Advanced Modular Housing Design

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U.S. Department of Housing and Urban Development | Office of Policy Development and Research

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Foreword

The damage from natural disasters exacerbates existing shortages of affordable housing and disproportionately affects vulnerable households. A disaster can lead to long-term displacement of residents if there is no nearby temporary housing, which both slows individual and community recovery.

HUD provided a research grant to the University of Florida to develop blueprints for rapidly deployable factory-built housing units using Advanced Modular Housing design. These units could be an important lifeline as communities recover from disaster. Manufacturers can use the blueprints in this report to build homes that can quicky re-house members of the community whose housing was damaged or destroyed from a disaster. These homes can also withstand future storm events.

The project team developed scalable design units that can be constructed off site in a factory and delivered on site post disaster. The smallest units include all the required amenities of a home, including a kitchen, bathroom, and sleeping space. This core unit can be expanded with add-on components to include up to three full bedrooms, as well as a full bathroom.

Importantly, the core units can be delivered quickly in the days following a disaster and placed in either a temporary or permanent location, and expansion components can be added later. This unique design would provide solid, storm-resistant shelter that can be quickly deployed to minimize resident displacement, but units can be expanded and made permanent when consistent with a community's long-term recovery plan. This report provides specifications and cost estimates so that these designs could be tested in real-world situations.

With this publication, HUD continues to play a leading role in disseminating information to manufacturers and policymakers about how to incorporate modular solutions in post-disaster recovery. The increasing likelihood and severity of natural disasters require innovative and rapid responses to help individuals and communities recover. Given the importance of innovative new solutions in post-disaster recovery, HUD is pleased to continue serving as a leader disseminating insights about advanced and resilient construction methods.

Solomon Greene

Principal Deputy Assistant Secretary for Policy Development and Research

U.S. Department of Housing and Urban Development

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List of Exhibits

Abbreviations

ABFE: FEMA Advisory Base Flood Elevation
AC: air-conditioning
AMH: Advanced Modular Housing
AMI: Area Median Income
AMHD: Advanced Modular Housing Design
ANSI: American National Standards Institute
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
CDs: construction documents
CFM: cubic feet per minute
CLT: cross-laminated timber
DfD: design for disassembly
EEMs: energy efficiency measures
EIA: U.S. Energy Information Administration
EUI: energy use intensity
FEMA: Federal Emergency Management Agency
FGBC: Florida Green Building Coalition
FRC: Florida Resilient Cities program
HUD: U.S. Department of Housing and Urban Development
HVAC: heating, ventilation, and air-conditioning
IECC: International Energy Conservation Code
ITC: Energy Investment Tax Credit
LEED: Leadership in Energy and Environment Design
LEED H: LEED for Homes
LF: linear feet
LVL: laminated veneer lumber
LVP: luxury vinyl plank
MEF: modified energy factor
NAHB: National Association of Home Builders
NGBS: National Green Building Standard
NREL: National Renewable Energy Laboratory

NOAA: National Oceanic and Atmospheric Administration

NPSJ: North Port St. Joe

PMI: private mortgage insurance

PV: photovoltaic

RECS: Residential Energy Consumption Survey

ROI: return on investment

SHGC: solar heat gain coefficient

TRAMCON: Training for Manufactured Construction

GLOSSARY

AMH design: Advanced Modular Housing design, the focus of this project

BEopt: A residential building-focused graphical user interface front-end for EnergyPlus developed by the National Renewable Energy Laboratory

Building envelope: The physical barrier between the conditioned and unconditioned, or interior and exterior, environment of a building

Core: The solid, storm-resistant "heart" of 1,200 ft^2 Core+ structure, providing essential housing functions, including kitchen, bath, laundry, and sleeping loft; the area of the Core module is 160 ft^2

Core+: The 1200 ft^2 AMH design model resulting from this research, comprising three distinct modular units: Core, Space, and Dwell

Dwell: The third and final module added to the Core+ model, which provides three full bedrooms and a full bathroom; the area of Dwell module is 193 ft^2

Energy factor (EF): A metric used to compare the energy conversion efficiency of residential appliances and equipment

Energy use intensity (EUI): A metric used in Building Energy Modeling calculated by dividing the total energy consumed by the building in 1 year (measured in kBtu) by the total gross floor area of the building

Green building rating system: A tool used to assess and rate buildings that meet certain standards and requirements regarding the environmental, resource, and health impacts of a building's design, construction, and operation

HUD code: means the HUD Manufacturing Construction and Safety Standards that regulate the assembly, manufacture, and performance of a manufactured home.

Hurricane: A tropical cyclone with maximum sustained winds exceeding 74 mph (119 km/h)

Leadership in Energy and Environment Design (LEED): The preeminent U.S. green building rating system

LEED Homes: A green building rating system for residential units issued by Leadership in Energy and Environment Design

Major hurricane: A hurricane in Category 4 or 5 on the U.S. National Hurricane Center scale, defined as having maximum sustained winds exceeding 130 mph (209 km/h)

Manufactured housing: means a structure, transportable in one or more sections, which in the traveling mode is 8 body feet or more in width or 40 body feet or more in length or which when erected on-site is 320 or more square feet, and which is built on a permanent chassis and designed to be used as a dwelling with or without a permanent foundation when connected to the required utilities, and includes the plumbing, heating, air-conditioning, and electrical systems contained in the structure. **Modular housing:** Residential units manufactured in factories via prefabrication and placed on a permanent foundation; they must comply with local building codes

National Green Building Standard (NGBS): A green building rating system developed by the National Association of Home Builders

Onsite construction: Conventional construction delivery in which building materials are delivered to the building site and used to create a structure

Prefabrication: A strategy of using components made off site in a factory, which are then transported and assembled on site to create a structure

R-value: A measure of the insulation's ability to reduce the rate of heat flow under specified test conditions

Simple payback period: The time required to recover a project investment without considering the time value of money

Solar heat gain coefficient (SHGC): A measure of the solar radiation emitted through a window

Space: The second module added to the Core+ model, which provides a flexible space that can serve as a den, sleeping porch, or full bedroom; the area of the Space module is 794 ft^2

System energy efficiency rating (SEER): A value used by the HVAC industry to determine how much cooling power an air conditioner provides for a given amount of electrical energy

U-factor: The rate at which wall, window, or skylight energy is lost by specifying how many BTUs can pass through one square foot of material in an hour

EXECUTIVE SUMMARY

Since the 2008 recession, the U.S. housing industry has generally recovered and, in some regions, has rebounded to prerecession levels. Nevertheless, the U.S. housing industry faces at least three key challenges: resiliency, sustainability, and affordability. *Resiliency* is a community's ability to minimize damage and recover quickly, *sustainability* is the ability to minimize the impact on the environment through material selection and energy efficiency and *affordability* is a measure of its cost and the purchaser's monetary ability. These challenges are exacerbated by natural disasters, such as major storm events that have heightened the risk of destruction to property and other infrastructure in U.S. coastal communities. Tragically, in some instances, storms have caused near-permanent damage to communities, including extreme shortages of housing stock.

This report provides detailed cost estimates that cover the cost of manufacturing the Advanced Modular Housing units, including the cost of transportation of units from the manufacturing plant to the site and all site-related costs. Additionally, these costs would include some savings if all units were transported and installed at the same time. These cost estimates provided by UFL researchers are useful for the industry and the consumer.

A team of experts from the University of Florida (UF) incorporated innovative technologies to rapidly deliver large quantities of post-disaster housing through Advanced Modular Housing (AMH) design to address the problem of housing demand in the context of the three key challenges facing the U.S. housing industry. Through collaborative research, the following two research questions were addressed:

- *How do we design and manufacture modular housing to help mitigate the impacts of climate change and reduce operational costs through hyper energy efficiency, the incorporation of renewable energy generation and storage systems, and other measures to make housing more sustainable?*
- *How can we maintain affordability while providing people with housing that can withstand increasingly frequent and damaging natural disasters?*

The main objective of this project is to collaborate with the modular home manufacturing industry to design post-disaster housing through AMH. AMH research aims to design factory-built housing that can withstand weather events and serve as a community asset. The attributes of advanced modular post-disaster housing include appropriate structural strength and construction flexibility (resilience), high levels of energy efficiency, the potential for energy self-sufficiency (sustainability), and selection of equipment (affordability). Environmental factors such as hurricane-force winds are primarily the guiding factor used to develop AMH technologies. The team focused on single-family post-disaster housing types suitable for the southeastern United States for this research.

The project involved organizing two workshops centered on post-disaster housing through AMH research and inviting industry leaders (modular home manufacturers, mechanical system and smart control device manufacturers) and other participants from the insurance and finance industry to attend. Through active collaboration, the AMH design—namely, the functional modules of *Core*, *Space*, and *Dwell* units—was engineered considering the three pillars of our research: resiliency, sustainability, and affordability.

The project team developed a complete set of Construction Documents (CDs) and active collaboration with community members in North Port St. Joe, Florida. Three recommendations are suggested for housing policymakers, namely, to (1) embrace resiliency, sustainability, and affordability as the fundamental basis of modular housing; (2) fit the specific functions (utility) and appropriate strengthening of modular housing to support weather-related disasters crucial for future-proofing; and (3) make modular housing affordable to help level the playing field for vulnerable households. The development of the AMH design directly addresses a key problem for Florida's lower-income homeowners: the high cost of energy consumption and its contribution to the housing cost burden.

In summary, this project resulted in the following deliverables—

- Design of a scalable AMH design as a solution for post-disaster housing with an emphasis on resiliency, sustainability, and affordability.
- Development of CDs of AMH design that include drawings of the three functional modules—Core, Space, and Dwell units—and information on photovoltaics (PVs) installation and energy storage system integration.
- Detailed estimation of Energy Efficiency Measures (EEMs) and their energy impacts.
- Detailed life-cycle costing of Core+ modules and evaluation of energy systems.
- How AMH design is a supply-side solution to the housing shortage and post-disaster housing in Florida.

In addition to developing a complete set of CDs, the project team actively engaged with community members in North Port St. Joe, Florida, and addressed community housing challenges, with potential for future development by the lot owners. We anticipate that the result of this post-disaster housing through AMH will be embraced by both the modular housing manufacturing industry and the buyers of their products.

The project report contains eight chapters.

Chapter 1 provides an introductory discussion of the key challenges facing the U.S. housing industry and the need for AMH research.

Chapter 2 provides a background of major U.S. hurricanes and the responses from the government and industries.

Chapter 3 discusses the AMH design methodology and introduces the functional modules of AMH design—namely, the Core, Space, and Dwell units.

Chapter 4 details the methodology used to compare AMH design's energy estimates.

Chapter 5 provides the energy-saving potential of various EEMs for Core+ modules.

Chapter 6 offers the detail related to the life-cycle costing of Core+ modules.

Chapter 7 discusses the characteristics of AMH design home occupants and provides insights into the affordable housing gap and the loss of lower-cost housing supply.

Chapter 8 concludes with AMH design as a supply-side solution to the housing shortage and for post-disaster housing in Florida.

CHAPTER 1. INTRODUCTION

Although the U.S. housing industry has shown an upward trend in growth in construction, several key challenges hamper significant growth overall. Some of these key challenges include resiliency, sustainability, and affordability of housing. To exacerbate these challenges, extreme weather events have caused near-permanent damage to communities, resulting in a severe housing supply deficit. Advanced techniques in modular housing that is constructed in factories offers a potential solution to alleviate extreme shortages of housing stock. This chapter discusses the scope of this Advanced Modular Housing Design (AMHD) research, detailing how the three key challenges were addressed. The next section introduces the project team and the industry collaborators who were instrumental in designing post-disaster AMH. That section is followed by the significance and the broader impacts of this research. The chapter concludes with a discussion on the project team's active collaboration with industry partners.

Scope of Advanced Modular Housing Design Research

Severe weather-related events such as hurricanes can leave large populations without adequate shelter, potentially for long periods. This problem will likely become even more challenging due to the increasingly powerful and more frequent hurricanes forecasted to strike the United States, particularly the coastal regions. Three main hazards affect a house during a hurricane: strong winds, battering rains, and ocean water swells (NOAA, 2018). To ensure that structures are constructed to withstand damage, housing designers must know firsthand the effects of hurricane damage and work collaboratively on construction projects to develop appropriate designs and advanced building safety techniques. Needless to say, the cost of recovery for human lives and infrastructure is high. Builders must strike a balance between affordability and the additional costs incurred by adding durable materials and using energy-efficient materials and methods to save and store energy for use after a hurricane disaster. This AMH research addresses the challenge of rapidly rebuilding communities damaged and perhaps even destroyed by major storms.

The main objective of the project is to collaborate with the modular home manufacturing industry to develop a roadmap considering technologies and processes that will enable the industry to design resilient post-disaster housing. The project focused on single-family post-disaster housing types suitable for the southeastern United States. Through the use of cutting-edge technologies and processes, the post-disaster housing through AMH can be rapidly manufactured in factories, withstand major weather events, and serve as a community asset. Hurricane-force winds, flooding, and storm surges must be considered in identifying the technologies used in AMH. The attributes required for post-disaster AMH include high levels of energy efficiency, the potential for energy self-sufficiency, appropriate structural strength, and construction flexibility (e.g., deconstructability and reassembly). This research addressed three key challenges facing the U.S. housing industry: resiliency, sustainability, and affordability.

1. **Resiliency.** Resiliency is a community's ability to minimize damage and recover quickly from extreme events and changing conditions. After a disaster, buildings must be assembled rapidly so that families can return to their homes on their own site after cleanup—if not severely damaged—within weeks instead of years. In cases where sites are severely damaged, rapidly setting up buildings in a central location for the families is crucial. More importantly, the newly built structures need to withstand and adapt to

sudden and prolonged changes due to climate change and storm damage long after the initial deployment of the structure. Greater resilience to change not only better prepares occupants for subsequent disasters but also builds a community asset that gains value with time. Furthermore, manufactured houses must have the capacity to grow and adapt to changing situations, including family size.

2. **Sustainability.** Sustainability, in the context of buildings, is the ability to minimize the impact on the environment through material selection and energy efficiency and to improve occupant comfort using optimal daylight, ambient temperature, and increased ventilation. Passively designed and low-energy housing equipped with renewable energy generation and storage technologies can greatly reduce energy costs, lower carbon emissions, and help make housing self-sufficient in terms of energy and water during power outages caused by disasters. Furthermore, through careful selection of building materials and appropriately designing for deconstruction, waste can be eliminated, and the building materials can eventually be recovered for reuse or recycling during deconstruction.
3. **Affordability.** A measure of a product cost relative to the purchaser's monetary ability is referred to as affordability. Housing is usually considered affordable if no more than 30 percent of household income is devoted to housing costs, including utility consumption. Florida's population growth, combined with the state's dramatic housing boom in the mid-2000s, has led to a shrinking supply of affordable single-family homes, especially for low-income households. More than 1.4 million households in the state with incomes below 60 percent of the annual median income (AMI) are cost burdened defined as households spending more than 40 percent of their income on housing. One-half of owners and more than two-thirds of renters are cost burdened by housing. With the help of life-cycle cost analysis, building materials and other accessories—solar photovoltaic (PV), hot water systems, etc.—can be integrated appropriately to enhance housing affordability.

Project Team and Industry Collaborators

The project team comprises experts from the University of Florida (UF). The four working teams included the *architecture team,* designed housing to improve resiliency, enhance energy efficiency, and increase affordability. The *energy team* developed whole-building energy models to estimate building energy use. Energy simulation model analysis included various energy efficiency measures (EEMs) to minimize monthly energy cost. The *life-cycle cost team* analyzed the initial cost, simple payback period, and life-cycle costs over a 30-year period of the building, site improvement, and EEMs, including renewable energy systems. Finally, the *affordability team* integrated the affordable housing context and the post-disaster recovery environment into the project. The project team collaborated with modular home manufacturing industries (Clayton Homes, Palm Harbor Homes, and Jacobsen Homes) and LG Electronics.

Significance of the Work

The manufacturing of modular housing represents a major shift away from fabricating housing on site. The shift to factory-built housing types is occurring for several reasons. The first is the ongoing inflation of construction costs caused by the demand for significantly more housing due to a growing population and economy(Khater et al., 2018). A second driver of this shift is the shrinking construction workforce caused by the retirement of the baby boomer generation of skilled tradespeople and the challenges of recruiting their replacements for an industry with high safety risks and challenging working conditions (Netzer, 2019). Modular housing can be produced with higher quality, greater precision, greater affordability, increased safety, greater speed, increased sustainability, and more inherent resilience than its site-built counterparts. Focusing on this industry and its design and manufacturing processes can produce a high return on investment (ROI) for the U.S. economy and population. The collaborative research in this report addressed the following two research questions:

- *How do we design and manufacture modular housing to help mitigate the impacts of climate change and reduce operational costs through hyper energy efficiency, incorporating renewable energy generation and storage systems, and other measures to make housing more sustainable?*
- *How can we maintain affordability while providing people with housing that can withstand increasingly frequent and damaging natural disasters?*

By accelerating the ongoing shift toward homebuilding in factories—i.e., modular housing—the United States can successfully address the need for housing to cope with major future challenges.

However, it should be noted that the AMHD research effort and this report did not address the subject of accessibility for persons with physical, cognitive, or sensory disabilities. This is a subject for future research and for the adaptability of the design documents and guidelines herein. This report does include some discussion of disability-related issues such as adaptability for persons with a disability and accessible site selection and preparation. Also, it includes some references to available HUD guidance such as the Fair Housing Act Design Manual. https://www.huduser.gov/portal/publications/PDF/FAIRHOUSING/fairfull.pdf.

As defined in the scope of the research, this publication focuses on energy efficiency, environmental factors, construction materials, building systems, and the like in advancing the goals of effectively addressing the key challenges of resiliency, sustainability, and affordability. Undoubtedly, the way dwellings are designed for the lives of the particular occupants will be interrelated and potentially supportive to this effort. While not the focus of this project, such design considerations are conceptually addressed to an extent by the Core+ model presented later in this document. Yet, the critical design issue of access for individuals with disabilities must be noted given its impact on the configuration of any residence. Inclusion of accessibility in the initial design will minimize the need for significant alterations and costly reconstruction for initial occupants with a disability and as the occupants' abilities change when they age or assume the responsibility as caretakers for others with disabilities. Over time, this approach will conserve resources, maintain affordability, and preserve the integrity of a given design.

Accessibility is equally as important as a civil right and ensures that people with disabilities have the same opportunities as others to benefit from approaches like those offered in this publication when implemented in a variety of situations. Lenders, investors, developers, designers, architects, inspectors, and builders may have obligations under Federal and other authorities to provide or ensure a minimum level of accessibility. Among the factors that must be considered include the types of housing to be constructed, obligations specifically related to housing programs, and any governmental financial assistance provided. An overview of these authorities is mapped out in the following paragraphs.

