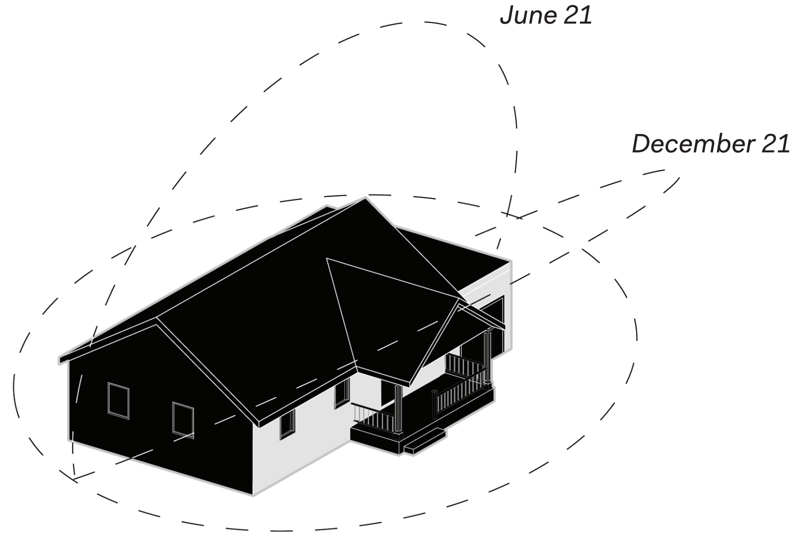
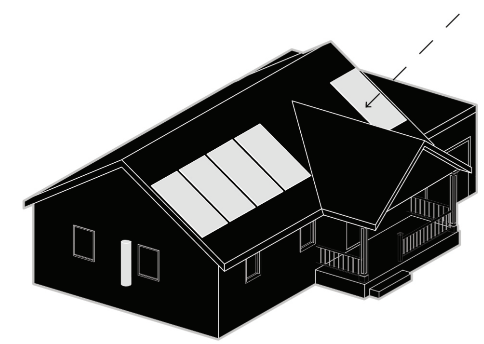


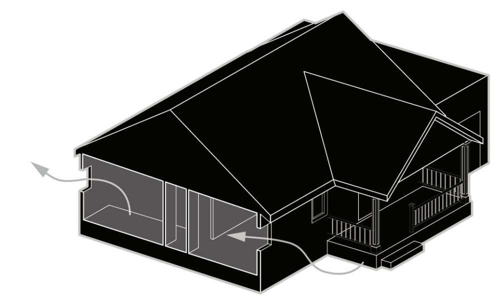
Fig. 2.10.–2.15. Axonometric diagrams of net zero strategies.



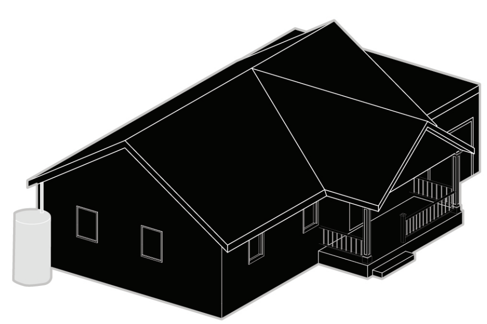
Solar Orientation
Orienting the house east-to-west maximizes solar gain for heating and allows natural daylighting. Owners can save on energy through passive design.



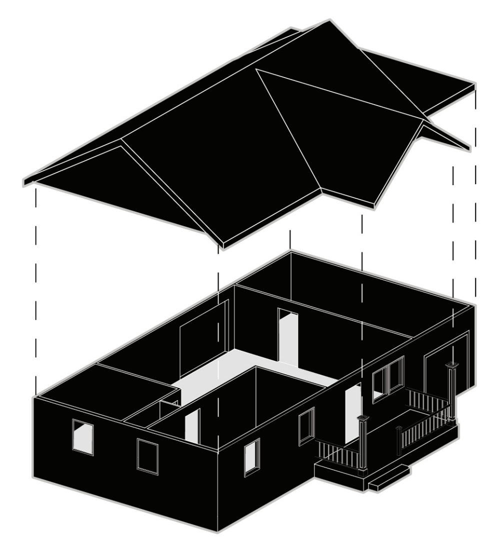
Photovoltaics + Storage
Solar energy is captured in PV panels, which help to offset the energy consumed within the household. Energy may be stored in batteries on site.



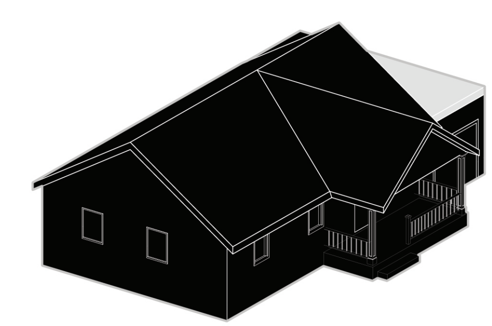
Natural Ventilation
Natural ventilation can improve air circulation while decreasing electric consumption and cost. Better ventilation provides a healthier indoor environment.



Rainwater
Sustainable water use and collection can be achieved with cisterns. The collected water can be used for toilets, yard work, and washing machines.



Thermal Mass
Thermal mass is the energy that is retained in a mass (ex: concrete flooring). The energy helps retain and dissipate heat, depending on the environment.



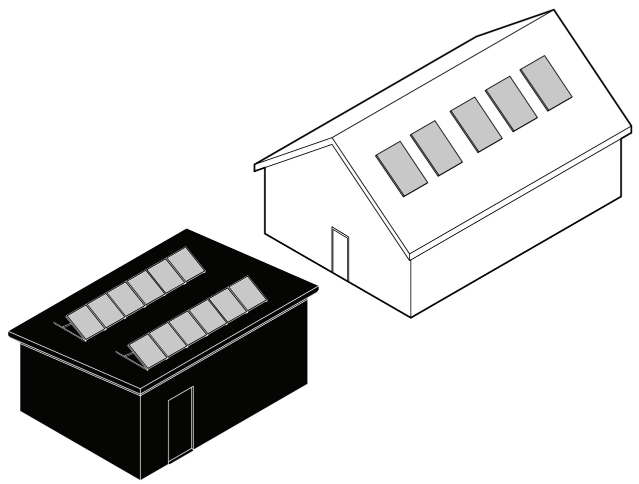
Green Roof
Green roofs act as vegetated buffers that help with rainwater collection, the propagation of local flora and fauna, and temperature reduction and regulation.

Study 2: **Proposed Net Zero Operations**

Net Zero Housing Typologies on Cape Ann

Cape Ann has traditionally included a variety of housing options, including multi-family homes in the downtown and village cores of each municipality. This development has been superceded by detached single-family homes on larger tracts during the post-war 20th century.

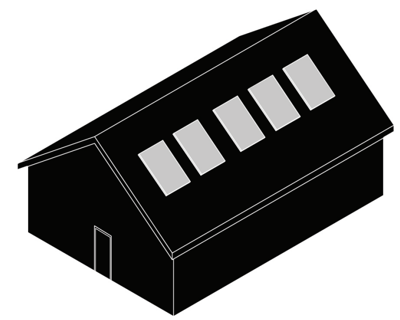
The housing stock on Cape Ann must be diversified with a variety of housing types that align with evolving lifestyle preferences for the region's aging population, working classes, younger families, and artists.



Accessory Dwelling Unit

1 unit

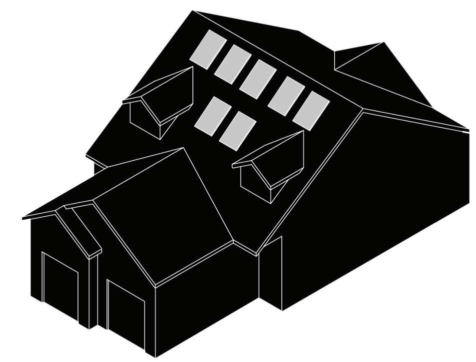
ADUs must have a minimum area of 250 ft^2 and a maximum area of 900 ft^2. These additions provide intergenerational housing, rental income, and diversify housing stock at low cost.