Both privately owned and publicly assisted housing, regardless of whether they are rental or for-sale units, must meet the accessibility requirements of the Fair Housing Act when they are located in a building of four (4) or more units built for first occupancy after March 13, 1991. The accessibility standards for compliance with the Fair Housing Act are set forth in 24 C.F.R. § 100.205, including crucial building features (a safe harbor) listed in § 100.205(e)(1)-(2)[1].

All Federally assisted new construction housing developments with a minimum of five (5) or more units must design and construct five (5) percent of the dwelling units, or at least one unit, whichever is greater, to be accessible for persons with mobility disabilities. An additional two (2) percent of the dwelling units, or at least one unit, whichever is greater, must be accessible for persons with hearing or visual disabilities. These units, routes, and common areas must be constructed in accordance with the Uniform Federal Accessibility Standards (UFAS). See HUD's Deeming Notice, 79 Fed. Reg. 29,671 (May 23, 2014), for an explanation of when recipients can use the 2010 ADA Standards to comply with Section 504. Federally assisted single family housing may also need to comply with Section 504 as a reasonable accommodation.

Title II of the Americans with Disabilities Act (ADA) covers housing provided or made available by public entities (state and local governments and special purposes districts). Title III of the ADA requires places of public accommodation and commercial facilities to be designed, constructed, and altered in compliance with ADA accessibility standards. Public accommodations at housing developments include any public areas that are open to the general public, such as a rental office. Public accommodations would also include, for example, shelters and social service establishments. New construction and alterations must be designed and constructed in accordance with the 2010 ADA Standards for Accessible Design. Title II of the ADA also includes a program access requirement, while Title III of the ADA requires readily achievable barrier removal.

For more information and references to disability related information sources, see HUD's website at https://www.hud.gov/program_offices/fair_housing_equal_opp/disability_overview.

Changes to the Homebuilding Process

Broader Impacts

The U.S. housing industry faces several key challenges: resiliency, sustainability, and affordability. The resilience of the structure is critical to withstand sudden and prolonged change due to climate change and storm damage and the ability to rapidly assemble on site or off site depending on site cleanup and severe damage after the disaster. Building sustainability is important to greatly reduce energy costs, lower carbon emissions, and increase self-sufficiency. Similarly, the affordability of the housing is essential and requires careful selection of building

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[1] The Fair Housing Act Design Manual can be found here: https://www.huduser.gov/portal/publications/PDF/FAIRHOUSING/fairfull.pdf

systems (HVAC, renewable energy and storage, etc.) using life-cycle cost analysis. This research developed a roadmap to enable the manufacturing modular housing industry to design post-disaster housing through AMH. The design and technology improvements identified by this research will affect the design of buildings, including the attributes required, such as appropriate structural strength and construction flexibility (resiliency), high levels of energy efficiency, the potential for energy self-sufficiency (sustainability), and the selection of equipment (affordability).

Practical implications to the modular housing industry. Among the practical implications of this research are the following:

- The selection of advanced technologies that promote resilience, sustainability, and affordability is critical in the manufacturing of modular housing. These technologies—which focus on energy modeling, performance assessment, cost analysis, etc.—will provide the industry with new products and opportunities and result in lower costs, higher productivity, better quality, lower operational and maintenance costs, and—potentially—lower insurance rates.
- The widespread deployment of AMH and the associated implementation of advanced manufacturing processes and technologies provide the opportunity to improve energy efficiency, achieve renewable energy systems, and reduce water usage. These advancements will help directly address the problem of climate change by reducing energy and water consumption and eliminating the operational carbon footprint of buildings while greatly improving affordable housing.

Acceptance by Relevant Stakeholders

The results of this research will likely be embraced by both the modular housing manufacturing industry and the buyers of their products because of the inclusive process of the research:

- The project team engaged key stakeholders from the outset. Among the participants in this effort were companies that manufacture housing and several of their industry associations. These companies actively engaged in the two workshops, one conducted at the UF (before COVID-19) and the latter via virtual conference (during COVID-19).
- The team for this research has developed good relationships with the industry and previously collaborated with them on developing TRAMCON, a training program for new workers in the industry. The project team continued building this relationship by collaborating with the companies and associations in meetings, conferences, design charrettes, and continuing education.
- The project team organized two workshops centered on this research topic that included industry leaders and other participants from the insurance and finance industry, the Florida Housing Finance Corporation, the Division of Emergency Management, the Federal Emergency Management Agency (FEMA), and the National Oceanic and Atmospheric Administration (NOAA) to advance the outcomes of this research.
- The outcomes of this work will be disseminated in both academic and trade journals and publications. Because of COVID-19 restrictions, the project team could not visit the major modular housing manufacturers' facilities to study existing manufacturing processes. However, manufacturers and key stakeholders actively participated in the

workshops, and their input and feedback were recorded and implemented in the design as appropriate.

CHAPTER 2. BACKGROUND

Natural disasters, such as major storm events, have created a heightened risk of destruction to property and other infrastructure in U.S. coastal communities. In collaboration with the modular home manufacturing industry, this research incorporated innovative technologies to rapidly deliver large quantities of post-disaster housing through Advanced Modular Housing (AMH) design to address the problem of housing demand in the context of the three key challenges facing the U.S. housing industry. To that end, several key attributes were considered and included in this effort after conducting a background study related to hurricane disasters and post-disaster responses, green building rating systems and standards, and energy efficiency technologies. This chapter discusses these topics, which were instrumental in designing post-disaster housing through AMH. The chapter starts with a short history of hurricane disasters and post-disaster responses by the government and industry. Because the research focused on single-family post-disaster housing types suitable for the southeastern United States, the hurricane-related literature focuses only on the southeastern United States. The chapter concludes with a discussion of green building rating systems and standards.

The History of Hurricane Disasters and Post-Disaster Responses

Among other natural disasters, flooding and storm surges caused by hurricanes are perhaps the most significant natural and extreme weather-related disasters in the United States, especially in the southeast, frequently causing enormous destruction and the leveling of communities. Hurricanes are tropical cyclones that produce sustained winds exceeding 74 mph (119 km/h).[2] This study focuses on the southeast areas of the United States, classified as zones 1, 2, and 3 on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zone map (Gilbride, 2013) (exhibit 1) . Because extensive literature on the catastrophic aftermath of hurricane events exists, this report briefly discusses the history of and damage from major hurricanes with landfalls in climate zones 1, 2, and 3 (exhibit 2); U.S. government reactions to disasters, mainly by the Federal Emergency Management Agency (FEMA); and the responses by industry and private companies.

Major U.S. Hurricanes

Since 1851, 298 Atlantic tropical cyclones have produced hurricane-force winds in every state bordering the Atlantic Ocean and the Gulf of Mexico, and Florida has been affected more than any other state (NOAA, 2018). The list of Florida hurricanes include approximately 500 tropical or subtropical cyclones—most notably, Hurricanes Andrew, Irma, and Michael in the 1992, 2017, and 2018 seasons, respectively (NOAA, n.d.b). The 1990s was the most active decade for the United States, with 31 hurricanes affecting the nation, as seen in exhibit 1. By contrast, the least active decades were the 1860s and 1970s, each with only 15 hurricanes affecting the country (NOAA, 2018). Refer to appendix A for historical facts on hurricanes.

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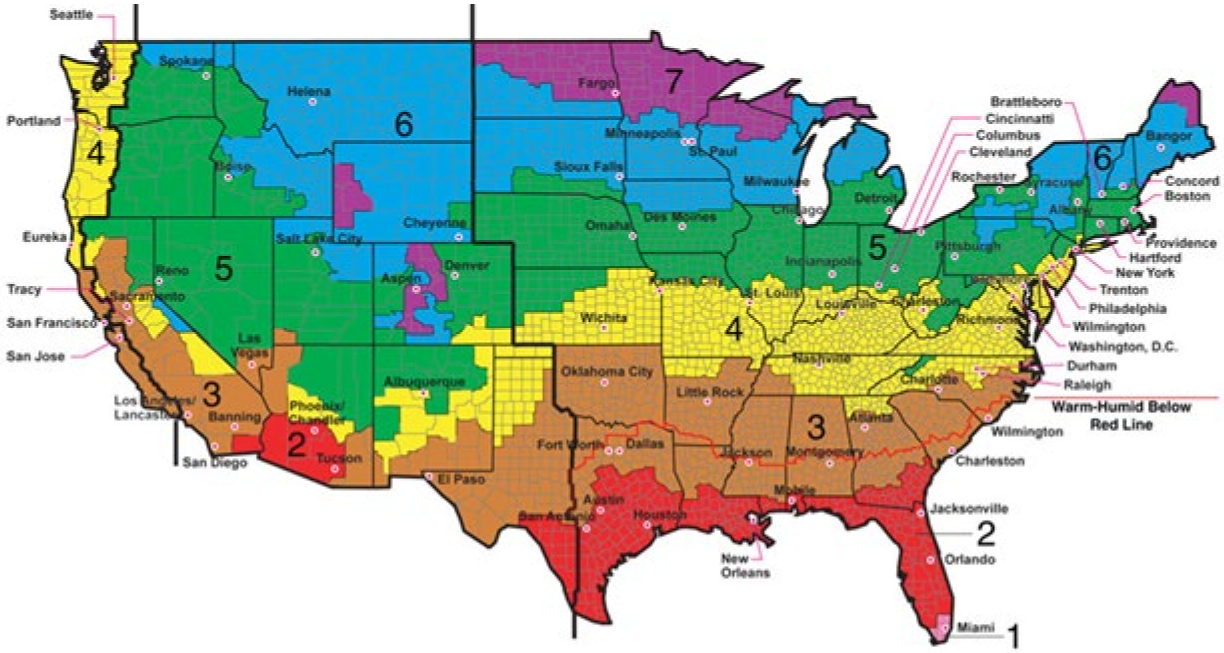
[2] In the western North Pacific, hurricanes are called typhoons; similar storms in the Indian Ocean and South Pacific Ocean are called cyclones (see National Hurricane Center and Central Pacific Hurricane Center: https://www.nhc.noaa.gov/climo/).

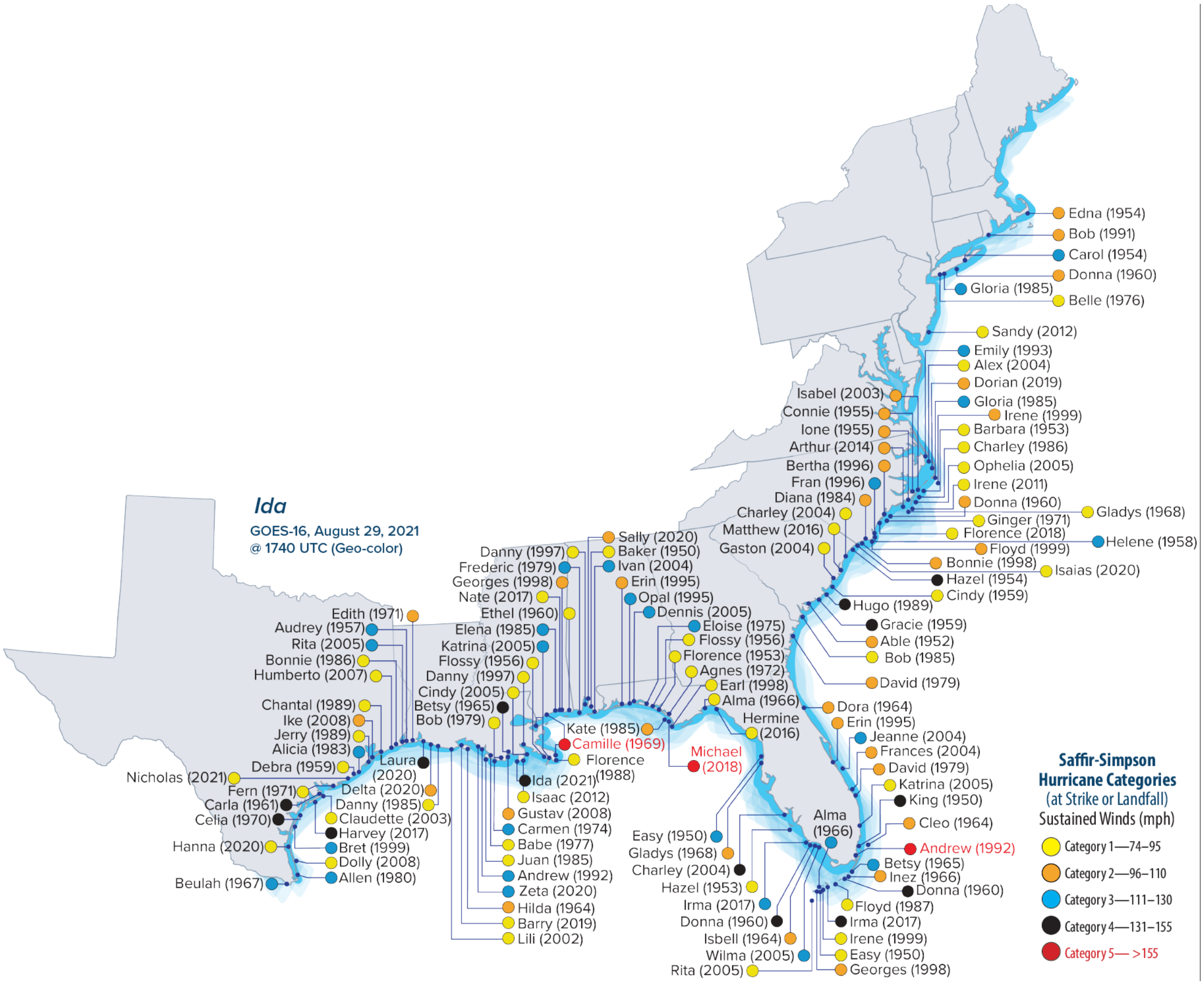
Exhibit 1. U.S. Climate Zone Map



Source: ASHRAE, 2019

Major Category 4 and 5 hurricanes that struck ASHRAE climate zones 1, 2, and 3 are listed in exhibit 3. Since 1900, climate zones 1 and 2 have experienced the most landfalls of Category 4 and 5 hurricanes (especially the state of Florida), and climate zone 3 has been affected to a lesser extent. The next section discusses the history of major U.S. hurricanes.

Exhibit 2. Continental U.S. Hurricane Strikes, 1950–2021



Source: NOAA, Continental United States Hurricane Strikes 1950–2021, 2022

Exhibit 3. Landfall for Major U.S. Hurricanes

Hurricane Name	Season	Category	Landfall States	Climate Zone
Andrew	1992	5	Florida	1
Camille	1969	5	Mississippi, Louisiana	2
Donna	1960	4	Florida	1, 2
Charley	2004	4	Florida	2
Katrina	2005	5	Louisiana	2, 3
Hugo	1989	4	South Carolina	3
Hazel	1954	4	North Carolina, South Carolina	3
Audrey	1957	4	Louisiana	2
Carla	1961	4	Texas	2
Irma	2017	4	Florida	1
Harvey	2017	4	Texas	2
Michael	2018	5	Florida	1, 2

Source: NOAA, n.d.a

Government Responses to Hurricanes

FEMA—founded in 1979—is part of the U.S. Department of Homeland Security. FEMA's mission is to help people before, during, and after disasters (FEMA, n.d.). FEMA and local officials work to supply recreational vehicles or trailers in response to a hurricane—for only 18 months. FEMA also allocates financial assistance to homeowners to repair or replace their wind-battered houses and provides temporary housing, hotel rooms, and short-term condominium rentals. Survivors of hurricanes also can live in temporary housing units provided by FEMA.

Before, during, and after every hurricane, FEMA publishes recovery advice for cleanup, returning home, finding insurance program information, and developing strategies to help children. FEMA also comments on shelters, travel conditions, fraud, and construction techniques to minimize damage. Construction recovery advisories cover the topics listed below:

- Rebuilding of flood-damaged homes.
- Attachment of rooftop equipment in high-wind regions.
- Installation of residential corrugated metal roof systems.
- Door and window design, installation, and retrofit.
- Rooftop solar panel design, installation, and maintenance.
- Rooftop equipment attachment and maintenance in high-wind regions.
- Coastal flood zone site determination, design, and construction.
- Safe room and storm shelter hurricane protection.
- Best practices for minimization of flood damage.
- Protection of building envelope fenestration.

- Repair and replacement of residential wood roof finishes.

This guidance is intended for homeowners, design professionals, building owners, officials, contractors, and other stakeholders (FEMA). In addition to FEMA, local government agencies such as the Florida Building Commission of the Florida State Government help those affected by disastrous situations by improving building codes after a disastrous hurricane. For instance, the Florida Building Commission developed the Florida Building Code System after Hurricane Andrew to streamline statewide adoption and requirements of advanced hurricane protection standards. Hurricanes Charley, Frances, Ivan, and Jeanne in 2004 and Hurricanes Dennis, Katrina, and Wilma in 2005 demonstrated the overall effectiveness of the code and revealed areas that need further clarification. The literature review shows that the government primarily supplied temporary housing and mobile units after hurricanes. However, no significant evidence emerged of successful efforts toward the rapid provision of permanent housing.

Industry Responses to Hurricanes

Tornadoes, cyclones, and other storms with strong winds damage or destroy many buildings. However, with proper design and construction, destruction by these forces can be greatly reduced. Various methods can help a building survive strong winds and storm surges. Unfortunately, at the time this report was written, government response did not generally include rapid permanent housing. In addition to receiving financial assistance, victims of housing disasters resulting from hurricanes are offered temporary shelters.

Prefabrication is a strategy of using components made off site in a factory, which are then transported and assembled on site to create a structure. This approach enables faster and more efficient construction processes, offering promising alternatives to traditional, site-built homes. Many types and models of prefabricated structures have been designed to withstand strong winds and, in a few cases, Category 5 disasters. Exhibit 4 lists prefabricated homes designed to withstand hurricanes.

Exhibit 4. Prefabrication Homes Designed to Withstand Hurricanes

Model	Benefits	Size (ft^2)	Price per ft^2	Unit Price	Materials	Additional Features
One (exhibits 5 and 6)	° Hurricane, fire, water, pest, and wind resistance ° Solar power ready ° Green friendly because of insulation	600–7,000	$165	$99,000–$1,155,000	° Advanced steel ° Insulated MgO wallboard panels ° LVL	° Modern design ° Can use precast concrete instead of LVL
Two (exhibits 7 and 8)	° Wind resistance up to 173 mph (Category 5) ° Meets IECC requirements	100–2,766 (average size: 560 ft^2)	$85	$8,500–$235,110	Prefabricated bamboo	-
Three (exhibit 9)	° Stormproof	685	$218	$149,330	Laminated wood, rubber, and cork with impact-	° Prefabricated and modular home

	° Wind resistance up to 180 mph (Category 5)				resistant doors and windows	° Cheaper and constructed in less time ° Sustainable add-on features, including a rainwater harvesting system and vertical garden
Four (exhibit 10)	° Wind, fire, and water resistant ° Green building ° Solar panel ready	650–850	$147	$95,550–$124,950	Steel, cork, impact resistant doors and windows	° Rapid construction ° Prefabricated ° Customized
Five (exhibits 11 and 12)	° Hyper-efficient ° Solar panel ready	291	$154	$44,814	Triple-glazed windows, ribbed steel panel	° Expandable ° Easy shipment

IECC = International Energy Conservation Code. LVL = laminated veneer lumber. MgO = magnesium oxide.

Source: Project team, University of Florida

Exhibit 5. Model One Hurricane-Resistant Home

Source: Katana House, n.d.

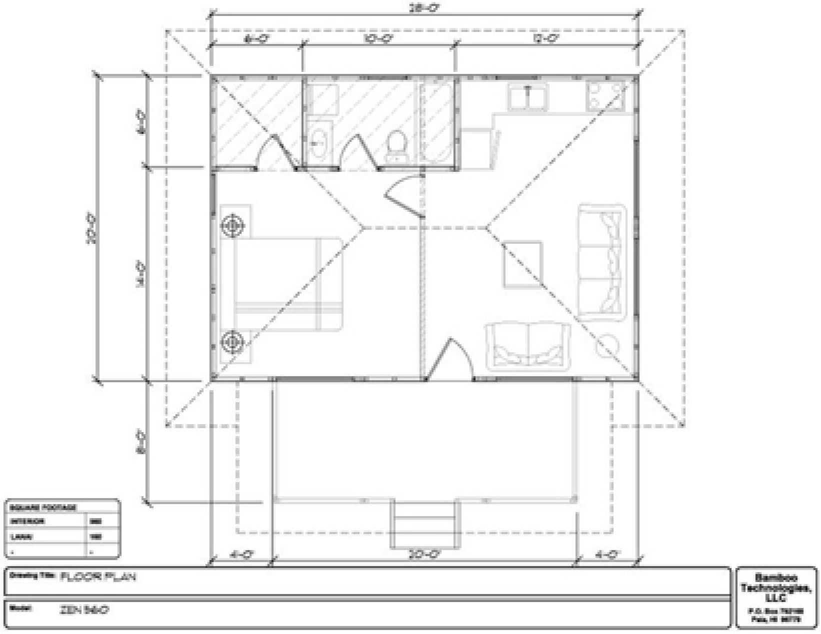
Exhibit 6. Model One Hurricane-Resistant Home

Source: Katana House, n.d.

Exhibit 7. Model Two Hurricane-Resistant NREL Home

Source: Bamboo Grove Furniture Inc., 2020

Exhibit 8. Floor Plan of Model Two Hurricane-Resistant Home



Source: Bamboo Living, n.d.

Exhibit 9. Model Three Hurricane-Resistant Home

Source: Ocala Custom Homes, n.d.

The ***NYC Emergency Housing*** prototype (see exhibit 10 below), built to full scale, addresses the displacement of city residents in any natural or manmade disaster. Multistory and multifamily units can be built in less than 15 hours. Panels and components allow users to achieve various arrangements and layouts to fit different urban conditions (Frearson, 2014).This modular housing prototype is built from various recyclable materials, such as cork for the floor. The total area of the prototype is 2,100 ft^2. Following the New York City code, the structure is steel. The prototype costs approximately $148,000–160,000 for each three-bedroom unit and $89,000–96,000 for a single unit (NYC Emergency Management, 2018)

Exhibit 10. NYC Emergency Housing Prototype

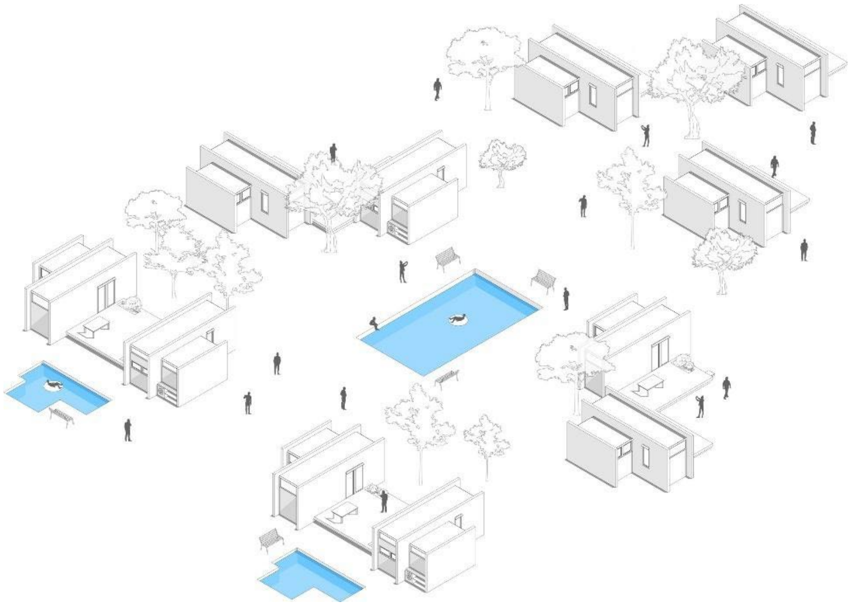
Source: Garrison Architects Design Post-Disaster Housing for New York, 2014

Monocabin M (see exhibits 11 and 12 below) includes a bedroom, bathroom, kitchen, and living area of 291 ft^2. The goals in designing this unit were to save time and money and lower the construction's environmental impact. This house contains a linear volume adjoined to a smaller box with the capacity for future expansion. The Monocabin M costs approximately $45,000. The home's flat roof is covered in ribbed steel panels. Triple-glazed windows have sandblasted aluminum frames.

Exhibit 11. Monocabin M

Source: Mandalaki Studio, 2018

Exhibit 12. Configuration in Urban Environment



Source: Garrison Architects Design Post-Disaster Housing for New York, 2014

Green Building Rating Systems and Standards

A green building rating system or building assessment system is used to assess and rate buildings that meet certain standards and requirements regarding the environmental, resource, and health impacts of a building's design, construction, and operation. Building assessment systems are created to promote high-performance buildings with advanced technology to withstand climate change. These rating systems have been designed to increase market demand for sustainable buildings in the construction industry. There are numerous green building rating systems worldwide with various approaches to evaluating a building. These rating systems include two major U.S. systems, Leadership in Energy and Environmental Design (LEED) and Green Globe; BREEAM in the UK; DGNB and Passivhaus in Germany; CASBEE in Japan; and Green Star in Australia, New Zealand, and South Africa. These assessment systems often use a third-party assessor, which certifies that the project has achieved specified levels of performance (Kibert, 2016). The literature review focused on three green building standards for housing design: the National Association of Home Builders (NAHB), LEED for Homes (LEED H), and the Florida Green Building Coalition (FGBC). The outcome of this project will be assessed by LEED criteria to show how many points have been covered by the proposed design. Refer to appendix G for examples of green building systems and standards, such as the National Green Building Standard, LEED H, and FGBC.

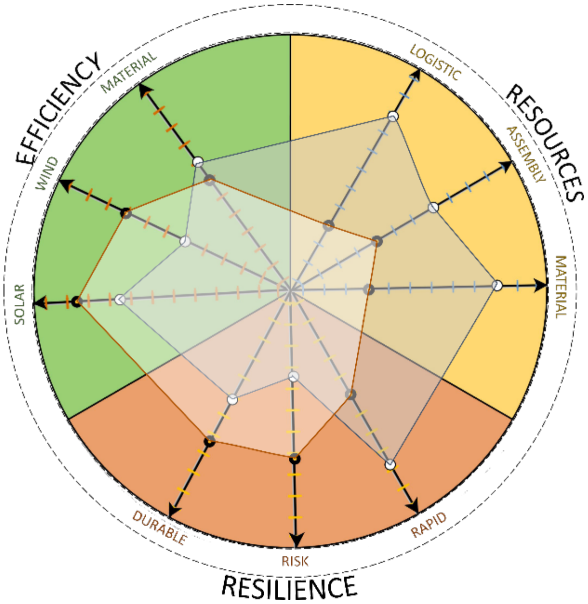
CHAPTER 3. ARCHITECTURE AND DESIGN

The Advanced Modular Housing design (AMHD) and architecture followed function. With design input from stakeholders during design charrettes, the AMHD evolved to its final form: material, assembly, and logistics. This chapter discusses how the AMH design was conceived. The first section provides an overview of the design methodology and the actual design of the three modules: Core, Space, and Dwell. These three modules are together referred to as the Core+ AMH design. This section also elaborates the purpose of each of these modules and the design intent for materiality and more. The next section in this chapter discusses the three components of AMH design: material selection, energy efficiency, and resiliency. One of the critical elements of the AMH design in this report is mass fabrication, yet allowing mass customization by home occupants. Mass customization of AMH design is through a four-step process that home occupants can use to customize and rebuild their homes. The four-step process includes site assessment, rebuild choice and finance options, construction or installation, and building adaptation.

Design Methodology (Matrix)

AMH design's three research areas are titled Resources, Efficiency, and Resilience, reflecting housing design and construction, passive energy systems, and building and community resilience (exhibit 13). Using the project team's expertise, the AMH design of a modular home focused on a hyper-efficient design that can cope with future severe weather events while also providing basic services needed for families during post-disaster recovery.

Exhibit 13. AMH Design Themes



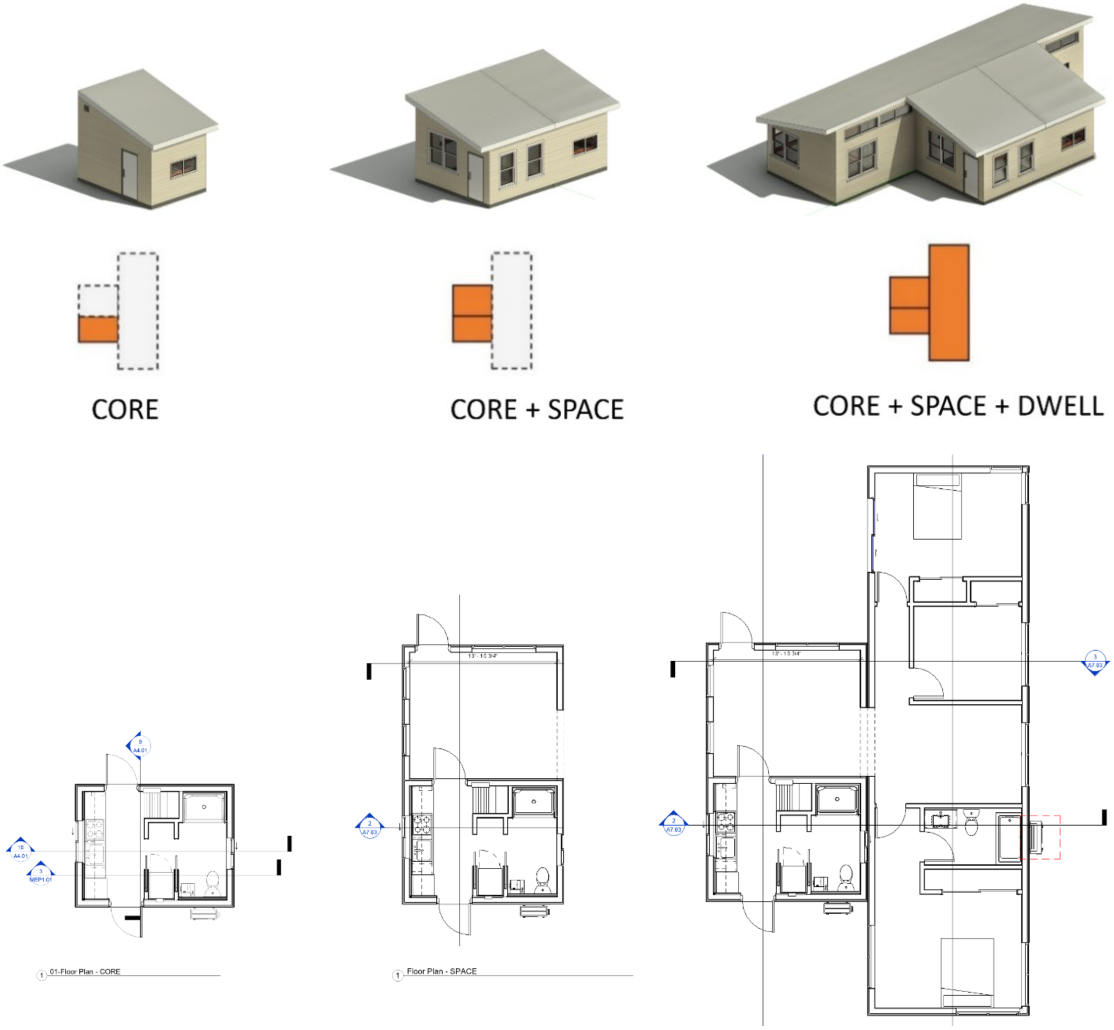
Source: Project team, University of Florida

Resilient, energy-efficient, and affordable housing available to people in post-disaster situations assumes a return to dwelling in a place of increased risk. This project is intended primarily for homes at risk from hurricane wind damage; storm-related flooding, including storm surge damage; and local flooding caused by extreme rain events. AMH units can be placed on new sites or provide replacement housing for homes damaged or destroyed by one of these risks. The fundamental question that drives AMH design is how resiliency, sustainability, and affordability can be improved in post-disaster housing over the longer term.

Core+ Overview

The outcome of the AMH design project is the development of the 1200 ft^2 Core+ model, which combines three distinct modular units: Core, Space, and Dwell (exhibit 14). The Core+ design focused on single-family post-disaster housing in Florida for this project. The following briefly describes the elements of the design.

Exhibit 14. Distinct Modules that Accomplish Three Core Functions of Housing: Core+Space+Dwell



Source: Project team, University of Florida

Core: This 160 ft^2 unit would be delivered to the site within days of a disaster. It could either be temporarily located in a parking lot or other location if the site is not yet prepared, or it placed permanently on-site. The unit is the solid, storm-resistant "heart" of the total structure providing essential housing functions, including kitchen, bath, laundry, and sleeping loft. The structure of the Core is robust and would provide maximum protection to residents during future storms. The Core unit is designed to provide protection through subsequent disasters, even if they follow immediately. The unit is designed to be deployed to high-risk areas, such as the Florida Keys. The Core is a rigid (self-supporting) and hardened structure, making it resilient in a storm and providing flexibility for different foundation types, even to the extent that it can be temporarily installed and anchored. The proposed material choice for the Core is light gauge metal framing with sheathing and closed-cell foam insulation, manufactured in a rigid assembly and delivered volumetrically.

Space: The second, 193 ft^2 module added to the Core provides a flexible space that can serve as a den, sleeping porch, or full bedroom. It is designed for flexibility and encourages homeowners to infill and modify the structure to accommodate their specific needs. This unit can be delivered with the Core unit or added later. It is wind resistant but not hardened. It is semi-rigid, requiring more support from its foundation. The proposed material choice for the Space is light gauge metal framing with sheathing and closed-cell foam insulation, manufactured in a rigid assembly and delivered volumetrically.

Dwell: The third, 794 ft^2 module added to Core+Space provides three full bedrooms and a full bathroom. This unit maximizes the dimensions of a modular structure and is built on a temporary chassis for rapid delivery. The Dwell structure completes the Core+ modular home, at a total of 1200 ft^2. The unit is delivered like a conventional manufactured home. Its material constraints are fewer, and it is built using the most conventional and, therefore, the most immediately inexpensive means. Its conventional construction has a larger impact on the cost of the overall home because the Dwell represents the most substantial element of the home.

Design Process for Three Research Themes

Material Selection

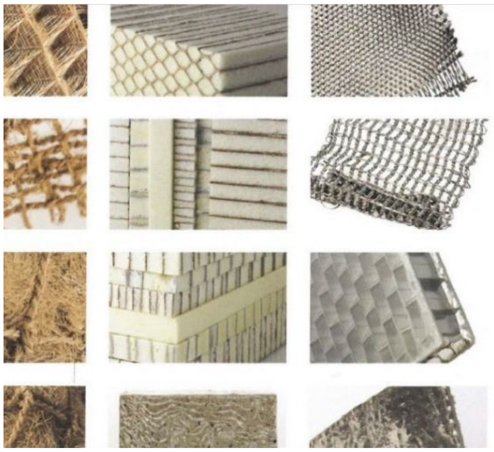
Housing affordability is affected by shortages of skilled craftspeople and construction labor, especially in a post-disaster situation. Conventional materials are increasingly scarce. Current practice and deployment of construction produce inferior products, which threatens the viability of the industry and contributes to accelerating inflation of costs, both societal and monetary.

The selection and sourcing of materials in the manufactured housing industry have remained nearly the same for decades. Likewise, manufacturing processes in this industry have changed little. Meanwhile, the modular building industry has increased its material palette, innovated in product sourcing, engineered new manufacturing processes, and experimented with logistics and the supply chain, end to end. However, most of this technological innovation has been applied within conventional building types, especially developer-driven multifamily housing. This research intends to incorporate relevant modular industry practices and innovation. Furthermore, this material research satisfies the program requirements of the AMH model as a home that is hyper-efficient, energy self-sufficient, affordable, and able to cope with future severe weather events and provide basic services in a post-disaster period, including rapid fabrication and swift delivery and installation.

Material selection for AMH design is a complex, meaning the materials for this project should be durable and low cost, energy efficient and low cost, and resilient and low cost. The following are the steps toward the selection of AMH design materials.

Material discovery seeks multi-duty material (thermal-environmental-structural), considering manufacturing, fabrication, transport, and durability (exhibit 15). It is also considered within the context of various possibilities and the question of intrinsic or extrinsic. Materials are considered along a spectrum of lightness. Seeking materials with the consideration of weight emphasizes the possibilities of interrelated material use: the duty a material is assigned in a system, its manufacture, how it is handled and composed for fabrication, and its transport. "The profusion of materials today and their frequent adaptation from one industry to another exhibit a certain resistance to traditional architectural classification systems" (Margolis, 2012) and, therefore, to conventional ways of thinking about construction options.