Single Family House

1 unit

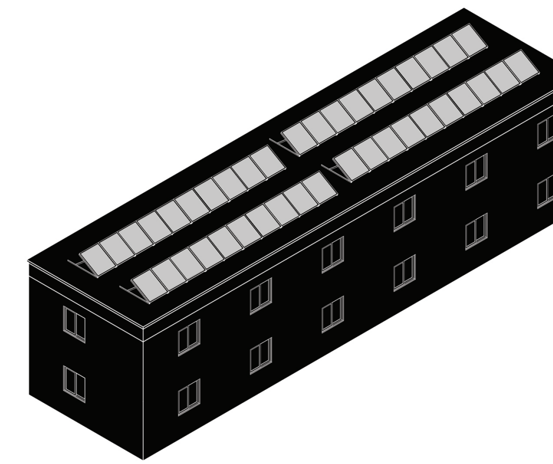
The majority of homes in Cape Ann are single-family houses. Diversifying the housing stock is important in providing affordable housing for different groups across Cape Ann.



Multifamily House

2–8 units

All four municipalities on Cape Ann are MBTA communities, which must have at least 50 acres of development with a minimum gross density of 15 units per acre.



Multifamily Complex

8+ units

There is a tradition of multi-family housing across the downtown areas of each municipality on Cape Ann dating back to the mid-19^{th} century. This tradition can be re-energized to provide diverse housing options.

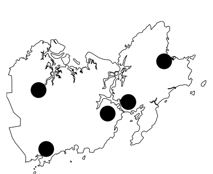


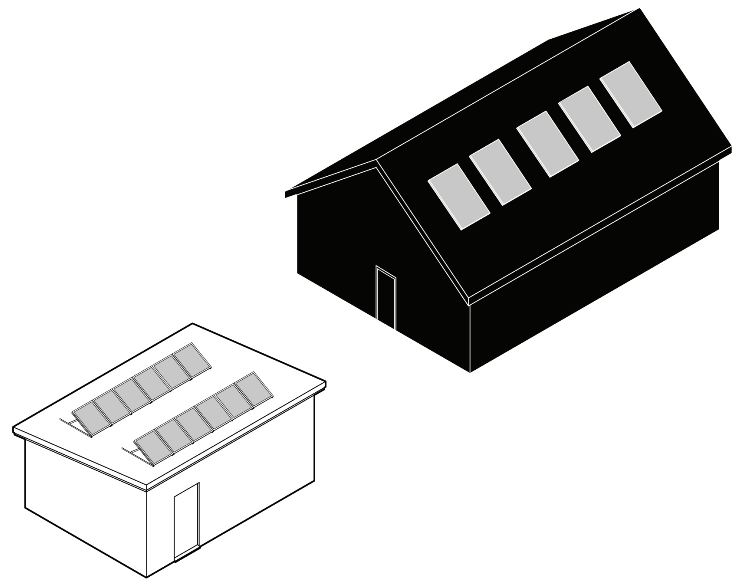
Fig. 2.16.–2.19. Axonometric diagrams of net zero strategies.

Study 2: **Proposed Net Zero Operations**

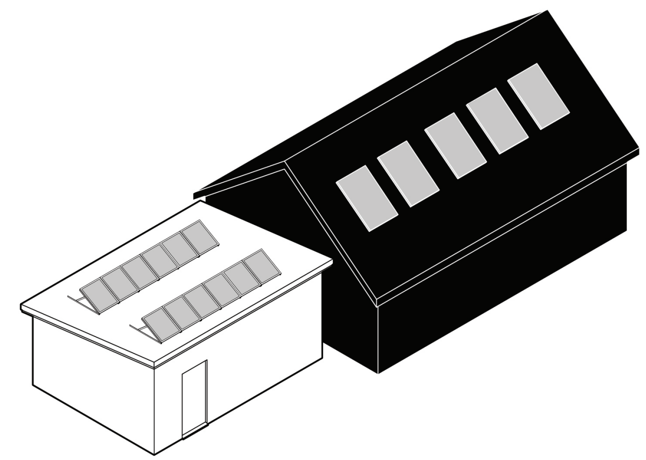
Net Zero Accessory Dwelling Unit (ADU) Typologies

Net zero accessory dwelling units should be immediately authorized for as-of-right construction in each municipality. While Gloucester and Rockport allow by-right ADU construction, Manchester-by-the-Sea and Essex require special permits. The introduction of zoning amendments to allow ADUs will increase the housing stock of small and affordable rental options in Cape Ann.

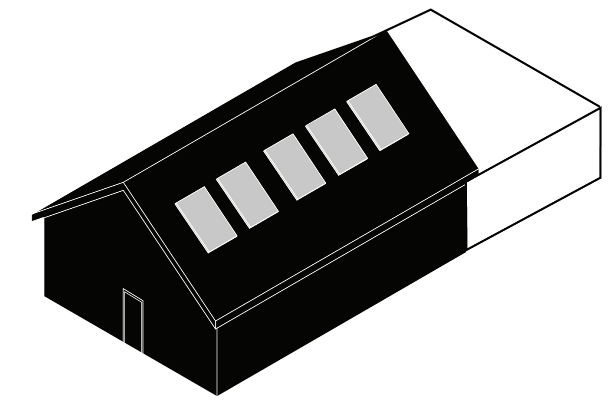
ADUs can be attached or detached to residential homes.



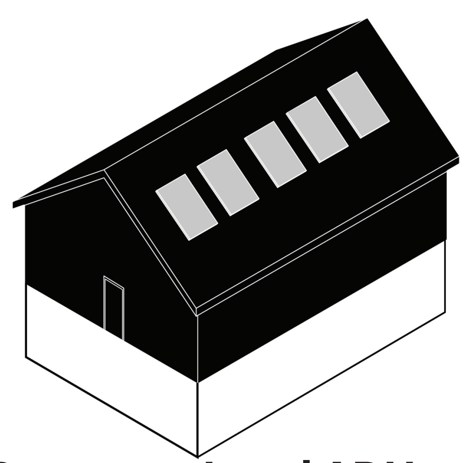
Detached ADU
A stand alone home on same lot of the primary home.



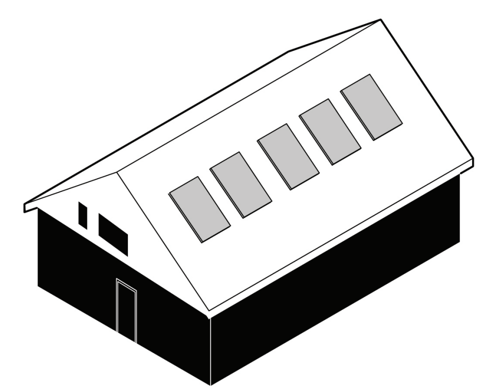
Attached ADU
An addition that connects to an existing house and can have separate or shared entry.



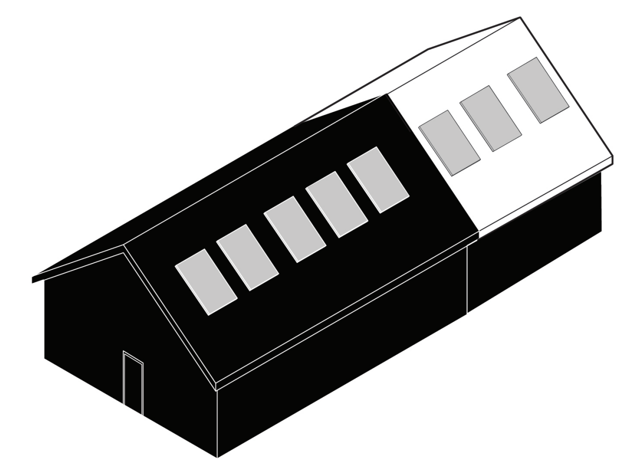
Garage Conversion ADU
The conversion of an existing garage into a dwelling.