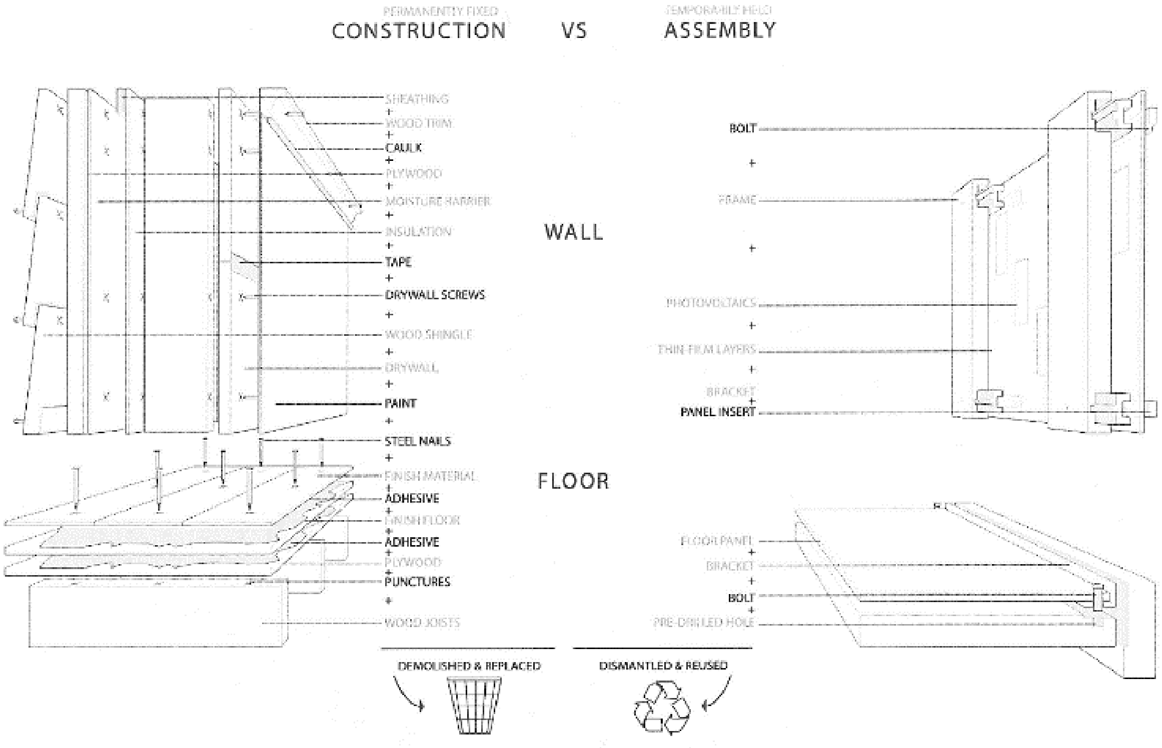
Exhibit 15. Composite (Multi-Duty) Materials



Source: Margolis, 2012

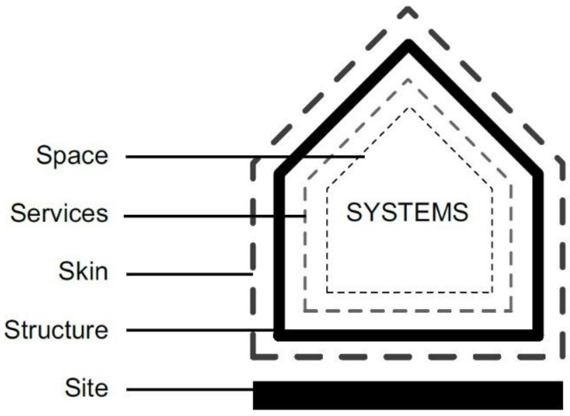
Assembly discovery seeks to reduce the number of parts, attachments, and manufacturing operations, considering assembly and disassembly sequence and design for disassembly (DfD) (see exhibit 16). Assemblies are classified along a spectrum of solidity (from layered to solid, from flexible to determined). Solidity is not to be considered exactly like concrete. Changing processes from construction to assembly results in fewer parts and therefore fewer joints and less to do, resulting in higher speed, better durability, and better recyclability. The breakdown of major building systems is also a list of major design opportunities when considered part of a holistic approach. The major building systems diagram conveys an attitude toward dwelling, which must be considered in resilient homebuilding (exhibit 17). The most to least durable components are site, structure, skin, services, and space.

Exhibit 16. Construction Versus Assembly



Source: Timberlake, 2014

Exhibit 17. Building Systems Diagram



Source: Brand, 1995

Logistics is typically considered in the context of transportation only. For AMH design, the logistics include conventional transport options, delivery distance, set, and connect requirements of post-disaster housing. Logistics decisions begin with resource extraction and continue through design and fabrication, then use, then disassembly.

> A thoughtfully integrated ecology of construction can logically lead toward significant reductions in energy and transportation costs; reductions in materials waste and redundant warehousing; the reusability and recyclability of building components; and massive savings of time, frustration, injury, and redundancy on the job site. (Anderson and Anderson, 2006)
>
> —Mark and Peter Anderson

Choices are available from a range of established fabrication typologies. Constraints include project schedule, transport capability, and flexibility. For AMHD, no single answer to those constraints exists. Conventional transport options, delivery distance, set, and connect requirements must be evaluated to accommodate the expanded needs of post-disaster housing when units must be mobilized quickly (exhibit 18). This requirement can be accomplished with the flexibility of delivery options: flat-bed tow trucks, Landoll trailers, and Terex crane trucks. One of the tenets of this AMH design is energy efficiency through passive and active design systems and the optimal selection of materials on the basis of their thermophysical properties. The next section provides an overview of the various energy efficiency measures incorporated in the AMH design.

Exhibit 18. Traditional Versus Expanded Mobilization Post-Disaster

Source: Smith, 2010

Energy Efficiency

The objective of AMH design is a climate-responsive design coupled with passive energy design strategies to achieve a hyper-energy-efficient building, which, in turn, can be equipped with advanced building systems and renewable energy technologies, including solar and wind power.

AMH design has considered various orientations—including north-south, east-west, northwest-southeast, and northeast-southwest—to determine the lowest energy consumption based on various wind patterns. The building fenestration ratio has been optimized through the iterative design process to achieve the least energy-consuming scenario. In addition, AMH design has integrated fenestration ratio optimization with orientation optimization to achieve the combined optimal result. By adding a combination of horizontal and vertical shading devices for south and east-west facades, solar energy can be used without incurring additional energy consumption due to excessive solar heat gains.

The minimum U-factor[3] for the components of the building envelope complies with the International Energy Conservation Code (IECC) requirements. In addition, given the climatic conditions of the project's location, highly reflective materials and colors for the building envelope have been recommended to reduce the effects of excessive solar heat gains. The effects of various interior architectural layouts on building energy consumption have been evaluated throughout the design process to assess the effects of interior design on building energy use.

Passive Design Strategies

The first step in an energy-efficient building design is to ensure that the design conserves energy in the context of surroundings and climate. This project uses a wide range of passive design strategies to ensure that the building design and structure will have significantly less demand for active utility and mechanical systems (exhibit 19). In addition to integrating energy efficiency technologies to supplement passive design strategies, AMH design is aimed at resiliency, meaning future-proofing, which is discussed in the next section.

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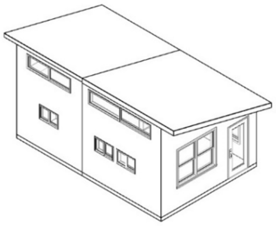
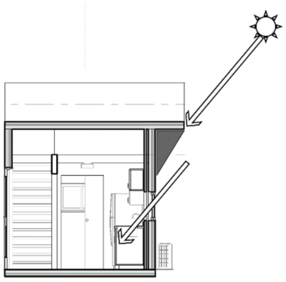
[3] *U-factor* is rate at which wall, window, or skylight energy is lost by specifying how many BTUs can pass through one square foot of material in an hour. To give an example, the higher the insulation (R-value), the lower the U-factor.

Exhibit 19. Passive Design Strategies

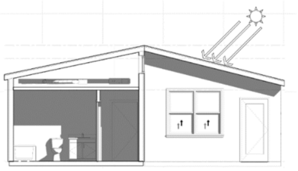
This project has, on average, 30% fenestration ratio for all facades to provide daylight in all seasons and sunlight in cold seasons. In this project we have also designed pitched roofs to shed rain and greater reflection of solar radiation, and can be extended to protect entries, porches, verandas, and other outdoor work areas.



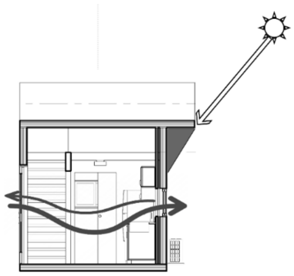
Operable clerestory windows will enhance the effect of "stack ventilation" by allowing the warmer air to leave the space at the higher elevation, which in turn, induces the admission of cooler air through the windows at the lower elevation.



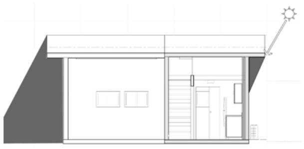
To avoid excessive solar radiation, south facing facades are equipped with overhang. We also use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain.



We provide double pane high performance gazing (Low-E) on west, north, and east, but clear on south for maximum passive solar gain.



In addition to overhang, having windows facing each other across the space will provide an ample opportunity for cross ventilation, which can significantly lower building cooling demands when outside temperature is relatively low.



We have designed screened porches and patios that can provide lower building cooling demands when the outside temperature is relatively high.

Source: Project team, University of Florida

Resiliency

The Core+ model design meets or exceeds all Florida building code requirements for wind loading, passive heating and cooling strategies, and systems to mitigate extended power failures, and it includes an affordable piling system that allows for easy home elevation at multiple levels to fit the needs of the site. These technical solutions are built into the project from the start and are required or added according to its risk profile. Many of these decisions will be determined during the site selection phase of the project, when a chosen home configuration is applied to a specific location.

Resiliency is also embedded in this project such that the AMH design can adapt over time. The term *resilience* originated in the field of ecology (Holling, 1973), but has had a much wider influence and, from the mid-1990s on, has been applied in multidisciplinary contexts to study the interactions between people and nature (Mamouni Limnios et al., 2014). The term is applied to a range of topics, including physical security, business continuity, emergency planning, hazard mitigation, and the ability of the built environment (for example, facilities, transportation systems, and utilities) to resist and rapidly recover from disruptive events (McAllister, 2016).

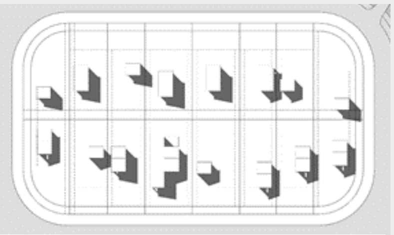
Resilience also has been used as a bridging concept that can facilitate inter- and transdisciplinary approaches to address fundamental complexities in decision making under conditions of risk and uncertainty (Sharifi and Yamagata, 2016). Resiliency could be defined as the "capacity of a system to absorb disturbance and reorganize while undergoing change to retain essentially the same function, structure, and identity"(Walker et al., 2004).

Resilience design in this project considers that, after a disaster, it is essential for buildings to be assembled rapidly so that families can return within a matter of weeks instead of years. In the context of AMH design and post-disaster housing, resilience increases the capacity for rapidly deployed structures to withstand or adapt to sudden and prolonged change due to climate change and storm damage long after the initial deployment of the structure. This aspect of the design allows for the structure to evolve with a neighborhood as climate, population, and tastes change with time. Greater resilience to change not only better prepares occupants for additional disasters but also builds a community asset that gains value with time. This project proposes that AMH design can have lasting value and contribute to the long-term value of a community, with durability in material, structure, and design that results in longevity. Sea levels change, as do demographics, temperatures, and building occupants. Manufactured houses must have the capacity to grow and adapt for several reasons.

The capacity for adaptation has been a primary focus of the design to enable residents to adapt the home to particular needs over time. Adaptations include options, selected in the balancing phase, that allow for the mass-produced shell of the building to take on characteristics derived from the community, environment, or building owner's preference. These elements include decks, carports, window shades, and trellises. The assembly itself is adaptable to particular sites or needs, and the building can be accessorized accordingly.

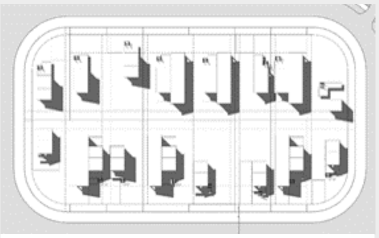
The final form of resilience is defined by the long-term value of the neighborhood and the ability of Core+ to contribute to a stable and valued community. This goal is achieved in three ways: (1) material value, (2) physical adaptability, and (3) climate change resilience. As discussed in the material section, the selected range of materials gives the community variety, affordability, and durability. Core+ not only was developed to grow using the components selected but also can grow long after the initial purchase (exhibits 20, 21, and 22). Additional components can be purchased and connected to the existing home to accommodate additional needs. Moreover, the home is designed so that traditional additions could also seamlessly expand houses in a way that provides choice and flexibility to the owner without detracting from the overall arrangement of houses.

Exhibit 20. A week after disaster, installing Core as the first immediate post-disaster solution



Source: Project team, University of Florida

Exhibit 21. A month after disaster, adding more units, including Space and Dwell



Source: Project team, University of Florida

Exhibit 22. Six months after disaster, adding more units, adjusting with the individual's needs

Source: Project team, University of Florida

AMH design was informed through design charrettes that gathered input from local architects and builders as well as national home manufacturers. Core+ was the focus of a community workshop in North Port St. Joe (NPSJ) in Florida, a community damaged by Hurricane Michael, which resulted in demonstrating and visualizing a range of six individual community member-led design options using Core+ that varied by program, flood risk level, orientation, and lot size. Challenges to providing Core+ housing were brought to light through the workshop, and the team received valuable feedback from community members to improve the design and the process. The completion of this design phase has led to efforts to pilot the project in Port St. Joe and potentially other communities across Florida. Refer to appendix D for a summary of the NPSJ workshop outputs.

Core+ Assembly and Manufacturing Process

In response to the primary goal to provide resilient, efficient, and affordable post-disaster housing, Core+ strikes a balance between the values of mass fabrication and mass customizations. Following a disaster in which significant amounts of the existing housing stock are damaged, labor shortages, permitting delays, and building material backlogs can significantly extend the length of time it takes to return displaced residents to their homes. Recovery from a disaster is often a long process, especially for lower-income homeowners and renters. Housing is a fundamental aspect of a rapid and equitable recovery. Several factors, including debris removal, regulations and permitting, availability of government funds, loan disbursements, and labor shortages complicate this process, which can take more than a year to complete. Especially for lower-income homeowners and renters, the wait can cause tremendous stress, loss of employment, bankruptcy, and homelessness.

As with current manufactured housing, there are drawbacks to AMH that include regional and micro-climatic conditions; specific siting requirements, including coastal flood risks; individual client stylistic preferences, budget constraints, and financing methods; local building controls; and the inevitable adaptations made by changing families and neighborhoods over time. Specific customizations will allow the specificities of client, site, and budget to refine AMH design to adapt to specific needs. This balance, better known as mass customization, allows for the production benefits of fabrication and individual preference. One way to alleviate this issue is mass fabrication or mass customization.

Mass-fabricated, or modular, housing reduces labor costs and allows for sufficient inventory of housing to be pre-built and shipped from safer environments to those damaged. As AMH design maximizes mass-fabrication technologies through its design and material assembly, the project team has developed the concept of Core+ as a modular home for rapid post-disaster deployment through mass customization.

Core+ uses factory-based modular construction processes to produce three housing units: *Core*, *Space*, and *Dwell*. These units can be assembled according to a purchaser's site, budget, and family needs. Each module of Core+ serves a specific role in providing affordable long-term housing immediately post-disaster.

In disaster recovery, home occupants go through four generalized stages to rebuild:

1. Site assessment—Initial assessment of damage.
2. Rebuild choice and finance options—Working with a manufacturer or builder and financial institution to choose and finance a new home.
3. Construction or installation—This is a substantial amount of time, especially for site-built houses.
4. Building adaptation—As families and communities grow and change, homes adapt and enable a certain amount of flexibility.

Stage 1: Site Assessment

Following a disaster, site evaluation is conducted by the Federal Emergency Management Agency (FEMA), local emergency management, and insurance companies to determine the extent of damage, the levels of compensation insurance will provide, and the authority to rebuild and to what extent. Many jurisdictions are implementing pre-disaster plans that move disaster-prone sites out of circulation, as they are increasingly vulnerable. FEMA may also deem a site a repetitive loss property and, instead of rebuilding, recommend a buyout. The AMH design project does not deal specifically with this process, but this overview provides the essential legal and financial groundwork for the next phases.

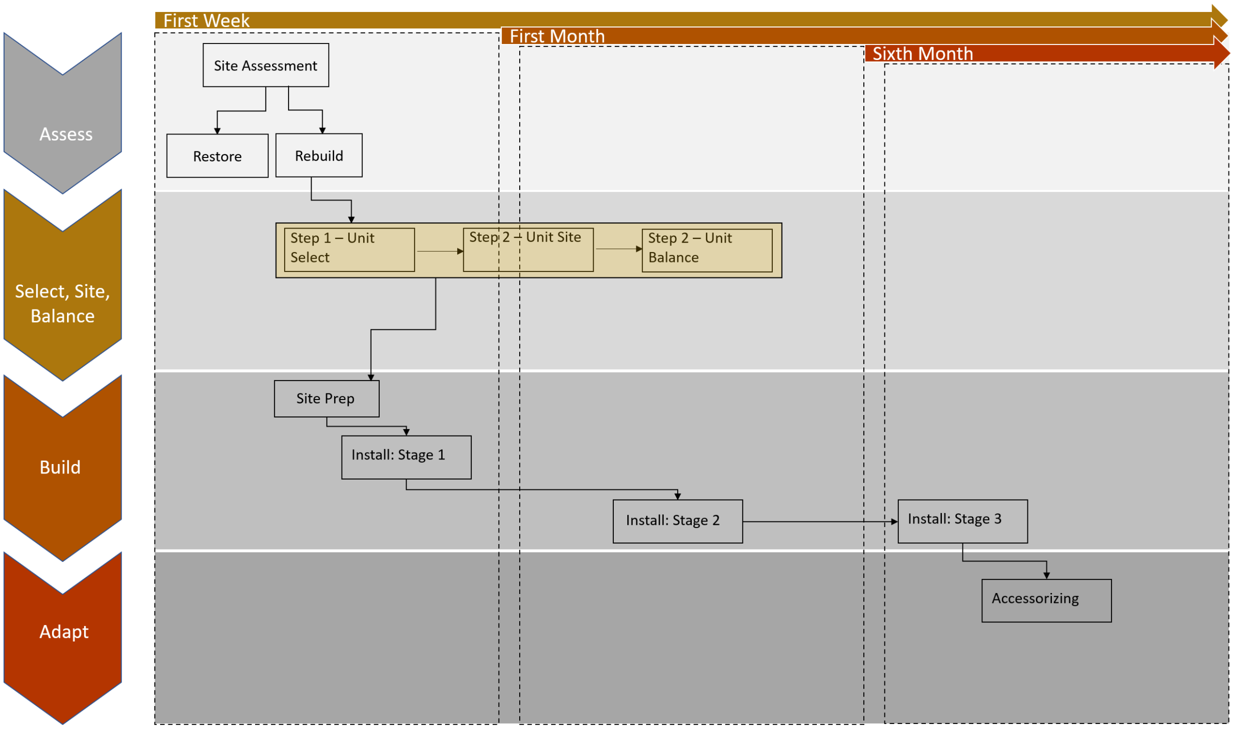
Stage 2: Rebuild Choice and Finance Options: Select, Site, Balance

The AMH design process is primarily focused on stage 2. The team has expanded this stage to include three main steps: Select, Site, and Balance. Each step serves as an interface between a homebuyer and the fabrication process of the structure. User feedback at each step provides upfront, monthly, and life-cycle cost options that will help users select the assembly of Core+ that best serves the specific requirements of their site, family, and financing.

Step 1: Unit Selection

This step allows for the selection of the number of units (Core, Core+Space, or Core+Space+Dwell) a buyer would like and the delivery timeframe. This step establishes a base price for the unit (exhibit 23).

Exhibit 23. Site, Select, Balance—The Process of Selection and Assembly of Core+

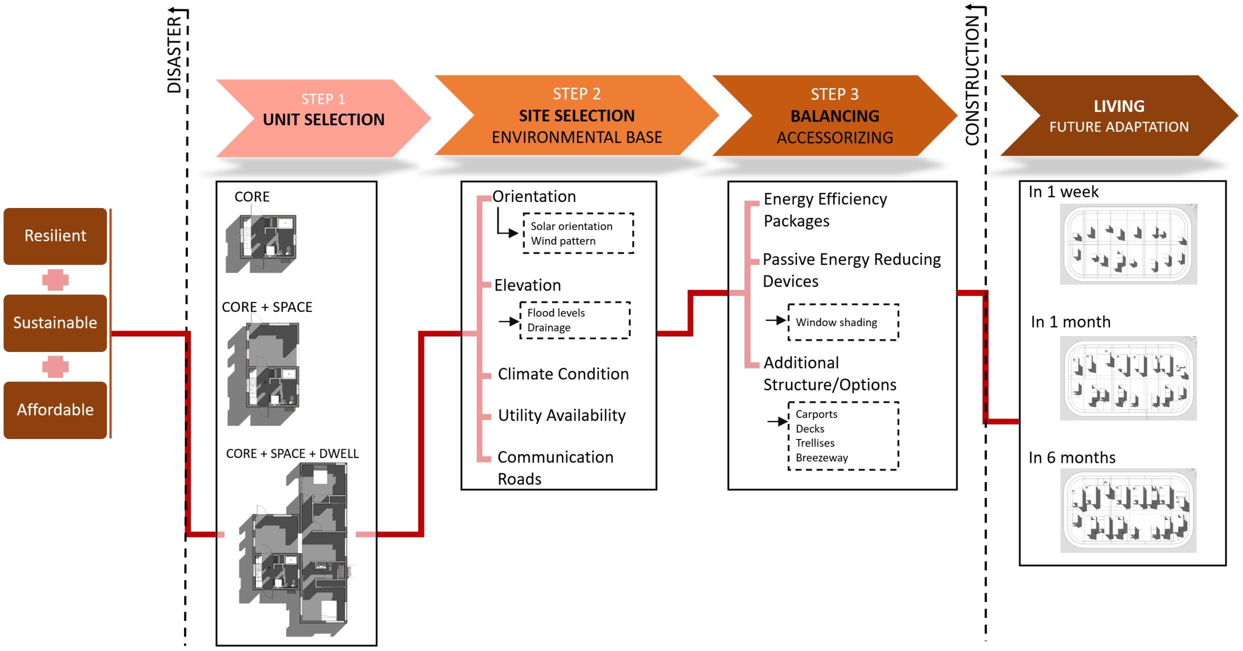


Source: Project team, University of Florida

Step 2: Site Selection

Core+ is designed for disaster recovery, so the specific sites for which the house is designed are vulnerable to a variety of threats. The southeast United States is specifically vulnerable to hurricanes, including storm surges and hurricane-force winds. Additional risks include inland flooding and extreme heat. The siting of the structure includes the orientation in relation to the cardinal directions, required height above the ground, local sun exposure, and other elements that shape the siting of the structure. Step 2 will alter the base price of the unit and introduce an estimated monthly utility cost (exhibit 24).

Exhibit 24. Select, Site, Balance



Source: Project team, University of Florida

Step 3: Balancing

Core+ allows owners to further refine the unit's design by allowing them to select among three energy efficiency packages. Passive energy-reducing devices include window shades and additional structures such as carports, decks, and trellises. The selected package will further adjust the base and monthly costs of Core+ and allow the model to work under different financial structures; detailed financial information is included in the Affordability section.

Stage 3: Build

The Core+ project covers a range of different construction phases intended to get people back into their houses as quickly and efficiently as possible following a storm, starting with the post-disaster deployment of a Core unit, placed possibly just weeks after a disaster on a preliminarily cleared site. Following this preliminary phase, a more conventional site preparation phase can begin, including utilities and concrete or block foundations. The installation of the modular units is rapid, but because the units can be delivered over time, there is consideration for simple systems for mating of units.

Stage 4: Adaptation Over Time

Resilience has been a key emphasis of the design so that occupants may adjust their houses over time to specific demands. Adaptations include choices specified during the balance phase, which enable the building's mass-produced shell to accept features drawn from the preference of the community, the environment, or the building owner, including decks, carports, window coverings, and trellises. The assembly is adjustable to certain places and demands, and the construction may be adjusted accordingly.

The project also anticipates how the community's strengths and weaknesses will change to adapt to future threats by estimating how communities reacted to previous catastrophes. In this way, AMH design has considered the aspect of time and allows the intervention of the buyers based on possible future demands.

CHAPTER 4. BUILDING SYSTEM DESIGN

Sustainability, in the context of buildings, is the ability to minimize the impact on the environment through material selection and energy efficiency and improve occupant comfort using optimal daylight and ambient temperature and increased ventilation. Passively designed and low-energy housing equipped with renewable energy generation and storage technologies can greatly reduce energy costs, lower carbon emissions, and help make housing self-sufficient in terms of energy and water during power outages caused by disasters. Furthermore, through careful selection of building materials and appropriately designing for deconstruction, waste can be eliminated, and the building materials can be eventually recovered for reuse or recycling during deconstruction. This chapter introduces the building energy system, renewable energy system, and energy storage systems relevant to U.S. homes. The next section discusses the methodology used for evaluating the AMHD, including energy efficiency measures, followed by a discussion of the energy use data for the various measures. This chapter concludes with a discussion of a net zero energy-capable AMH design that uses renewable energy and energy storage systems.

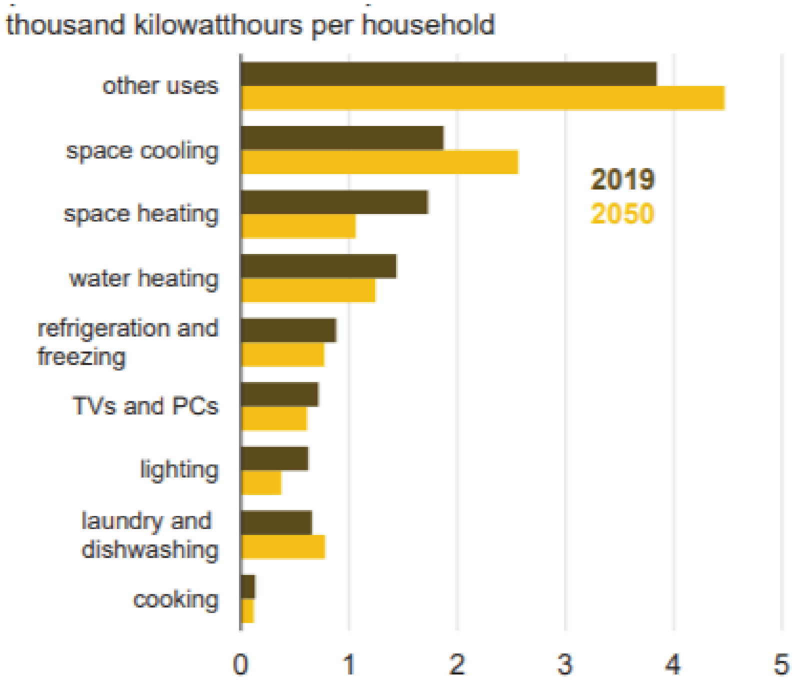
Building Energy System and Energy Modeling

Building Energy System

In the AEO2020 reference case (EIA, 2020) the total delivered residential energy intensity in the United States, defined as annual delivered energy use per household, will decrease by 17 percent between 2019 and 2050 as the number of households grows faster than energy use (EIA, 2020: 118). The main factors contributing to this decline include gains in appliance efficiency, onsite electricity generation (for example, photovoltaic [PV]), utility energy efficiency rebates, rising residential natural gas prices, lower space heating demand, and a continued population shift to warmer regions (see exhibit 25). Demand for space cooling from electricity will increase through 2050 as a result of more cooling degree days. The demand for space heating from fuels such as natural gas, distillate fuel oil, propane, and electricity will decrease through 2050 as a result of fewer heating degree days (EIA, 2020: 116).

Space cooling was responsible for approximately 1 Gt of CO2 emissions and nearly 8.5 percent of total final electricity consumption in 2019. Governments can reduce the impact of rising space cooling demand by supporting advanced building envelope technologies. As the first measure to reduce the amount of energy needed for space cooling, proper building design can improve thermal insulation and reduce air leakage by incorporating advanced envelope components, such as reflective roofs, dynamic equipment, passive-building technologies, integrated storage, and renewables. Building energy codes have proved to be an effective instrument for improving building energy performance (IEA, 2020).

Exhibit 25. Residential Purchased Electricity Intensity



Source: EIA, 2020

Energy use due to building envelope—such as walls, roofs, and windows—is significant, so these systems must be selected appropriately to reduce the energy use of the whole building. Below, the various building envelope components are briefly discussed.

Building Envelope

A building envelope is the physical barrier between the conditioned and unconditioned, or interior and exterior, environment of a building. The building envelope comprises the material components in the roof, floor, exterior walls, windows, and doors that protect the interior environment from wind, precipitation, heat, light, and noise (National Institute of Building Sciences, 2015).

Exterior Walls

The wall assembly includes different products for support, water control, air control, noise control, thermal control, and finish. Products include exterior cladding, exterior sheathing, sheathing membrane, interior sheathing, vapor barrier, insulation, and structural components (Afework et al., 2021).

Doors and Windows

The largest "holes" in the building envelope are exterior doors and windows. Exterior doors and windows that are airtight are imperative as they are key to the air control, water control, and thermal efficiency of the building envelope. Typical doors are not thick enough to provide very high levels of energy efficiency on their own. Glass inserts and poorly installed or damaged weather stripping can add to the inefficiency of energy conservation. Properly installed weather stripping is crucial in maintaining the best insulation for doors.

Gas-filled windows with low-E coatings and a low U-factor provide better thermal resistance. The U-factor is the rate at which a window conducts non-solar heat. The solar heat gain coefficient (SHGC) measures the solar radiation emitted through a window. When considering a window's SHGC, whole-unit U-factors and SHGCs should be emphasized because they accurately reflect the energy performance of the entire window Vigener and Brown, n.d.).

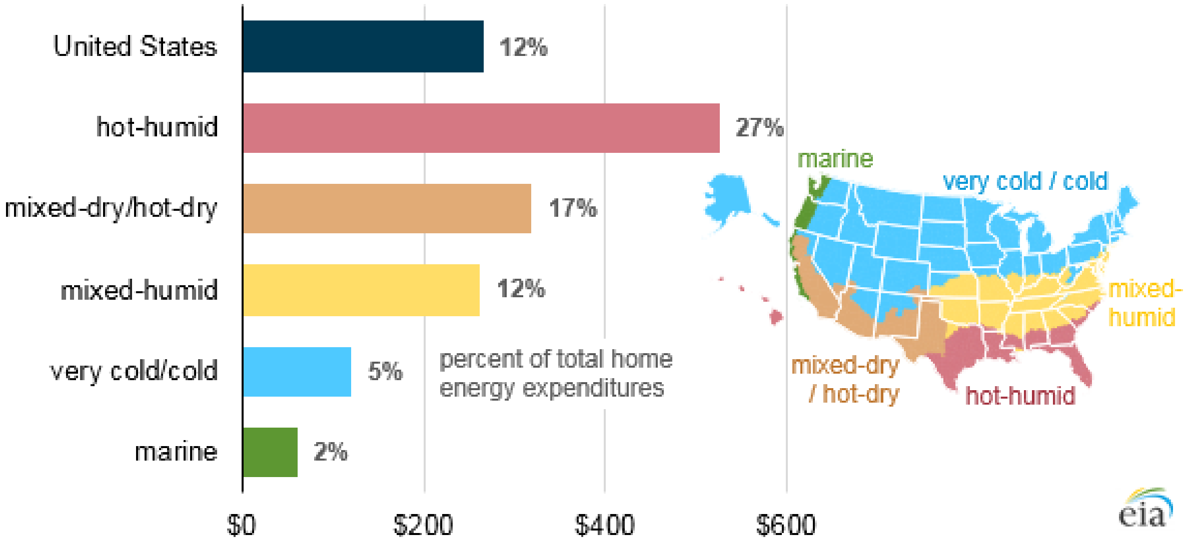
Roof

A roofing system contributes to protecting the building from outdoor weather conditions. Roof layers include decking, ice/water barrier, underlayment, starter strips, shingles, and ridge caps. Weatherization materials and proper flashing are important to ensure an airtight, waterproof seal. Building energy codes (for example, IECC) specify the thermophysical properties of building envelope systems by climate zone.

Air-Conditioning

Air-conditioning energy usage in residential buildings in the United States accounts for 27 percent of total energy usage in hot-humid climate zones (exhibit 26) (Berry, Mayclin, and Woodward, 2015). In 2018, the average annual electricity consumption for a U.S. residential utility customer was 10,972 kWh, an average of approximately 914 kWh per month. Hence, an air-conditioning system consumes approximately 2,962 kWh annually. A typical air-conditioning system comprises a condenser, furnace, composer coil, expansion valve, etc. (Mayclin, 2018).

Exhibit 26. U.S. Average Residential Air-Conditioning Expenditures by Climate Region, 2015



Source: Mayclin, 2018

Heating Ventilation

In 2019, space heating of U.S. buildings accounted for 38 percent of delivered energy. The U.S. Energy Information Administration (EIA) projections indicate that the United States will gain more than 58 million people and 24 million households by 2050, and the total square footage of U.S. residences will expand by 33 percent. By 2050, 71 percent of households will be in single-family homes, which typically have more air-conditioned floor space than multifamily or mobile homes. These single-family homes will consume 86 percent of the energy used in U.S. residential air-conditioning. Space heating is the largest end use in single-family detached homes, at 46 percent of total consumption. For residents of large apartment buildings, space heating accounts for only 25 percent of consumption (Sourmehi, 2021).

Water Heater

Space heating and water heating were the top two energy-consuming uses in U.S. homes in 2015, based on the EIA's latest Residential Energy Consumption Survey (RECS) (Berry, Mayclin, and Woodward, 2015). Variation in water heating consumption of different buildings is mostly caused by the number of occupants in a home. Households use a variety of fuels for water heating, which affects the end-use shares of household energy expenditures. Household energy consumption varies considerably by the type of home construction (Berry, 2018).

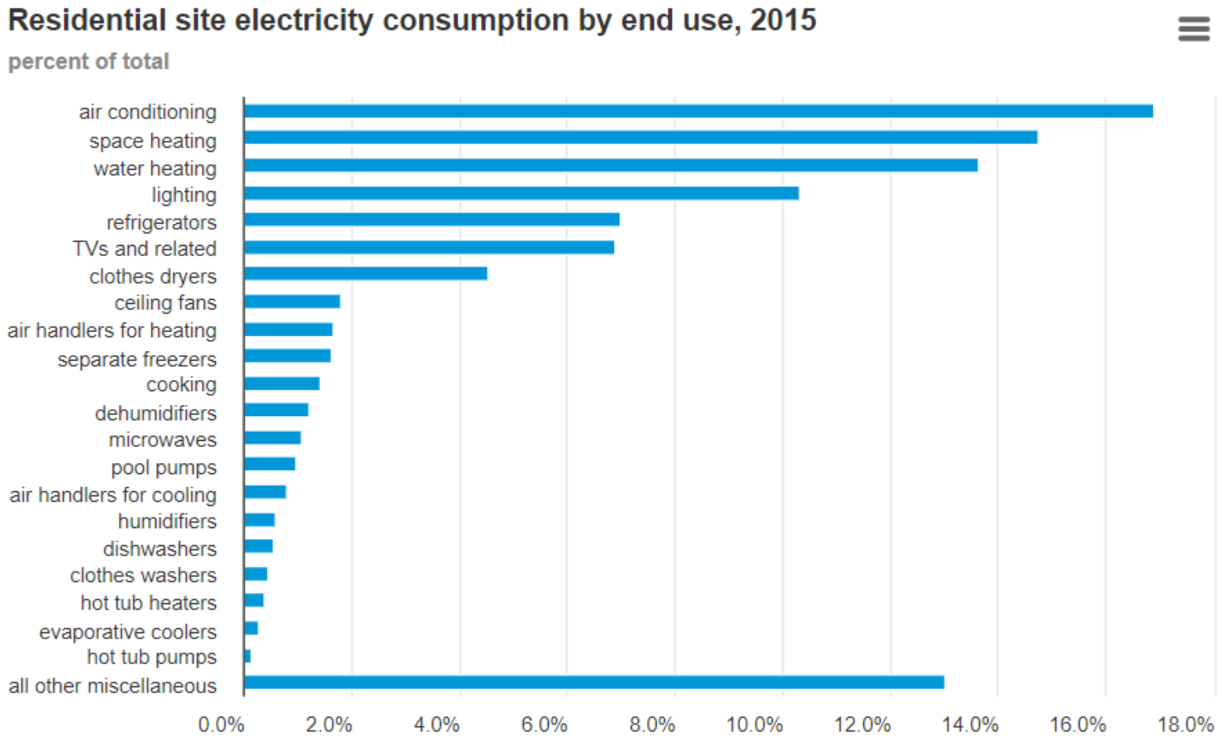
Lighting

In EIA's 2021 energy report, the lighting consumption for residential building is decreasing to meet the lighting demand AEO 2021 reference case (EIA, 2021). EIA estimates that in 2020, lighting energy use was about 62 billion kWh, which is about 4 percent of total residential-sector electricity consumption and about 2 percent of total U.S. electricity consumption (EIA, 2021).