Basement Level ADU
A basement conversion, where floor to ceiling height and exit safety standards must be met.



Upper Level ADU
A separation of stories that is provided through a stairway to upper level.



Above Garage ADU
An addition of a second story to an existing garage. It can be single- or multi-level.

Existing Structure (1,800 ft^2 min. area)
Accessory Unit (900 ft^2 max. area)

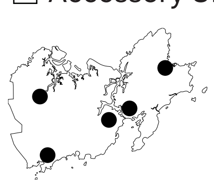


Fig. 2.20.–2.25. Axonometric diagrams of ADUs.

Study 2: **Proposed Net Zero Operations**

Existing Zoning Layers Across Cape Ann

Each municipality currently maintains its own zoning code, including base zoning districts, overlay districts, and a broad suite of regulations for use, dimensions, and other factors.

The special permitting processes required in Manchester-by-the-Sea and Essex restrict development and should be replaced by as-of-right zoning ordinances for Accessory Dwelling Unit (ADU) construction.

Fig. 2.26. Matrix of existing zoning regulations.

Gloucester

Base Zoning Districts

15

Overlay Districts

6

Regulations

Uses
Dimensions
Setbacks
Height
Off-street parking
Off-street loading
Signs
Noise
Litter
Smoke
Screening
Mobile homes, trailers, camps
Dumping and filling
Home occupation
Wireless communication facilities
Assisted living
Open space
Wind energy
Marijuana

Rockport

Base Zoning Districts

7

Overlay Districts

4

Regulations

Uses
Dimensions
Setbacks
Off-street parking
Trailers
Fences
Alternative energy sources
Microwave antennas
Septic systems
Personal wireless communication facilities
Marijuana
Coastal flood protection
Solar
Removal and filling
Open space
Signs and billboards
Animals
Exterior lights
Automobile service and filling stations

Manchester-by-the-Sea

Base Zoning Districts

8

Overlay Districts

3

Regulations

Use
Dimensions
Setbacks
Personal wireless telecommunication services
Helicopters
Land clearing
Solar
Off-street parking
Driveways
Junk Cars
Topographic Changes
Marijuana
Signs
Antennae
Open Space
Wind Energy

Essex

Base Zoning Districts

3

Overlay Districts

3

Study 2: **Proposed Net Zero Operations**

Undeveloped Municipal Parcels out of the Floodplain

There are over 4,000 acres of undeveloped and underdeveloped municipal parcels out of the floodplain across the four municipalities that may be suitable for future development.

Communities should take an inventory of all municipal parcels to evaluate which parcels could potentially be developed and which should be conserved in perpetuity.

Municipalities should also consider the potential of developing upland conservation land and purchasing floodplain properties that can be deconstructed and returned to nature in perpetuity, thus increasing the amount of recreational and open space across Cape Ann and helping to alleviate affordable housing issues on the Cape.

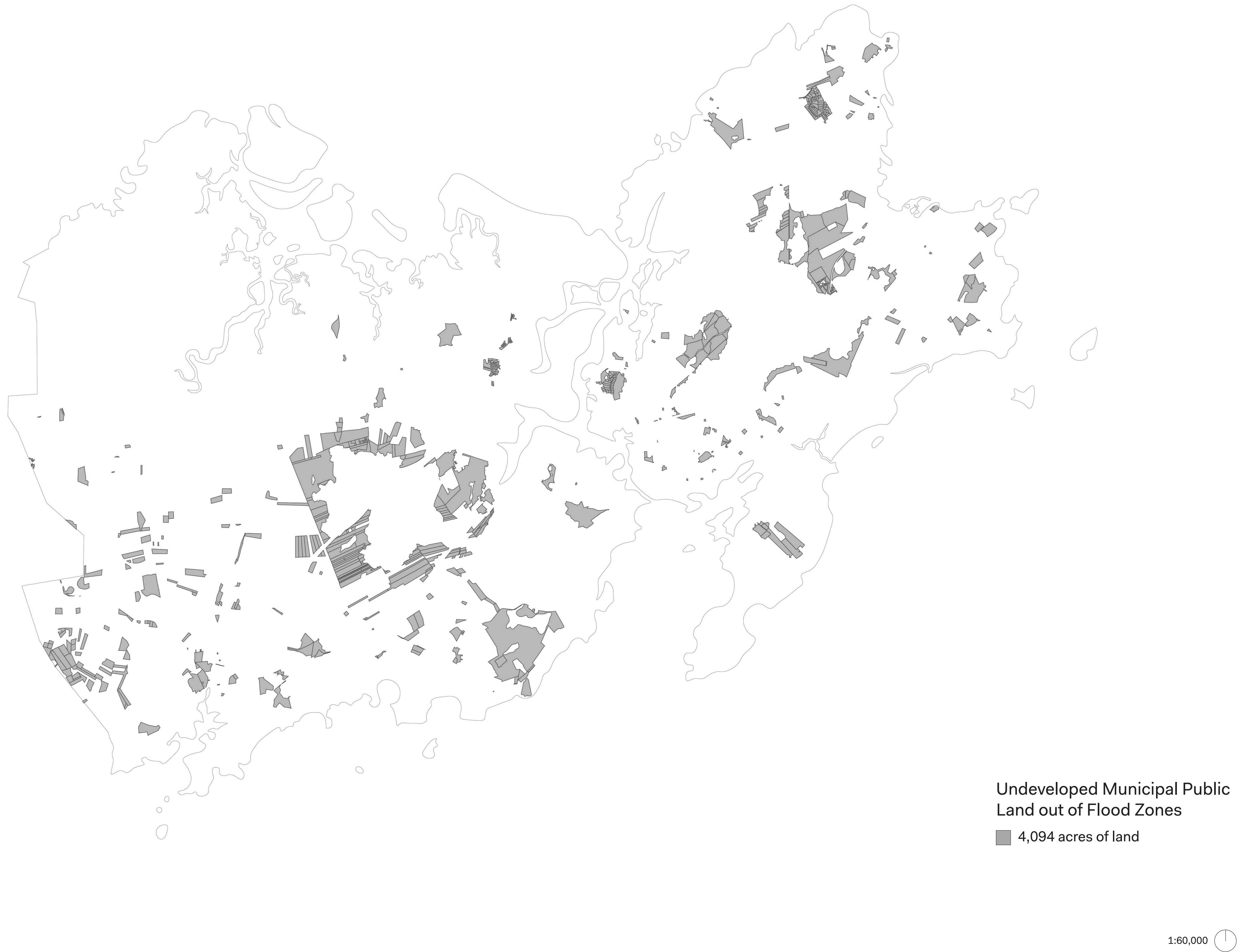


Fig. 2.27. Map of undeveloped and underdeveloped municipal public land.

Net Zero Housing: Key Considerations

Residential and commercial buildings in the United States use 70% of the electricity generated in the United States. Mitigating climate change requires decarbonizing all aspects of the built environment, including construction processes and energy generation. Solar technologies, including photovoltanic panels, have become cost efficient in recent years and will continue to become more affordable and widely adopted across the globe.