Appliances

U.S. households need energy to power numerous home devices and equipment, but on average, 51 percent of a household's annual energy consumption is for just two energy end uses: space heating and air-conditioning. Water heating, lighting, and refrigeration are near-universal and year-round home energy uses. These three combined end uses account for 27 percent of total annual home energy use (see exhibit 27). The remaining share of home energy use is for devices such as televisions, cooking appliances, clothes washers, clothes dryers, and a growing list of consumer electronics, including computers, tablets, smartphones, video game consoles, and internet streaming devices (EIA, 2021).

Exhibit 27. Residential Site Electricity Consumption by End Use, 2015

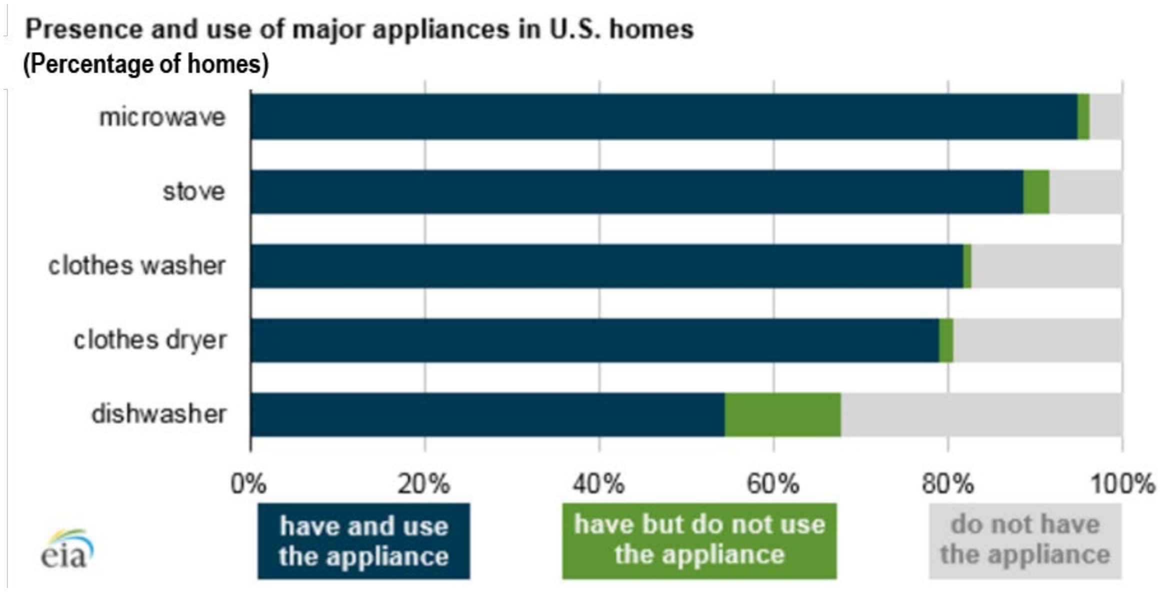


Source: EIA

Refrigerator: Refrigerators are used in nearly every home. The shares of annual electricity end uses can change from year to year on the basis of the weather. The most-used refrigerator in a home costs $81 per year to operate on average, whereas the second refrigerator has an average annual operating cost of $61. Second refrigerators are often smaller than the home’s primary refrigerator, and they may not be in use the entire year. Of those households with a second refrigerator, 17 percent reported that it was in use 6 months or less in 2015. Separate freezers cost $69 per year to operate on average.

Dishwasher: Of the 80 million households that have a dishwasher, 16 million (almost 20 percent) did not use their dishwashers in 2015, based on RECS data. Overall, slightly more than one-half (54 percent) of all U.S. households both have a dishwasher and use it at least once a week (see exhibit 28) (McNary, 2017).

Exhibit 28. Presence and Use of Major Appliances in U.S. Homes



Source: McNary, 2017

Renewable Energy Systems

Photovoltaic systems: Residential solar PV capacity will increase by an average of 6.1 percent per year through 2050 in the AEO2020 Reference case, and commercial PV capacity will increase by an average of 3.4 percent per year. PV costs will decline most rapidly before 2030, despite the phasedown in the federal Energy Investment Tax Credit (ITC) from 30 percent in 2019 to 10 percent in 2022 and the 4-year Section 201 tariff levied on PV cells and modules in 2018 EIA, 2020).

PV growth is also sensitive to electricity prices. In 2050, electricity prices will vary the most from the AEO2020 Reference case in the Low Oil and Gas Supply case, by 9.7 percent and 9.2 percent for the residential and commercial sectors, respectively. Residential PV capacity will increase by 1.7 percent, and commercial PV capacity will increase by 14 percent relative to the AEO2020 Reference case.

A small solar electric or PV system can be a reliable and pollution-free electricity producer for a home. Small PV systems also provide a cost-effective power supply in locations where it is expensive or impossible to send electricity through conventional power lines.

Electricity generation technology options include solar, wind, microhydropower, and hybrid electric systems (solar and wind).

- Small wind electricity generation systems: Small wind electric systems are among the most cost-effective home-based renewable energy systems.
- Microhydropower systems: A 10-kW microhydropower system can generally provide enough power for a home (U.S. Department of Energy, 2019).
- Small hybrid solar and wind electric systems: Because the peak operating times for wind and solar systems occur at different times of the day and year, hybrid systems are more likely to produce power when needed.

For many municipal governments, drinking water and wastewater plants typically are the largest energy consumers, often accounting for 30 to 40 percent of total energy consumed. Overall, drinking water and wastewater systems account for approximately 2 percent of energy use in the United States, adding more than 45 million tons of greenhouse gases annually (EPA, 2019).

Energy Storage via Batteries

According to EIA, in 2017, wind and solar electricity generation set a record by exceeding 10 percent of U.S. energy generation. News in the automotive world was dominated by announcements of major automakers stepping up production of electric vehicles or, in some cases, phasing out gasoline-powered engines altogether.

Powering the average consumer's home—including heating, ventilation, and air-conditioning (HVAC) systems; lights; appliances; and televisions—requires a tremendous amount of energy. Significant weather variation is another complicating factor. Going off the grid would require a solar array coupled with battery storage that is properly sized on the basis of energy consumption. Because battery storage technology is evolving and battery banks are not widely available, it is still not yet cost-effective for the average consumer to purchase.

CHAPTER 5: BUILDING ENERGY MODELING

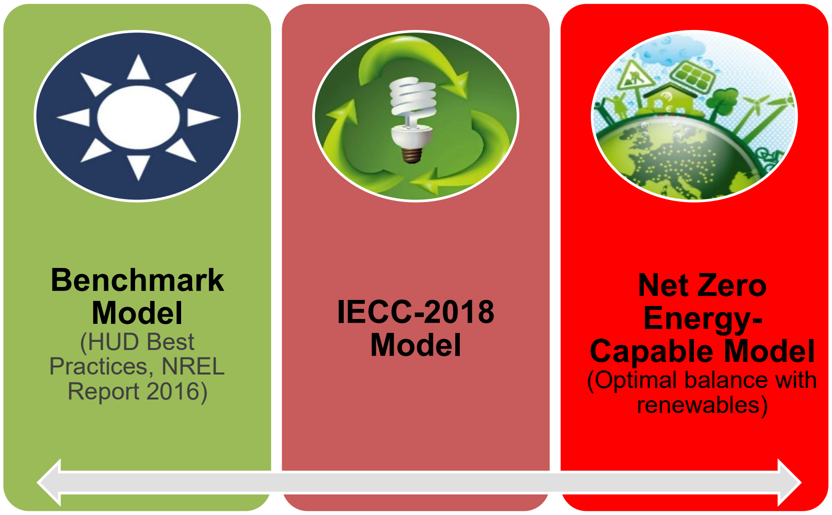
Whole-Building Energy Performance Assessment

A series of whole-building energy models were developed for estimating the energy use of Core+. Developing energy models of buildings involves extraction, organization, and use of existing building geometry and thermophysical data as model inputs.

Approach

Simulation Program and Analysis Methodology: Three models were developed for this study: a model that uses National Renewable Energy Laboratory (NREL) Report 2016[4] (also referred to as the reference or benchmark model), a model that uses IECC-2018, and a model that uses renewable energy and storage systems to achieve net zero energy (also referred to as the net zero energy-capable building). Whereas the first two models use a prescriptive set of input data from the two references, as stated earlier, energy efficiency measures (EEM) for the net zero energy-capable model include the optimal design of renewable energy systems that will offset the operational energy use of the building. Exhibit 29 shows the building energy models developed for this study. For this study, eQUEST and BEopt[5] energy simulation tools were used. The important parameters considered for green building design are neighbors of buildings, use of PV, electrical appliances, wall insulation material, and ceiling material. Exhibit 30 shows the steps followed to estimate energy savings.

Exhibit 29. HUD AMHD Building Energy Model Design



Source: Project team, University of Florida

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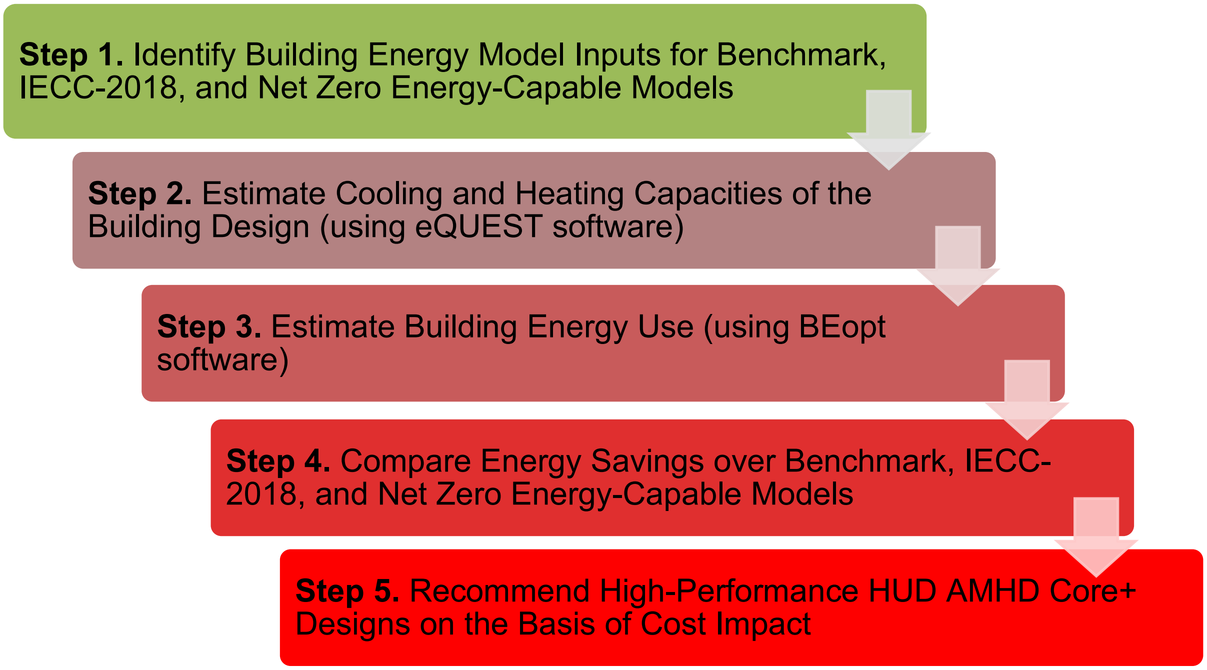
[4] This report is specifically used for manufactured homes.

[5] eQUEST uses the DOE-2 calculation engine. This software is used for estimating the cooling and heating capacities of the building design (Hirsch, n.d.). These capacities are inputted into BEopt software, a residential building-focused graphical user interface front-end for EnergyPlus™ developed by the National Renewable Energy Laboratory.

Exhibit 30. Building Energy Model Simulation Methodology



Step 1. Identify Building Energy Model Inputs for Benchmark, IECC-2018, and Net Zero Energy-Capable Models

Step 2. Estimate Cooling and Heating Capacities of the Building Design (using eQUEST software)

Step 3. Estimate Building Energy Use (using BEopt software)

Step 4. Compare Energy Savings over Benchmark, IECC-2018, and Net Zero Energy-Capable Models

Step 5. Recommend High-Performance HUD AMHD Core+ Designs on the Basis of Cost Impact

Source: Project team, University of Florida

The following are some of the modeling assumptions used in estimating the energy use of AMH design: the heating setpoint is maintained at 70 °F based on IECC-2018. The wall and roof reflectances are input as 0.45 based on ASHRAE 90.1-2019. The mechanical ventilation and water heater capacities are derived from the equations discussed on the BEopt website. The shading is assumed as 70 percent shading in summer (that is, 30 percent not shaded) and 30 percent shading in winter (that is, 70 percent not shaded). Assumptions were used for appliances and plug loads.[6] To compare various energy efficiency measures, this report uses Energy Use Intensity (EUI).[7] Charleston, South Carolina, is used as the project site. Per ASHRAE 90.1, Charleston is in climate zone 3 (see exhibit 31).

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[6] This project uses inputs from NREL Report 2016 for appliances, including 434 kWh/year for refrigerators, 318 kWh/year for dishwashers, modified energy factor (MEF) = 1.41 for clothes washers, EF = 3.1 for clothes dryers, 499 kWh/year for cooking ranges, 80 CFM for kitchen range hood exhausts, and 0.3 W/CFM/fan for bath fan power. The plug load input is calculated per the equation from BEopt as follows: Annual electric use [kWh/year] =1108.1 + 180.2 × (# of bedrooms) + 0.278 × (finished floor area in ft^2).

[7] The Energy Use Intensity (EUI), calculated by dividing the total energy consumed by the building in 1 year (measured in kBtu) by the total gross floor area of the building, is used as the basis of comparison between the models. The unit of EUI is $kBtu/ft^2/year$.

Exhibit 31. Model Inputs

	NREL Report 2016	Source	IECC-2018	Source
Walls—Insulation	½-in vinyl-covered drywall, R-11 fiberglass batts, ¼-in ThermalStar board (R-1) (perm rating >5)	Field Evaluation of Advances in Energy-Efficiency Practices for Manufactured Homes (Table 2)	Wood frame R-20	Climate Zone 3 Table R402.1.2
Walls—Reflectance	0.45	ASHRAE 90.1 2007	0.45	ASHRAE 90.1 2007
Roofs—Insulation	R-22 blown fiberglass, vented roof cavity with asphalt shingles	Table 2	R-38	Table R402.1.2
Roofs—Reflectance	0.45	ASHRAE 90.1 2007	0.45	ASHRAE 90.1 2007
Ceiling—Insulation	See Roofs—Insulation		See Roofs—Insulation	
Floor	R-14 fib blanket, 60% carpet; 40% vinyl	Table 2	R-19	Table R402.1.2
Windows (U-Value/ SHGC)	U-factor: 0.47 SHGC: 0.73 Single pane, metal frame	Table 2	U-factor: 0.32 SHGC: 0.25	Table R402.1.2
Shading	70% shading in summer (30% not shaded) and 30% shading in winter (70% not shaded)		70% shading in summer (30% not shaded) and 30% shading in winter (70% not shaded)	
Door	U 0.4	Table 2	U 0.4	Same as NREL Report 2016
Infiltration	7.7 ACH50	Table 2	3 ACH50	Table R402.1.2
Cooling Set Point	78	IECC-2018	78	IECC-2018
Heating Set Point	70	IECC-2018	70	IECC-2018
Mechanical Ventilation	49.6 CFM Equation: 0.01*Floor	Equation from BEopt	49.6 CFM Equation: 0.01 ×	Equation from BEopt

	Area+7.5 × Num_of_BR		floor area + 7.5 × Num_of_BR	
AC	EER: 7.7 SEER: 13.0	Table 34	SEER 14	https://www.energycodes.gov/technical-assistance/training/courses/residential-provisions-2018-iecc
Heating	Electric furnace	Table 34	Electric furnace	Table R405.2
Duct Leakage	6.5 CFM/100 ft^2, all ducts insulated to R-12 located in pier and beam (approx. weighted avg. R-8)	Table 34	4 CFM/100 ft^2, R-13 insulation	R403.3.4
Water Heater	Electric, 40 gal, 0.90 EF	Table 34; equation from IECC Table 405.5.2	Electric, 40 gal, 0.948 EF	https://www.energycodes.gov/technical-assistance/training/courses/residential-provisions-2018-iecc
Lighting	100% incandescent	Table 38	90% LED	
Refrigerator	Benchmark = 434 kWh/year	Table 38	N/A	Same as NREL Report 2016
Dishwasher	Benchmark (318 kWh/year)	Table 38	N/A	Same as NREL Report 2016
Clothes Washer	Standard (MEF = 1.41)	Table 38	N/A	Same as NREL Report 2016
Clothes Dryer	Electric (EF = 3.1)	Table 38	N/A	Same as NREL Report 2016
Cooking Range	Benchmark (499 kWh/year, electric)	Table 38	N/A	Same as NREL Report 2016
Kitchen Range Hood Exhaust	80 CFM	Table 38	N/A	Same as NREL Report 2016
Bath Fan Power	0.3 W/CFM/fan	Table 38	N/A	Same as NREL Report 2016

Bathroom Exhaust Rate (Default per Building America House Simulation Protocols)	32 CFM avg. 60 min/day (intermittent)	Table 38	N/A	Same as NREL Report 2016
Additional Plug Loads	None	Table 38	N/A	Same as NREL Report 2016

AC = air-conditioning. ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers. CFM = cubic feet per minute. EER = energy efficiency ratio. EF = energy factor. IECC = International Energy Conservation Code. MEF = modified energy factor. N/A = not applicable. NREL = National Renewable Energy Laboratory. SEER = system energy efficiency rating. SHGC = solar heat gain coefficient.