Study 2: **Key Considerations**

Built Environment and Climate Change

The world has seen drastic increases in energy demands, with power consumption nearly doubling from 2010 to 2018.[26] Technological advancement and population growth are the cause of these demand increases.[27] In the United States, residential and commercial buildings use 70% of generated electricity.[28] Globally, buildings contribute a third of energy-related greenhouse gas (GHG) emissions.[29] Energy, which drives the global economy, directly correlates with these carbon dioxide emissions.[30 31] The building sector needs to transform its heavy reliance on GHG within the industry to help limit global warming. This literature review centers on the latter, and how a focus on energy reduction and low embodied carbon development is crucial to meeting the 1.5°C target.[32]

Net Zero Energy

Net zero energy (NZE) is the net sum of renewable energy production against energy consumed throughout one year.[33] While gradually becoming the energy standard within the building industry, there is no universal definition of net zero energy. In the US, there are three categories of net zero buildings (low-rise, high-rise, and community). All of these buildings must balance energy demand from energy sources, create minimal net carbon dioxide releases, be financially feasible, and substantially reduce energy consumption throughout the building's lifecycle.[34] As benefits, net zero construction provides a reduced cost of living, and higher resale values.[35]

Energy Reduction

Occupant education, passive design strategies, and mechanical system efficiency significantly reduce the energy required for heating, lighting, ventilation, and air conditioning.[36 37] Passive design strategies maximize the benefits of siting, thermal mass, building envelope, and occupant behavior. Mechanical design strategies reduce energy consumption by employing high-efficiency mechanical systems, appliances, and lighting.[38 39] Listed below are key passive and mechanical design considerations when constructing NZE housing.

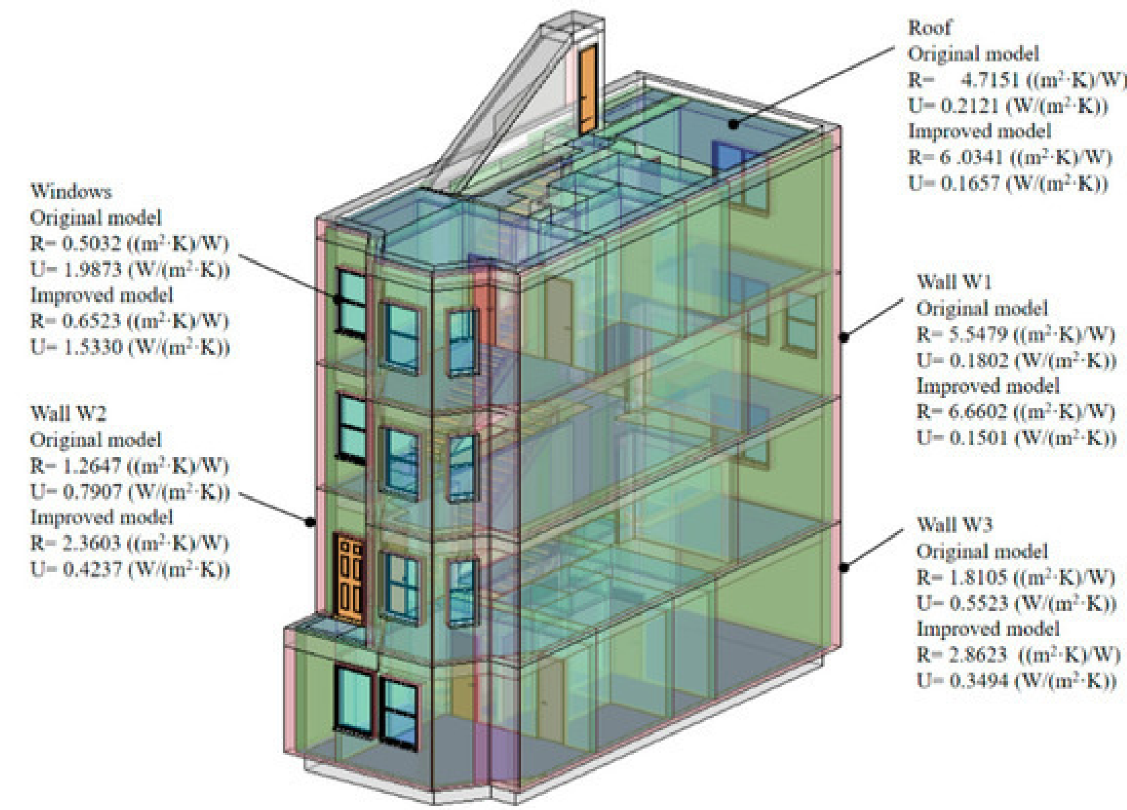


Fig. 2.28. *R and U values for townhouse renovation.* Kaewunruen, et al., "Potential Reconstruction Design of an Existing Townhouse in Washington DC for Approaching Net Zero Energy Building Goal," *Sustainability*, 2019.

Study 2: **Key Considerations**

Siting (Solar Orientation, Lighting, Shade)
Siting the house to maximize gains from solar orientation, massing, and interior layout are crucial for energy reduction.[40] Understanding the local context and environmental conditions is essential to maximize gains from siting.[41] Orienting housing east-to-west (maximizing southern exposure) reduces the need for artificial daylighting.[42] Open floor plans also improve daylighting by allowing light deep into the floor plate. Conversely, it is important to design for shading to minimize solar gain in the summer and maximize it in the winter.[43]

Thermal Mass (Thermal Bridges, Radiant Control)
Thermal mass is a material's ability to retain energy.[44] It attracts and retains sunlight's heat, acting like a "storage battery."[45] A material with high thermal mass takes longer to heat because it stores a larger quantity of energy.[46] Conversely, it takes longer to cool since there is more energy to dissipate. Combining thermal mass with passive ventilation strategies can help with heat retention during the winter and cooling during the summer. However, occupant behavior is essential for energy efficiency. For example, "neglecting to open windows at night during hot summer days can have catastrophic results [concerning]...thermal comfort and energy efficiency, yielding exactly the opposite... intended results."[47]

Building Envelope (Airtightness, Ventilation, Insulation, Moisture)
Poor building envelope performance can account for significant energy loss. Air infiltration, heat transfer, and moisture control must be detailed to ensure minimal losses. In New England, moisture control is critical and greatly affects a project's ability to achieve NZE. If appropriately installed, high-density foam, spray polyurethane foam (SPF), structural insulated panels (SIPs), and insulated concrete forms (ICFs) can act as insulation and air and vapor barriers.[48]

Occupant Behavior
Occupant behavior is an important variable to consider when designing for NZE. A study on NZE homes in Martha's Vineyard concluded that achieving NZE was more dependent on occupant behavior than building design.

Electrical & Mechanical Systems (HVAC, Water Heating, Appliance, Lighting)
Electrical and mechanical systems consume large amounts of energy within a home. Mechanical system losses occur from HVAC and water heating while electrical system

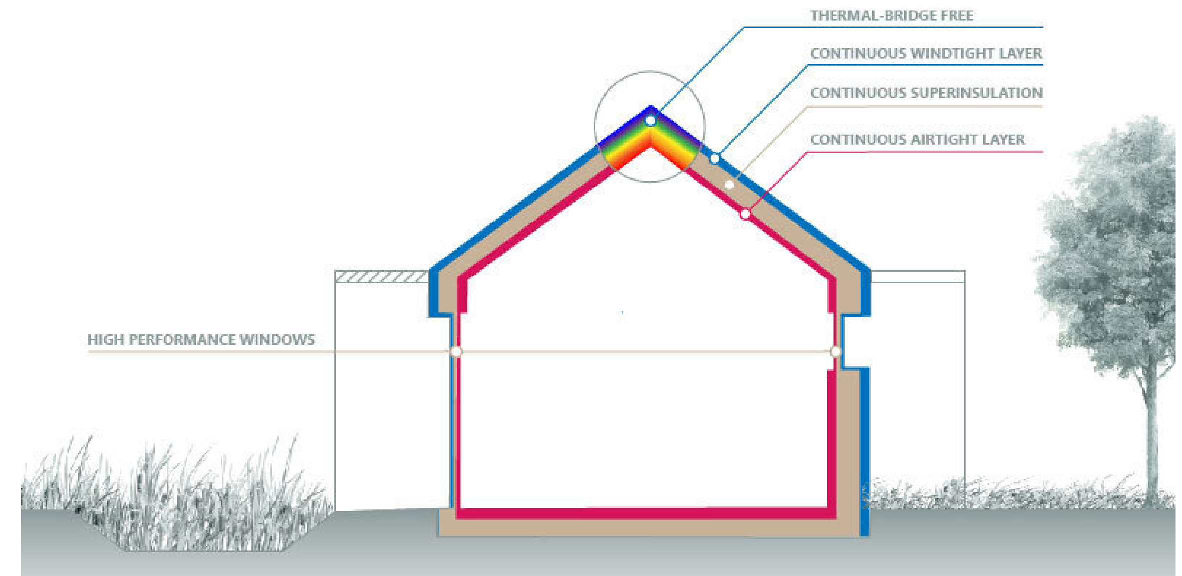


Fig. 2.29. *Passive House Insulation*. Diagram by Gharpedia, 2022.