Reference Model

NREL Report 2016 (also referred to as the reference model) is used in this study to compare energy savings. In 2016, the National Renewable Energy Laboratory—on behalf of the Department of Energy's Building America Program—reported a field testing and analysis that evaluated whole-building approaches and estimated the relative contributions of select technologies toward reducing energy use related to space conditioning in new manufactured homes. Three side-by-side lab houses were built in Russellville, Alabama, which belongs to ASHRAE climate zone 3. The NREL house model is a three-bedroom/two-bathroom house with an area of 1,040 ft^2. NREL Report 2016's house A is used for this project as the reference model. It is to be noted that this reference model was built to the HUD Code.

AMHD Model: Core

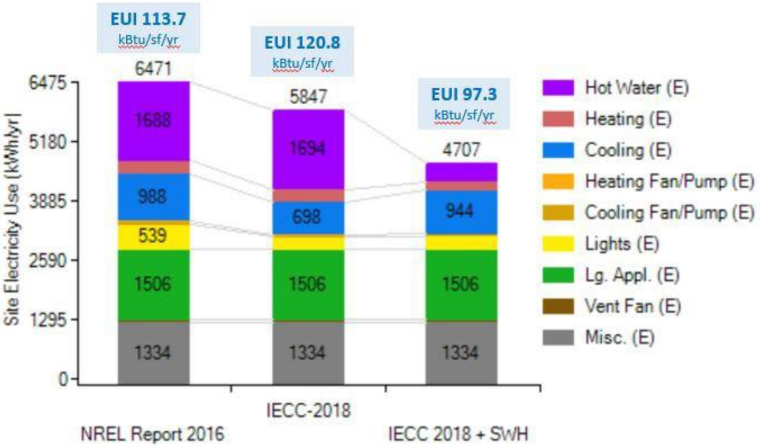
Considering different specificities and regulations, model design, and site variabilities, model simulation inputs are set up differently for three components: Core, Space, and Dwell. Core is a solid, storm-resistant, structurally robust unit that can be delivered immediately, which has a kitchen, a bathroom, and a sleeping space. Space is modular assembly with maximum flexibility and a flat frame system that can be as open as a porch or manufactured with modular pieces that could enclose the house. Space could be delivered with the Core or may be added later. Dwell is a full-size mobile unit that completes the model. One of the tenets of AMH design is flexibility; as the family size grows, additional modular pieces may be added to the Core and Space, as necessary, with some limitations.

Modeling Results

Exhibits 32 to 44 show the energy savings of individual building components (represented in colors) over the NREL Report 2016 reference model. The net zero energy model refers to IECC-2018 with solar water heat (SWH), PV, solar thermal, and storage. All model orientations are set with up as north.

AMHD Model #1: Core

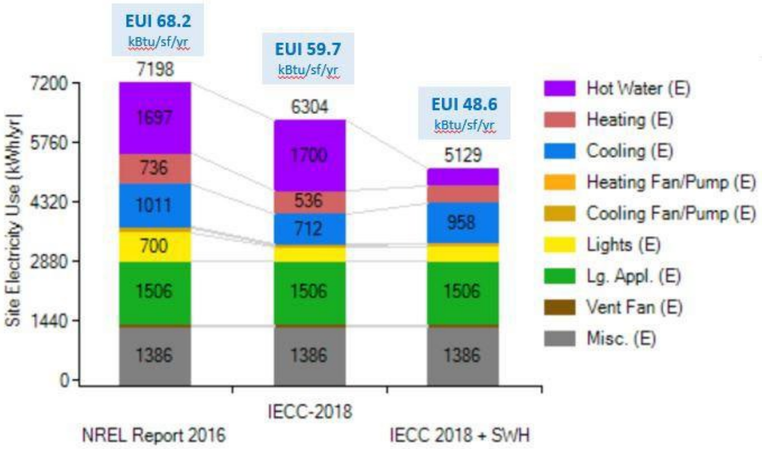
Exhibit 32. Energy Savings of Individual Building Components



E = energy. EUI = energy use intensity. IECC = International Energy Conservation Code. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet. SWH = solar water heat.

AMHD Model #2: Core+Space

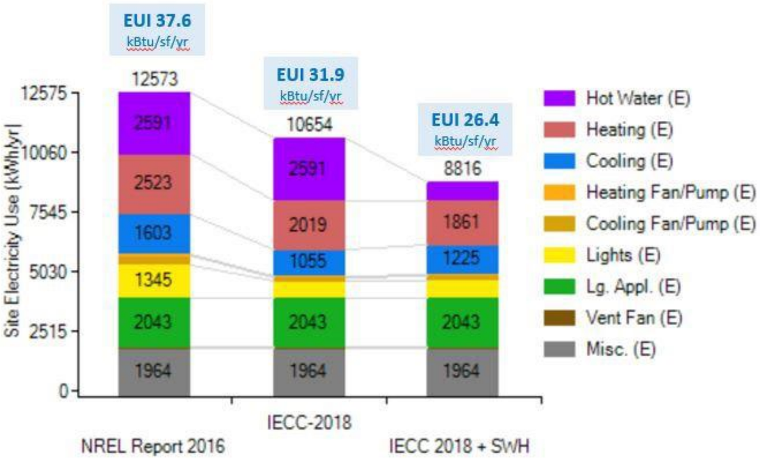
Exhibit 33. Energy Savings of Individual Building Components



EUI = energy use intensity. IECC = International Energy Conservation Code. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet. SWH = solar water heat.

AMHD Model #3: Core+Space+Dwell

Exhibit 34: Energy Savings of Individual Building Components



EUI = energy use intensity. IECC = International Energy Conservation Code. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet. SWH = solar water heat.

AMHD Model #4: Net Zero Energy-Capable

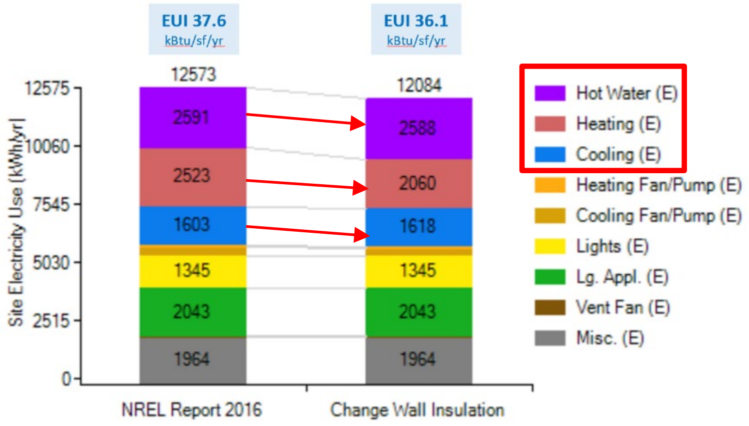
Considering the post-hurricane situation, the project team integrated a PV system and an energy storage system as alternatives for Core to ensure that residents have enough electricity to use for at least 2 days during a power outage. The National Hurricane Center defines the official hurricane season as June 1 to November 30. As the weather forecast and conditions for Charlotte, North Carolina, indicate, more than 60 percent of all hurricanes occur in September and October.

Energy Efficiency Measures

This section introduces the energy efficiency measures (EEMs) relevant to IECC-2018 with the Core+Space+Dwell model. The energy impact of individual EEMs (for example, change in wall U-factor) over the NREL Report 2016 reference model is shown in the following subsections.

Walls: Whereas the reference model uses R-11, the IECC 2018 model requires wood-framed walls for climate zone 3 with an R-value of at least R-19. The energy savings of the change in wall insulation over the reference model are shown in exhibit 35.

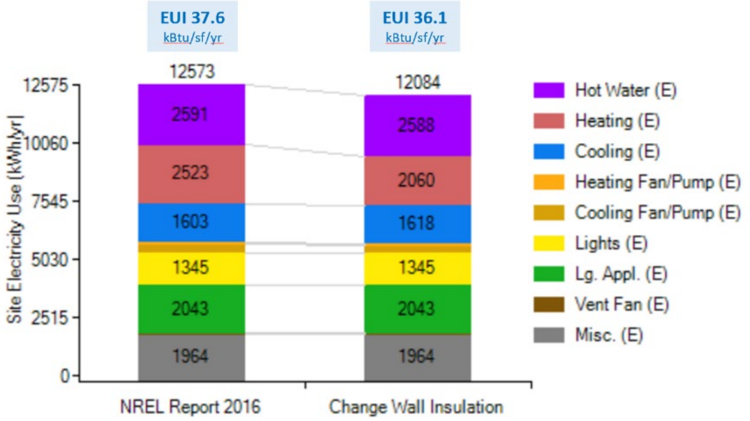
Exhibit 35. Energy Impact of Wall Insulation over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Ceiling and Roof: The IEEE-2018 model requires ceilings and roofing with an R-value in climate zone 3 of at least R-38. The energy savings of the change in ceiling and roof insulation over R-22 from the NREL Report are shown in exhibit 36.

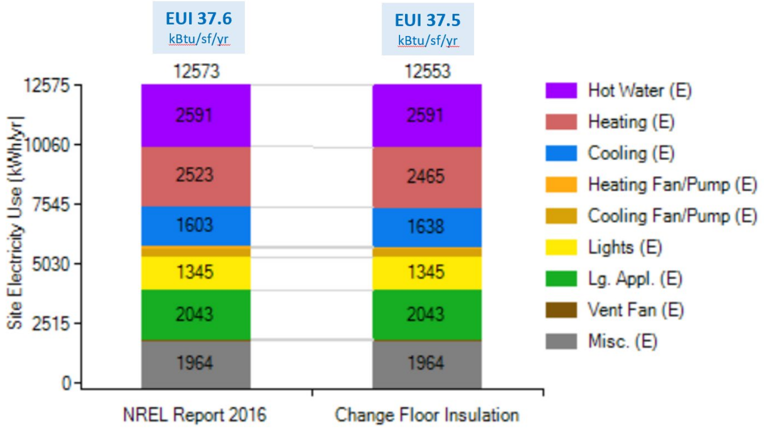
Exhibit 1. Energy Impact of Ceiling/Roof Insulation over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Floor: The floor is designed as a concrete slab. The minimum floor R-value of the IECC-2018 model is R-19. Compared with the R-14 fiberglass blanket from NREL, the building's total energy has no significant changes (see exhibit 37).

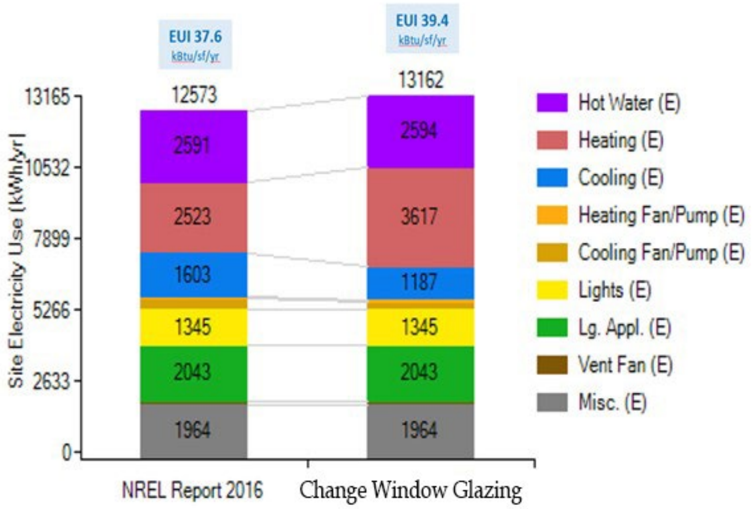
Exhibit 37. Energy Impact of Floor over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Window: The IECC 2018 model requires that the fenestration U-factor not exceed 0.32 and the solar heat gain coefficient (SHGC) be lower than 0.25. The NREL Report 2016 model features a window input with a U-factor of 0.47, SHGC of 0.73, a single pane, and a metal frame. The total energy savings from the NREL Report 2016 model input are shown in exhibit 38.

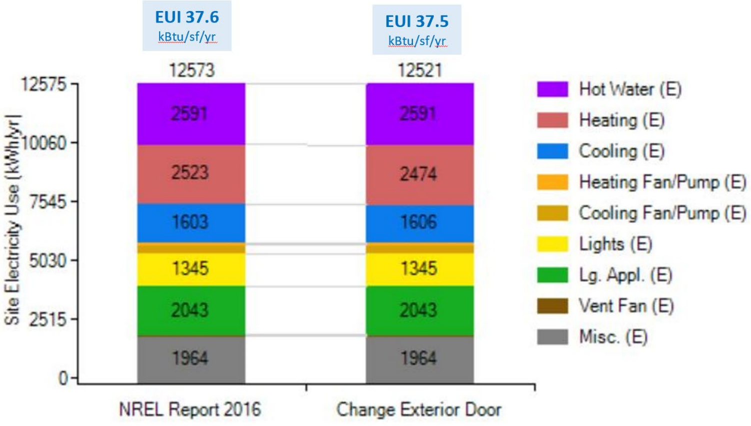
Exhibit 38. Energy Impact of Window over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Door: The IECC 2018 model requires that the fenestration U-factor not exceed 0.32. The NREL Report 2016 model features a window input with a U-factor of 0.4. The total energy savings from the NREL Report 2016 input are shown in exhibit 39.

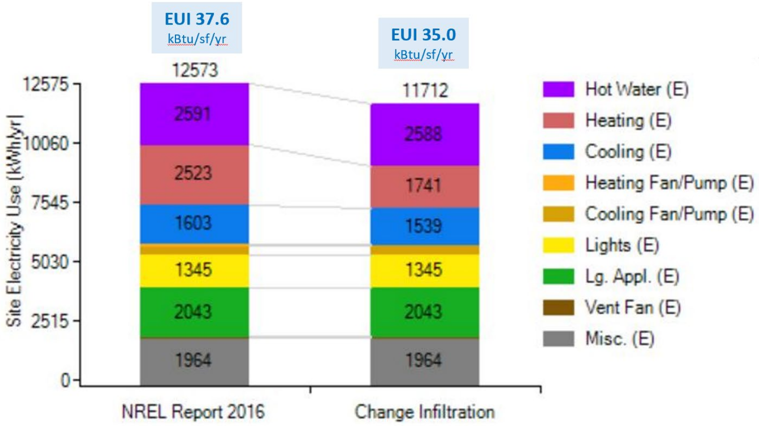
Exhibit 39. Energy Impact of Exterior Door over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Infiltration: In climate zones 3 through 8, building and dwelling units must be tested and verified as having an air leakage rate not exceeding 3ACH50 and reported at a pressure of 0.2-inch w.g. (50 P). The NREL Report 2016 model has 7.7 ACH50 for infiltration. The energy savings of the change in infiltration over the reference model are shown in exhibit 40.

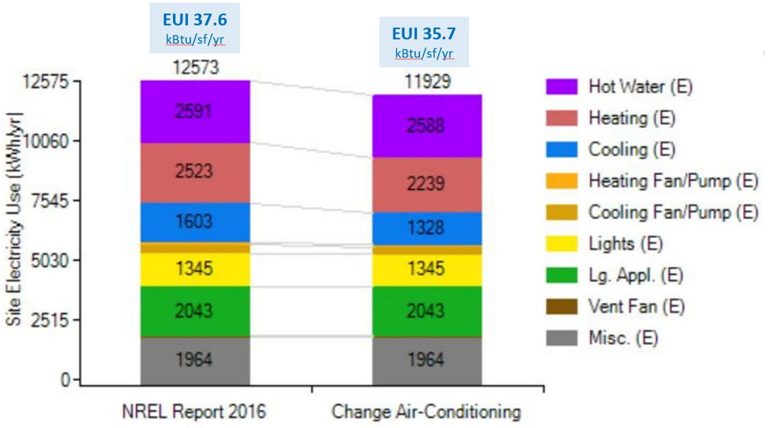
Exhibit 40. Energy Impact of Infiltration over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Air-conditioning: The IECC 2018 model requires a higher system energy efficiency rating (SEER) of 14 in climate zone 3. The NREL model has an air-conditioning input of SEER 13.0. The energy savings of the change in air-conditioning over the reference model are shown in exhibit 41.

Exhibit 41. Energy Impact of Air-Conditioning over Reference Model



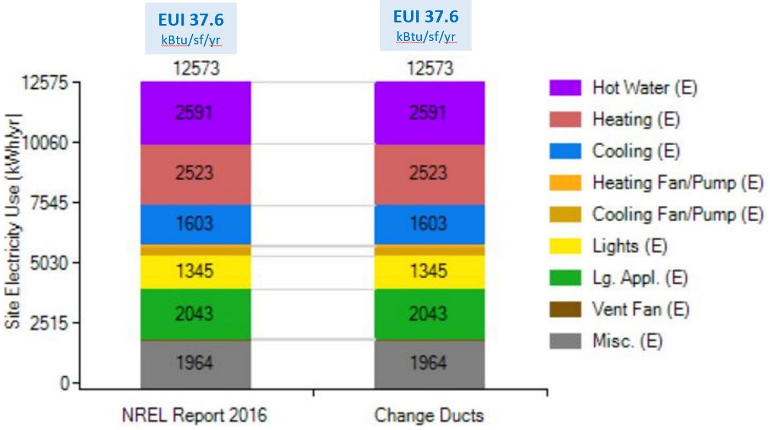
EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Ventilation: This project uses the equation from BEopt in the mechanical ventilation calculation for both cases:

0.01 × Floor Area + 7.5 × Number_of_Bedroom cubic feet per minute (CFM)

Ducts: The NREL Report 2016 model has a duct leakage input of 6.5 CFM/100 ft^2, with all ducts insulated to R-12 located in the pier and beam. The IECC 2018 model requires that the total duct leakage be less than or equal to 4 CFM/100 ft^2 and insulated to an R-value of not less than R-13. The energy savings of the change in air-conditioning over the reference model are shown in exhibit 42.

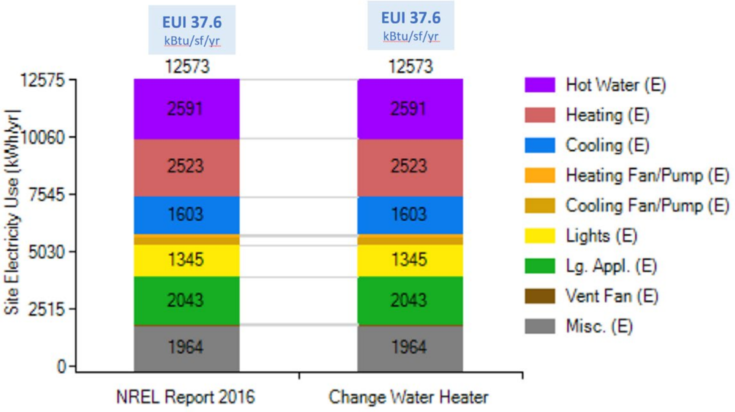
Exhibit 42. Energy Impact of Duct Leakage over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Water Heater: The energy factor (EF) of the NREL model is set at 0.90 and for the IECC model is 0.948. The energy savings of the change in the water heater are shown in exhibit 43.