Study 2: **Key Considerations**

losses are caused by appliance use and lighting. It is essential to consider equipment size, rating, and proper installation when optimizing systems.

HVAC and Appliances
Efficient systems and appliances (such as an Energy Star rating) for furnaces, air-conditioners, water heaters, and duct/piping systems help with energy efficiency.[49] Smart meters monitor household (and appliance) energy usage, allowing occupants to monitor their consumption over time.[50]

Electrical Lighting
Energy reduction through electrical lighting can occur through maximized daylighting, automation (sensors), dimmers, or energy-efficient lightbulbs.[51] Dimmers, motion sensors, daylight sensors, and daily programming are lighting controls applied to most bulbs. They help to regulate light use (energy).

Water Heating
Solar thermal systems and electric heat-pump water heater systems are two methods of producing domestic hot water (DHW) with solar panels. Both systems are sustainable and will provide financial savings; however, each system has its own pros and cons. Solar thermal systems require direct sunlight to heat water. They are placed on roofs and do not require tank space inside the home.[52] Heat pump systems, one of the most efficient systems available, move heat from the air to water and thus can heat water at any time of day. However, heat pumps require increased space as a tank is placed inside the home.[53]

Energy Production
Solar, geothermal, and wind energy can provide on-site renewable energy for a NZE home.[54] Solar energy is the most popular choice for domestic NZE energy generation; its popularity is partially due to a breakthrough in the prices of PV panels. The IEC notes that the "growth is concentrated in states with supportive solar policies" but describes how, as manufacturing grows, it will become more prevalent.[55] PV panels are one of three different solar energy technologies. PVs produce electricity most often for residential buildings. Concentrating solar power is most often used for large-scale commercial buildings. Solar thermal collectors produce heat for water and space heating/cooling, and are most often used for residential buildings.[56]

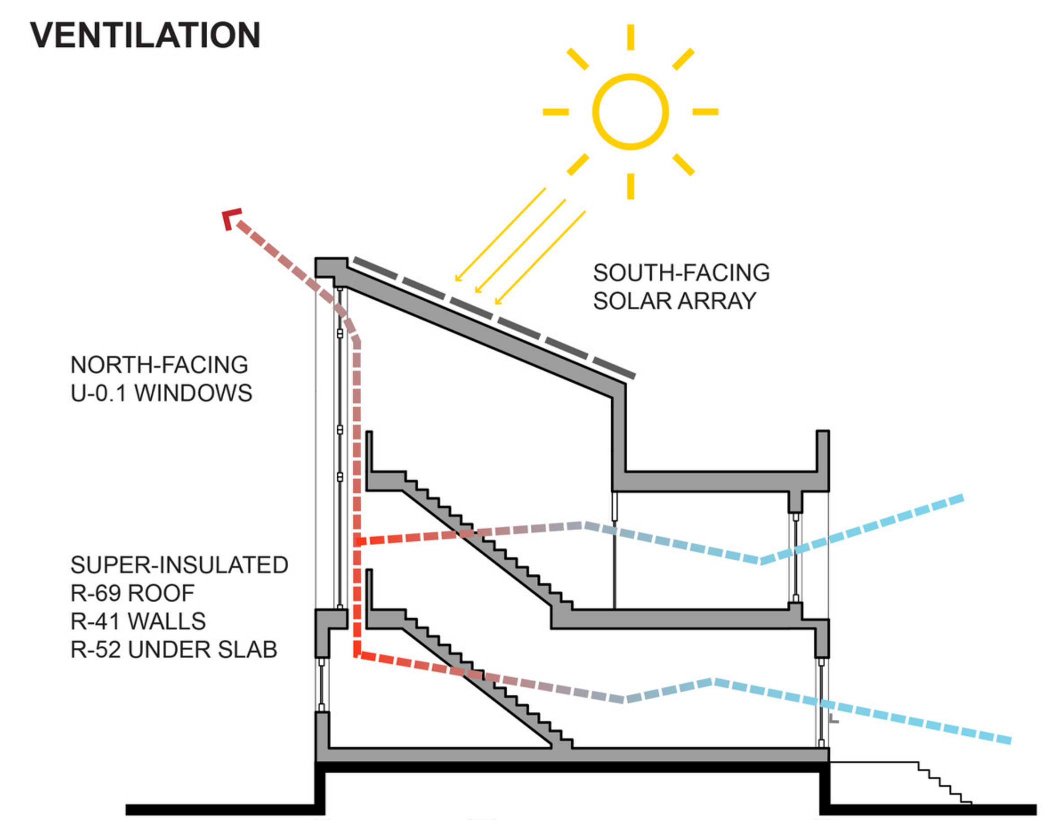


Fig. 2.30. *Ventilation and site orientation of passive housing*. Photograph by Interface Studio Architects, 2020. www.archdaily.com/633320/e-interface-studio-architects.

Study 2: **Key Considerations**

PVs are adaptable; they can mount to rooftops, walls, or the ground. The type of PV, the temperatures and sunlight levels, climate, tilt, and the azimuth of the modules are all critical to their placement. Generally, sites with good solar access should have PV panels that face south and are tilted roughly the same number of degrees as the site's latitude in order to generate the maximum annual energy.[57] It is essential to consider the amount of energy the house(s) will require to help determine the size of the solar array.[58]

Net Zero Energy Barriers
Energy storage (battery and meter), cost, and energy modeling are three predominant barriers to NZE homes. Other potential barriers include occupant behavior, equipment requirements, and mechanical problems.[59]

Storage
Energy storage occurs through a meter or into a battery for future domestic use. The meter spins backward when the PV panels produce more electricity than consumed and spins forwards when electricity consumes energy from the grid.[60] The homeowner pays for the net electricity consumed (delivered from the grid minus produced for the grid). Net metering can be a safety net when the solar electric system is not producing as much electricity as required, for example, with cloudy weather. In Massachusetts, storing solar energy in batteries is uncommon because of the upfront and added cost. Batteries are unnecessary to achieve NZE; however, they provide homeowners security and resiliency. When grid outages occur, electricity is still accessible due to the stored domestic energy within the battery.

Cost
The upfront cost of equipment, systems, and setup is a barrier to NZE construction. NZE homes face long payback periods without state and federal incentives. For example, energy retrofits provide a return on investment after 10–20 years.[61] Many owners do not have the capital for energy retrofits and NZE systems without incentives; therefore, the state and federal governments provide rebates and incentives.[62] Massachusetts has relatively large incentives for homebuyers and renovators, who generally a six-eight year payback period for solar electric systems.[63]

Fig. 2.31. *Retrofitted net zero house in Massachusetts*. Photograph by Revision Energy, 2019. Revision Energy, *Guide to Massachusetts Solar, Massachusetts Solar Incentives, Programs & Pricing*, 2019.

Study 2: **Key Considerations**

Energy Modeling
Energy modeling is essential to maximize building performance when designing NZE buildings.[64] However, the modeling can be distorted, and an NZE home may perform differently than predicted. Energy modeling uses historic local weather data and does not yet account for climate change.[65] When designing a NZE home, using the newest, most accurate, and localized regionally specific data is essential.

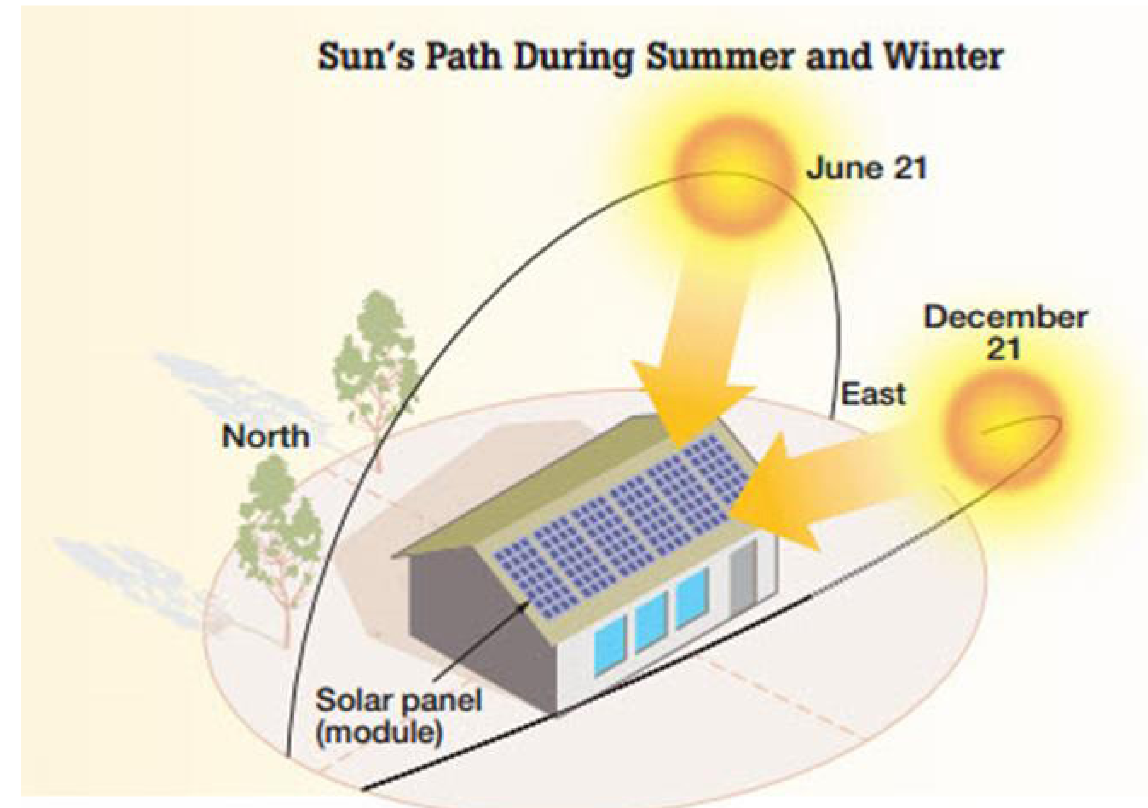


Fig. 2.32. *Solar path*. U.S. Department of Energy, New England Clean Energy, 2022.

Net Zero Housing: Cape Ann Context

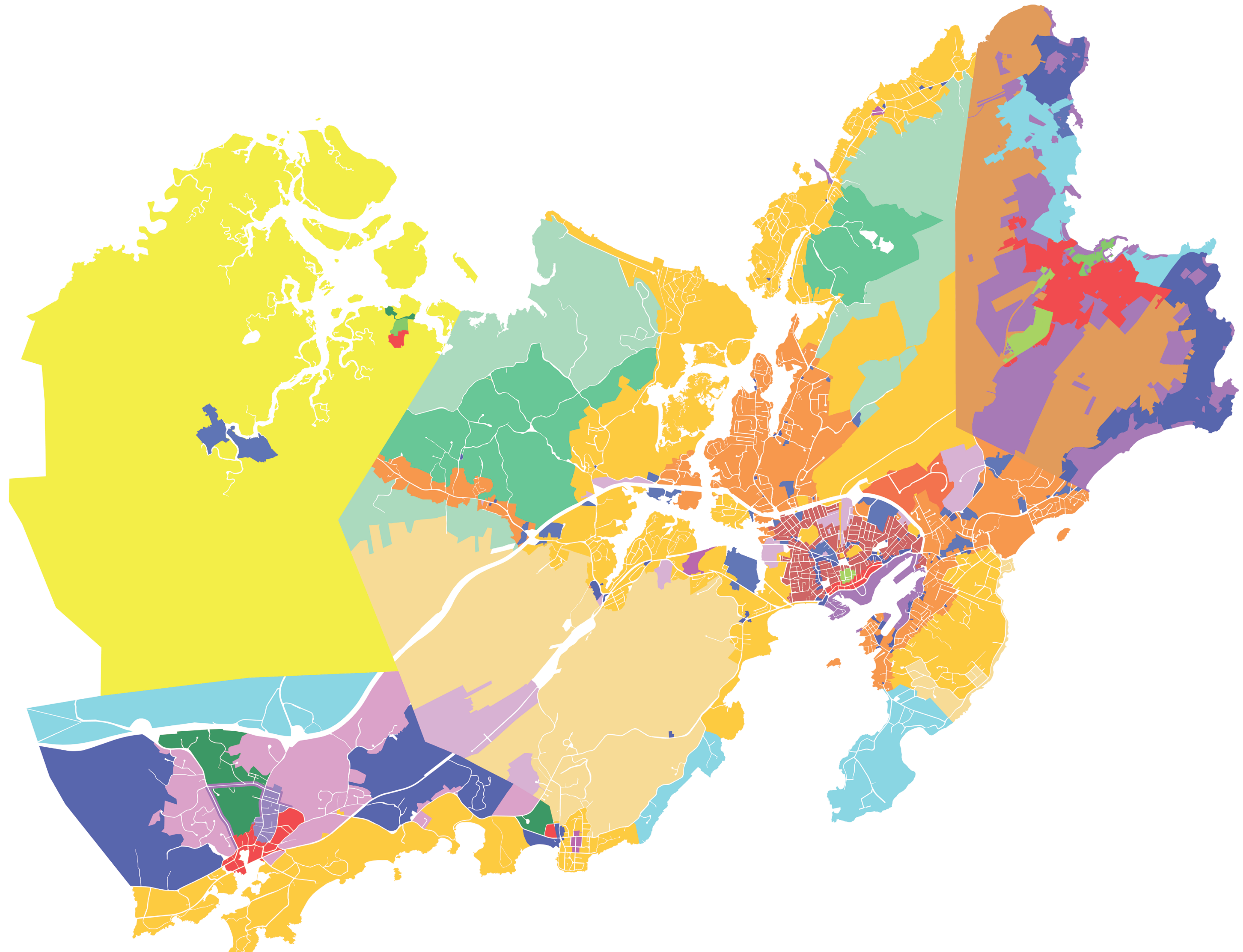
Several residents on Cape Ann have converted their existing homes into net zero properties in recent years. This individual innovation should be supported by municipalities with incentives for net zero construction.

The process of constructing housing involves community participation in the form of Town Meeting and Zoning Board meetings. These forums are an important democratic feature of municipal decision-making. However, they may also unintentionally bias policy discussions in favor of an unrepresentative group of overwhelmingly older, male longtime residents and homeowners. Such participatory inequalities have far-reaching implications for the future of equitable housing on Cape Ann. It is critical that discussions about relocation foreground affordable housing and enable representative community participation.[66]

Study 2: **Cape Ann Context**

Existing Zoning

Existing zoning ordinances vary widely across each municipality. Each municipality's zoning ordinance relies on special appeals to zoning authorities, which impede development compared to as-of-right zoning ordinances. Each municipality should work to lessen the restrictions for multi-family housing and affordable housing development. Each municipality should also pass flood overlay districts for current FEMA zones, future areas that will be impacted by sea level rise, and historic wetlands and waterways.



Existing Zoning District

Gloucester
- Business Park
- Central Business
- Civic Center
- Extensive Business
- General Industry
- Marine Industry
- Neighborhood Business
- Residential-10
- Residential-20
- Residential-30
- Coastal Residential-40
- Residential-5
- Rural Residential-80
- Rural Residential-40
- Village Business

Rockport
- Single Residential 'AA' District
- Single Residential District
- Residential 'A' District
- Residential District
- Semi-Residential District
- General District
- Downtown
- Town Owned

Manchester
- General
- Limited Commercial
- Single Residence A
- Single Residence B
- Single Residence C
- Residential D
- Residential E

Essex
- Residential
- Central Conomo Point
- Southern Conomo Point
- Downtown *proposed

1:60,000

Fig. 2.33. Map of existing zoning districts across Cape Ann.

Study 2: **Cape Ann Context**

2030 Housing Demand and Stock Projections

The Cape Ann population is aging more quickly than other areas in the Commonwealth of Massachusetts. The population is also declining.

Housing development is slow across Cape Ann, and stock has not kept up with increasing demand for diversified housing options, including smaller apartments and condos for younger and elderly residents.

In addition, there are parcels across Cape Ann located in the current FEMA floodplain and the future floodplain.

City of Gloucester

2030 Projections

Population

27,723

Household Size

2.05 people

Number of Households

13,218

+89 since 2020

Number of Parcels in Floodplain

1,769

Town of Rockport

2030 Projections

Population

6,763

Household Size

2.00 people

Number of Households

3,338

+3 since 2020

Number of Parcels in Floodplain

540

Town of Manchester-by-the-Sea

2030 Projections

Population

5,028

Household Size

2.13 people

Number of Households

2,347

+219 since 2020

Number of Parcels in Floodplain

497

Town of Essex

2030 Projections

Population

3,757

Household Size

2.16 people

Number of Households

1,742

+150 since 2020

Number of Parcels in Floodplain

540

1 household

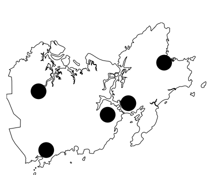


Fig. 2.34. Matrix of existing households within the floodplain.

Study 2: **Cape Ann Context**

Housing Demand and Affordability

Each of the four municipalities on Cape Ann is below the 10% affordable housing stock threshold required by Massachusetts Chapter 40B.

There are also extreme affordability gaps across Cape Ann, especially in Manchester-by-the-Sea. The affordability gap pushes lower- and middle-class families out of Cape Ann, including teachers, fishermen, and public safety officers who cannot afford to live in the communities where they work.

City of Gloucester	Town of Rockport	Town of Manchester-by-the-Sea	Town of Essex
Affordability	Affordability	Affordability	Affordability
Median Household Income	Median Household Income	Median Household Income	Median Household Income
$75,973	$83,683	$145,881	$119,369
Median House Price	Median House Price	Median House Price	Median House Price
$632,587	$754,921	$1,105,596	$754,333
Affordability Gap	Affordability Gap	Affordability Gap	Affordability Gap
$329,415	$420,189	$522,075	$276,857
Affordable Housing Demand	Affordable Housing Demand	Affordable Housing Demand	Affordable Housing Demand
12 per year	12 per year	12 per year	19 per year
Percentage of Affordable Housing	Percentage of Affordable Housing	Percentage of Affordable Housing	Percentage of Affordable Housing
~7.2%	~3.5%	~5%	~2.9%

1 household

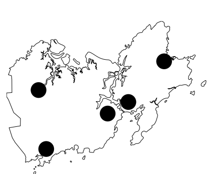


Fig. 2.35. Matrix of housing affordability.

*10% of housing stock should be deemed affordable under M.G.L. Chapter 40B.

Study 2: **Cape Ann Context**

Net Zero Housing on Cape Ann

The Shift to Solar in Massachusetts

Typically, Massachusetts consumers use a mix of fossil fuel power, with an estimated 90% of the electricity produced coming from fossil fuel and nuclear energy generated outside New England. Each year Massachusetts spends $22 billion on energy; 80% ($18 billion) is paid to out-of-state corporations, a lost economic opportunity.[67]

A switch to solar would mean that for every 1,000 kWh generated by PV systems, 2.03 pounds of sulfur dioxide, 0.54 pounds of nitrogen oxides, and 1,102 pounds of carbon dioxide emissions are prevented from entering the atmosphere. Solar PVs produce fewer emissions than fossil fuel electric generation, even accounting for production, transportation, and installation.[68] Harnessing the sun's energy through photovoltaics is a positive step toward lowering emissions. In Massachusetts, using PVs at the residential scale is feasible due to progressive regulations and the financial incentives offered to supplement the upfront costs. In 2018 the state had 2,300 megawatts of capacity—the seventh-most in the country, providing nearly nine percent of the state's electricity.[69]

Photovoltaics in MA

In New England, PV panels for residential use are attached to rooftops, as unused open land is rare in urban settings. Often free from obstruction, rooftops provide contractors with an easy surface for installation. Massachusetts's historic and vernacular housing typologies have gable, shed, and gambrels roofs, providing a sloped surface to shed water and snow properly. A slope is essential for PV panels to keep free of debris and capture the sun. In Massachusetts, PV panels should be installed at a 30-45 degree angle to the horizon to maximize solar generation.[70] Although the geography lacks the continuous sunlight observed in many other states, which leads to less robust energy production, Massachusetts's incentives and policies greatly contribute to its success in solar electric generation.[71]

Solar Energy Production

In Massachusetts, a 1kW solar electric system produces 1,200 kWh a year. The estimate means that a household with a standard 5kW solar electric system produces 6,000 kWh a year, covering 80% of a household's average energy consumption. These energy estimates do not account for the potential of solar water heating, solar space heating, and solar cooling, which would reduce the state's dependence on fossil fuels. Massachusetts

Fig. 2.36. *Solar installations on Cape Ann rooftops*. Resonant Energy, 2022.
Resonant Energy, "Cape Ann Solar Campaign," 2022.

Study 2: **Cape Ann Context**

has the potential to build "8.7 gigawatts of solar electric generating capacity—enough to produce the equivalent of 17% of the electricity Massachusetts consumes each year." Presently, the state only capitalizes on 1.3% of this potential.[72]

The Cape Ann region uses over 324,609 MWh of electricity and over 12,931,108 therms of natural gas annually. Individual buildings should be outfitted with solar panels to increase resilience. Approximately 20,361 buildings across Cape Ann are suitable for solar power installation. These buildings have annual solar radiation greater than 800 kWh and greater than 30m2 of rooftop space for solar installations. If every suitable rooftop on Cape Ann was outfitted with solar panels, residents could generate 516,206 MWh of electricity per year.[73]

The undeveloped public land across Cape Ann could produce 4,272,900 MWh of solar energy annually to power Cape Ann. This would build on a regional tradition of climate innovation that the City of Gloucester pioneered with Blackburn Industrial Park's wind turbine installations. Each community could lease fifteen-acre parcels of underdeveloped municipal land to solar companies. Each of these solar farms would produce enough electricity to power 400 homes. The lease proceeds would then enter a climate trust to fund adaptation projects across Cape Ann.[74]

Solar Incentives

Without the 26% Federal Investment Tax Credit or any local incentives, solar panels are an estimated 14 to 19 thousand dollars, with estimated future savings of $42,000 to $57,000. Although the upfront cost can be daunting for owners, the payback period is roughly 4.8 to 6.4 years, with an electricity bill offset of 77% to 104%.[75] Investing in solar PV panels minimizes emissions and can also produce financial returns throughout their twenty-plus-year life span through Massachusetts's net metering program.[76]

Massachusetts has many incentives for homebuyers and renovators, seeing a six-to-eight year payback period for solar electric systems. Solar electric systems can be directly owned or purchased or rented through third parties. Although requiring the most significant upfront financing, direct ownership has the highest rate of return on investment by allowing owners to take part in tax and purchasing incentives.[77]

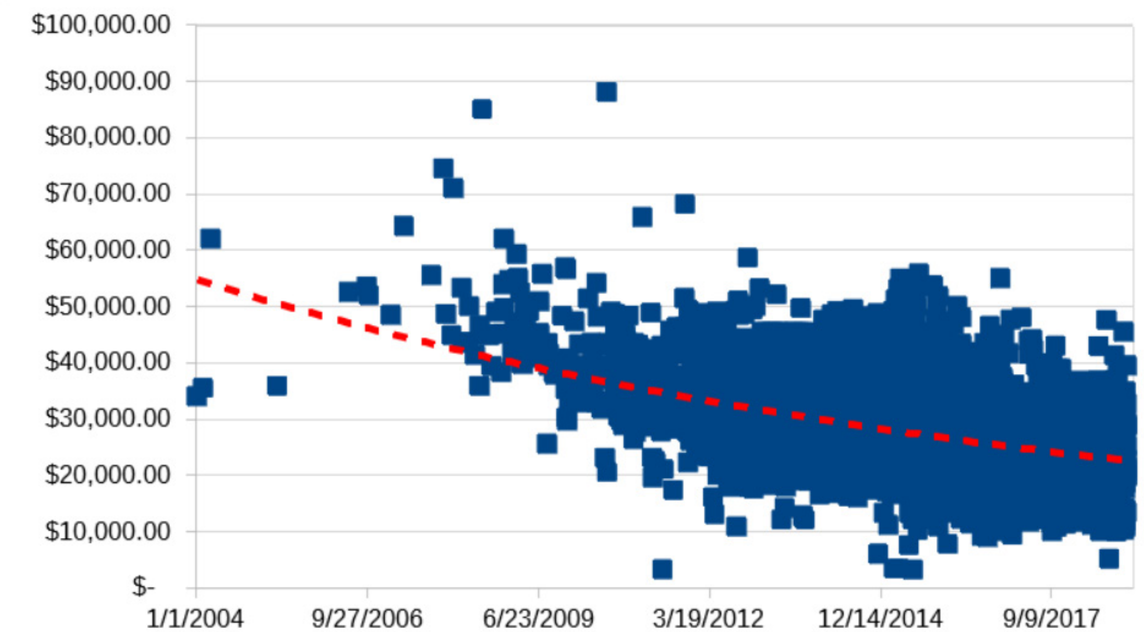


Fig. 2.37. *Savings on solar panels over time*. Alt Energy Store, 2018.
Alt Energy Store, Solar Incentives and Rebates in Massachusetts.

Study 2: **Cape Ann Context**

Transit-Oriented Design

Transit-oriented development (TOD) aims to concentrate housing, social and civic services, employment, and public transportation nodes. Town and cities reduce their carbon footprints by concentrating these essential services and connecting them through rapid transit, bike lanes, and walking paths.[78] Not only does it help shift away from urban sprawl, but it can also provide equitable access to housing and promote inclusive access to local amenities. The City of Portland, its suburbs, and neighboring communities benefit from the connectivity and diversity TOD encourages. TODs spur growth near transit stations, improve affordability for all community members and minimize automobile use by developing more sustainable communities.[79 80]

Gloucester, Rockport, Manchester-by-the-Sea, and Essex are all MBTA communities, and required to reform zoning laws to legalize the construction of TODs near public transit stations under Section 3A of Massachusetts General Law chapter 40A.[81] The law has been contested by community and government members across Cape Ann. This law requires new zoning districts to be developed within 0.5 miles of public transit in Massachusetts. These districts must also include multifamily housing with no age restrictions.[82] The towns of Essex, Manchester-by-the-Sea, and Rockport require 750 units and Gloucester 2,270 units with a minimum gross density of 15 units per acre.[83] Although Essex does not have a community rail station, it is an MBTA-adjacent community, meaning that it has transit services within half a mile of the municipal boundary. In Manchester-by-the-Sea, limited commercial districts (East and West), downtown development and other new decentralized mixed-use development are proposed to meet the needs. In Gloucester, TOD is proposed around the T stop between Maplewood Avenue, Myrtle Square, and Washington Street, and in Rockport, a TOD district is proposed around its T station at Pooles Lane, Main Street, and Railroad Avenue.[84 85]

TOD takes many forms depending on its context. As noted in the Final Report for Rockport, the specific development strategy for each community will be scaled appropriately.[86] It will embed the vernacular building culture of that region to maintain and foster the communities character.[87] TOD tailored to each community can maintain the traditions of the North Shore while providing equitable housing and access to public transportation for all.

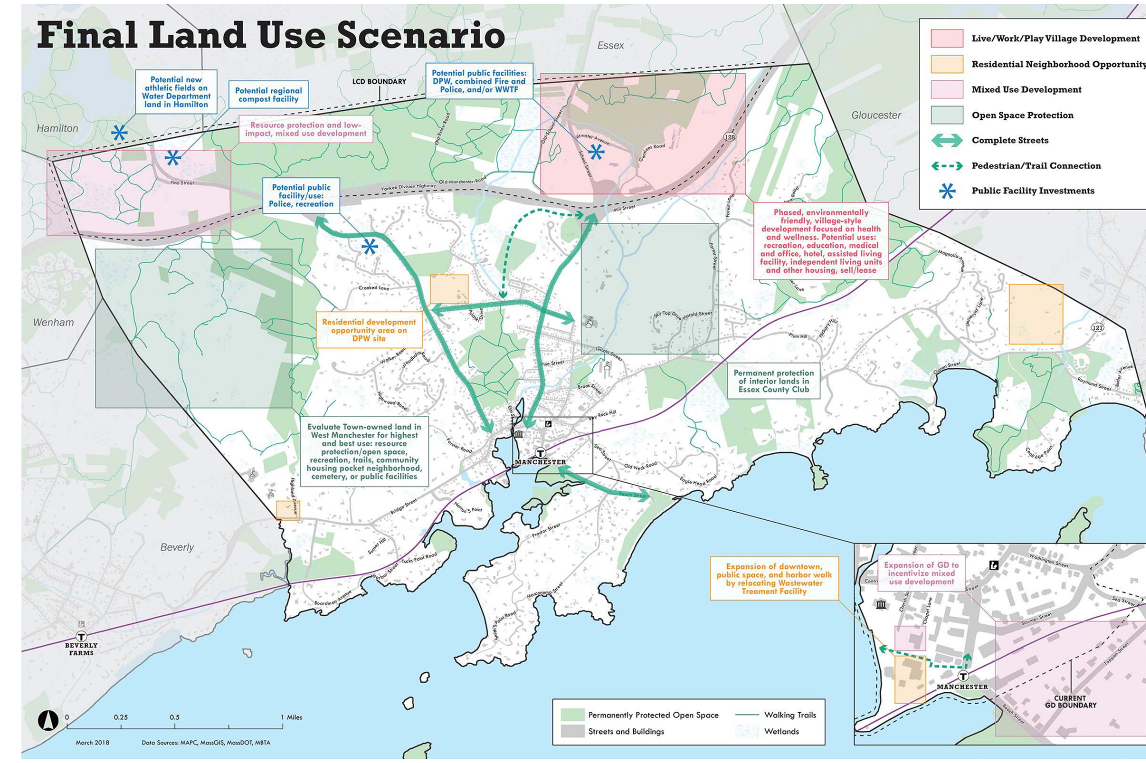


Fig. 2.38. *Manchester-by-the-Sea Economic Development and Land Use Diagram.* MAPC and Manchester-by-the-Sea, Final Report, Manchester-by-the-Sea Housing, Economic Development, and Land Use Scenario Study, 2018, 19.

Fig. 2.39. *Proposed Railroad Development District.* MAPC and City of Gloucester, Public Meeting 3, Reimaging Railroad Strengthening Connections Downtown, 10.

Fig. 2.40. *Proposed Rockport Transit-Oriented Plan.* MAPC and City of Rockport, Final Report, Rockport Station Area Transit-Oriented Village Plan, 2018, 18.

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