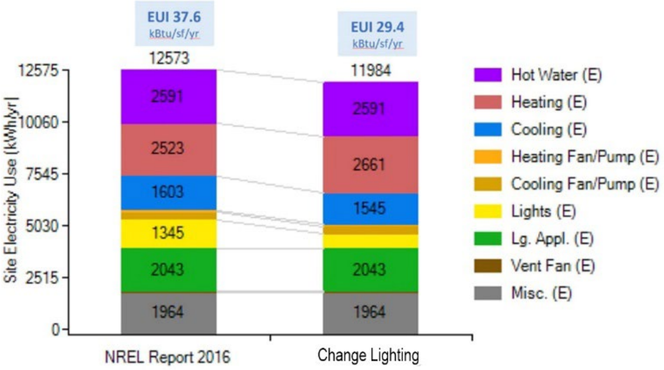
Exhibit 43. Energy Impact of Water Heater over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

Lighting: IECC 2018 requires that not less than 90 percent of the permanently installed lighting fixtures contain only high-efficiency lamps. NREL has an input of 100 percent incandescent for the lighting system. The energy savings of the change in lighting are shown in exhibit 44.

Exhibit 44. Energy Impact of Lighting over Reference Model



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. NREL = National Renewable Energy Laboratory. sf = square feet.

High-Performance AMH Design

The model results reveal that the reference model using inputs from NREL Report 2016 has an EUI of 37.6 kBtu/ft^2/year. The second model (IECC, 2018) has an EUI of 31.9 kBtu/ft^2/year. The total energy savings are 15.2 percent over the reference model. Heating, cooling, and lighting have significant energy savings. With the addition of the solar water heating system, model 3 has an EUI of 26.4 kBtu/ft^2/year. The total energy savings are 33.8 percent over the reference model. The solar water heating system brings significant changes in the hot water energy cost.

A net zero energy-capable AMH is designed by integrating renewable energy and storage systems. For the energy storage system, the project used September as the month.

Other Systems: Electrical, Water, and Wastewater

Electrical and Wiring System

The initial point of the electrical systems in this project is the local utility company-provided transformer, which reduces the line to a single voltage system passing through master switches and electric meters. The electrical wiring leads from the master switch and meter to the circuit breaker panel and then to appliances such as refrigerators, microwaves, and stoves. Given its relatively small scale, this project is supplied with electricity by two wires, one phase wire and the other neutral, which is known as a single-phase supply. In terms of distribution circuits, there are two types of subcircuits in this project: (1) lighting load subcircuit and (2) power load subcircuit. This building has a concealed wiring system (Grondzik and Kwok, 2014).

Water Supply and Distribution

Given the small scale of this project and the climate of the southeast United States, where the chances of ground freezing are minimal, this project is equipped with an “upfeed” water supply system. The supply has two main purposes: (1) supplying water to cold water main lines and branches and (2) supplying water to the domestic hot water system. This project is also equipped with a “hot water loop” to ensure fast access to hot water, when needed, in addition to the water heater and hot water tank. Moreover, PVC water pipes are used in this project to minimize the chances of corrosion.

Wastewater

The drainage water from the kitchen, showers, toilets, etc., is considered wastewater. The materials used within the building’s waste piping and for venting include cast iron, copper, and PVC. The layout of the wastewater piping follows the conventional “flag” symbol, in which the mast is the soil stack, the horizontal top of the flag is the branch vent, the bottom is the soil or waste branch, and the outer edge is the vertical pipe of the last fixture (Grondzik and Kwok, 2014). The construction slope for the drainage system, on average, is one-fourth in. drop per 1-foot drainage length of pipe.

CHAPTER 6. LIFE-CYCLE COSTING

This chapter discusses the life-cycle costing of the Core+ modular home. RS Means 2021 onsite Residential Cost Data were used for estimating the cost of a Core+ home. The three research themes of Advanced Modular Housing (AMH) design are energy efficiency, resiliency, and affordability. A thorough understanding of the life-cycle costing of the AMH design and its various energy efficiency options (and related cost savings) will provide homeowners with better knowledge of the actual costs over a period of time. The project team's design intent is to develop these options such that the final Core+ AMH design is affordable.

For the life-cycle costing of AMH design, the average national prices for materials and installation were adjusted for the house's location, Charleston, South Carolina. The literature and interviews with manufacturers of modular homes revealed that material costs for modular homes are 10 percent less than those of site-built residential homes owing to bulk purchase. In addition, installation costs for modular homes are considerably less than those of site-built homes owing to higher labor productivity (controlled environment, repetition of similar activities, and working on the factory floor rather than working at heights) and using more advanced tools and equipment. The reported decrease in labor cost varied as low as 33 percent and as high as 50 percent. For this project, a 40-percent reduction in installation cost was considered.

As previously discussed in chapter 3, a baseline energy model was developed based on National Renewable Energy Laboratory (NREL) Report 2016 in climate zones 2 and 3 (primarily warm-humid climates). To recap, the energy consumption of the Core+ modular home was calculated using the BEopt energy model to simulate a city in climate zone 3 (Charleston, South Carolina). Next, the Core+ modular home exterior envelope and mechanical and electrical systems were upgraded for energy efficiency measures (EEMs) to meet International Energy Conservation Code (IECC) 2018. Two hyper-energy-efficient options were considered to reduce the energy consumption of IECC 2018. The first option was to replace the electric water heater with a solar water heater, which reduced the energy consumption by 13.7 percent, and the second option was to increase the air-conditioning system energy efficiency rating (SEER) from 14 to 17, which resulted in a 2.4-percent energy reduction compared with the IECC 2018 model.

The following energy-efficient upgrades were considered to bring the NREL Report 2016 house in compliance with IECC 2018:

- Increasing wall insulation from R-11 to R-24.
- Increasing roof insulation from R-22 to R-38.
- Increasing floor insulation from R-14 to R-19.
- Reducing U-factor and solar heat gain coefficient (SHGC) for windows from 0.47 and 0.73 to 0.32 and 0.25, respectively.
- Reducing infiltration from 7.7 ACH50 to 3.0 ACH50.
- Increasing air-conditioner SEER from 13 to 14.
- Reducing duct leakage from 6.5 cubic feet per minute (CFM)/100 ft^2 to 4.0 CFM/100 ft^2.
- Increasing duct insulation from R-12 to R-13.
- Increasing energy efficiency of water heater from 0.90 to 0.95.
- Changing lighting from 100 percent incandescent to 100 percent LED.

Cost Estimating

Exhibits 66, 68, and 70 (see appendix A) show detailed estimations for the manufacturing cost of the Core unit, Core and Space units, and Core+ modular home, respectively, based on the developed construction drawings and specifications provided in Chapter 3—Architecture and Design. The materials and installation costs have been provided for framing (floor, walls, and roof), exterior walls (insulation, finishes, doors, and windows), roofing (roofing materials, insulation, and accessories), interiors (floor, wall, and ceiling finishes; interior doors; and stairs), specialties (kitchen cabinets, countertops, and appliances; washer; dryer; and water heater), mechanical (plumbing and fixtures for bathrooms and heating, ventilation, and air-conditioning [HVAC] system), and electrical (circuit panel, wiring, devices, and lighting fixtures). The manufacturing costs for Core, Core and Space, and Core+ are approximately $33,000, $45,000, and $99,000, respectively.

When determining the total cost of a modular house, the costs of site work and excavation, footing, crawl space foundation walls, transportation of units from the manufacturing plant to the site, connection of the units to the foundation and to each other, and connection of utilities should be added. Exhibits 67, 69, and 71 (see appendix A) provide detailed cost estimates for site work and installation for the Core unit, Core and Space units, and Core+ modular house, respectively. The site work, transportation, and installation costs for the Core unit, Core and Space units, and Core+ modular house are $6,150, $11,550, and $30,420, respectively. There would be some savings in these costs if all units (Core, Space, and Dwell) were transported and installed at the same time. Exhibit 45 shows the total cost of the Core+ modular house in this case. Needless to say, there are costs for site improvements such as higher foundation, carport, wooden deck, etc., which are discussed in the next section.

Exhibit 45. Total Cost of Core+ Modular House if All Three Components Are Installed at Once

Choice of Unit Config.	TOTAL COST ($)
Core	33,000
Core and Space	45,000
Core+	99,000

Onsite Construction	TOTAL COST ($)
All at once	30,000
2-stage delivery (2 months)	32,000
3-stage delivery (6 months)	34,000

Estimating Cost of Site Improvement

The cost estimates for several site improvements are provided in exhibit 46. These improvements include increasing the depth of foundation walls for high flood level areas, a wooden deck, a carport, a one-car garage (attached or detached), a concrete driveway, and a fence. Exhibit 46 shows that increasing the height of the foundation walls by 2 ft and adding a 20 ft × 8 ft carport, 300 ft^2 of wood deck, 400 ft^2 of concrete driveway or walkway, and 200 linear feet (LF) of fence will increase the cost of the Core+ modular house by $24,000, for a total cost of $153,043. The following section discusses the monthly mortgage payment, additional costs for energy efficiency measures, and related cost savings.

Exhibit 46. Monthly Mortgage and Electricity Costs for a Core+ Modular House with Selected Site Improvements

Site Improvement	Unit	Per-Unit Cost ($)	Upfront Cost ($)
Higher foundation elevation (ft)	2	750	1,500
Carport (12 ft × 20 ft)	1	4,500	4,500
Wooden deck with skirting (ft^2)	300	37	11,100
One-car garage, attached	0	15,000	—
One-car garage, detached	0	20,000	—
Concrete driveway/walkway (ft^2)	400	6.2	2,480
Fence (LF)	200	15	3,000
Parging and paint crawl space CMU (ft^2)	450	3	1,463
Initial costs			24,043

CMU = concrete masonry unit. LF= linear feet.

Monthly Mortgage Payment and Electricity Costs

In chapter 4, the annual electricity consumption of the Core+ modular house was estimated to be 12,474 kWh. Assuming an electricity cost of $0.13 per kWh, the average monthly electricity cost for the Core+ modular house is as follows:

(12,474 kWh × $0.13 per kWh) / 12 = $135[8]

Exhibit 47 shows that the monthly mortgage payment for the $153,043 Core+ modular house is $978. This monthly payment is based on a 30-year loan with a 5-percent fixed interest rate and a 5-percent down payment. It also includes private mortgage insurance, property taxes, and insurance.

The total monthly payment for mortgage and electricity of the Core+ modular house with selected site improvements will be $978 + $135 = $1,113 per month.

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[8] Electricity cost does not include utility taxes and surcharges and should be used for reference purposes only.

Exhibit 47. Data for Calculation of Monthly Mortgage Cost for the Selected Core+ Modular House

Monthly Mortgage for a $153,043 Modular House	
	Conventional Loan
Term Length (Year)	30-Year Fixed
Interest Rate	5%
Down Payment (%)	5%
Down Payment ($)	$7,652
Principal and Interest	$780
PMI	$20
Property Taxes and Insurance	$178
Monthly Mortgage	$978

PMI = private mortgage insurance.

Cost of Adding Energy Efficiency Measures

Chapter 4 provided several EEMs for a Core+ modular house and used BEopt to calculate energy savings due to these measures. Changing the electric water heater to a solar water heater incurs an additional cost of $2,500 but reduces the annual electricity consumption of the house by 1,703 kWh. Another EEM is to increase air-conditioner efficiency from 14 to 17 SEER. The additional cost for this change is $600, and the reduction in annual electricity consumption is 299 kWh. Exhibit 48 shows that adding these two EEMs to the Core+ modular house increases its cost by $3,100 from $153,043 to $156,143 but reduces the annual electricity consumption by 2,002 kWh from 12,474 to 10,472 kWh. Assuming an electricity cost of $0.13 per kWh, the average monthly electricity bill will be as follows:

(10,472 kWh × $0.13 per kWh) / 12 = $113

Exhibit 49 shows that the monthly mortgage payment for the $156,143 Core+ modular house is $998. This monthly payment is based on a 30-year loan with a 5 percent fixed interest rate and a 5-percent down payment. It also includes private mortgage insurance, property taxes, and insurance.

The total monthly payment for mortgage and electricity of the Core+ modular house with selected site improvements and EEMs is $998 + $113 = $1,111.

Exhibit 48. Monthly Mortgage and Electricity Costs for a Core+ Modular House with Selected Site Improvements and Additional Energy Efficiency Measures

Stage 3—BALANCE					
Environment	Cost/Unit ($)	Units	Up Front ($)	Monthly Savings ($)	Costs
HVAC SEER 14 to 17	600	1	600	(4.00)	
Solar HW	2,500	1	2,500	(18.00)	
Galvanized Steel Roof	6,700	0			
Initial Costs			3,100		$ 156,143

Monthly Energy Costs				(22)	$ 113
Monthly Mortgage Costs					$ 998
Monthly Total Cost					$ 1,111

HVAC = heating, ventilation, and air-conditioning. HW = hot water. SEER = system energy efficiency rating.

Exhibit 49. Data for Calculation of Monthly Mortgage Cost for the Core+ Modular House with Selected Energy Efficiency Measures

Type of Loan	Conventional
Term Length (Year)	30-Year Fixed
Interest Rate	5%
Down Payment (%)	5%
Down Payment ($)	$7,807
Principal and Interest	$796
PMI	$20
Property Taxes and Insurance	$182
Monthly Mortgage	$998

PMI = private mortgage insurance.

Life-Cycle Cost Analysis

Each simulation's energy savings and associated energy costs were calculated and compared against the baseline. For energy savings, the total annual energy consumption of the Core+ home was used, and for the energy-related costs, the utility bills were annualized considering the specific energy costs for the house location.

Under the cost analysis, this study evaluated the initial construction costs, the simple payback period, and the life-cycle costs over 30 years. The initial construction cost refers to the model's costs associated with the building materials, equipment, and labor. The simple payback period refers to the time required to recover the project investment without considering the time value of money. It is often defined as the break-even point—the year at which the initial investment is offset by the benefits accumulated—which in this case was the energy-associated costs. The life-cycle costs were calculated by summing the net present value of life-cycle expenses associated with the loan, home maintenance, replacement cost, and utility bills. For this AMH design, the project team evaluated the integration of electric and solar water heaters and their relative cost impacts, as discussed below.

Electric Versus Solar Water Heater

The following example demonstrates how the life-cycle costs of different EEMs were calculated. In this example, the base Core+ modular home included an electric water heater. The total cost of the home was estimated to be $153,043, and the annual energy consumption, based on BEopt simulation, was 12,474 kWh.

The electric water heater was then changed to a solar water heater. The additional costs for this change were estimated to be $2,500, and the annual energy consumption was reduced to 10,771 kWh.

The simple payback period was calculated on the basis of the energy-associated costs.

Initial investment = $2,500
Annual energy savings = (12,474 –10,771) × 0.13 = $221.40
Simple payback period = initial investment/energy savings = $2,500 / $221.40 per year = 11.3 years.

Next, the present worth of the home's life-cycle costs for the duration of the mortgage loan was determined for each case. Exhibit 50 shows the variable quantities used to determine the present worth of the home's life-cycle costs for the electric water heater case. Exhibit 72 (see appendix A) shows that the present worth of mortgage, maintenance, and electricity costs for the first 30 years is $269,528, based on a down payment of 5 percent, interest rate of 5 percent, and 30-year term loan for the home financing. The electricity cost was assumed to be $0.13 per kWh, with an annual energy inflation rate of 3 percent; the maintenance cost was assumed to be 1 percent of the initial cost, with an inflation rate of 1.7 percent per year; and the discount rate was assumed to be 2.5 percent. In this example, the life-cycle cost is limited to the mortgage loan term (30 years), so two replacement costs at years 10 and 20 were included. It was also assumed that the house's energy consumption would increase by 1 percent annually due to the degradation of the equipment, appliances, and envelope materials.

Exhibit 50. Life-Cycle Cost Data for the Core+ Modular House with an Electric Water Heater

Name	Unit	
Term of loan	yr	30
Electricity cost	$/kWh	0.13
Initial cost	$	153,043
Down payment	%	5.0
Down payment	$	7,652
Interest rate	%	5.0
Discount rate	%	2.5
Energy inflation rate	%	3.0
General inflation rate	%	1.7
Maintenance cost	%	1.0
Annual energy consumption	kWh	12,474
Loan amount	$	145,391
Yearly payment	$	9,458
Replacement cost	$	1,700

kWh = kilowatt-hour.

The same financing parameters, electricity cost, energy inflation rate, maintenance costs, and inflation and discount rates were used to calculate the present worth of the life-cycle cost for the solar water heater option (exhibit 51). In this example, the life-cycle cost is limited to the mortgage loan term (30 years), so only one replacement cost at year 15 was included. Exhibit 73 (see appendix A) shows that the present worth of the lifecycle cost over the first 30 years for the solar water heater is $265,745, which is $3,783 less than that of the base Core+ modular house with an electric water heater.

Exhibit 51. Life-Cycle Cost Data for the Core+ Modular House with a Solar Water Heater

Name	Unit	
Term of loan	yr	30
Electricity costs	$/kWh	0.13
Initial cost	$	155,543
Down payment	%	5.0
Down payment	$	7,777
Interest rate	%	5.0
Discount rate	%	2.5
Energy inflation rate	%	3.0
General inflation rate	%	1.7
Maintenance cost	%	1.0
Annual energy consumption	kWh	10,771
Loan amount	$	147,766
Yearly loan payment	$	9,612
Replacement cost	$	4,200

kWh = kilowatt-hour.

Exhibit 74 (see appendix A) compares the life-cycle cost of electric and solar water heaters. Considering an energy inflation rate of 3 percent and increasing the energy consumption of the house by 1 percent annually due to degradation of the equipment, appliances, and envelope materials will make the solar water heater a better option than the electric water heater. The life-cycle cost of the electric water heater is lower only in the first 3 years owing to a lower initial cost. The simple payback method that resulted in 11.3 years for this case is not accurate because it does not consider the time value of money and other factors that affect the life-cycle cost. Similar to the two water heater options discussed above, the project team evaluated two air-conditioners of various SEER values. Each of these options has a cost impact on the overall project.

14 SEER Versus 17 SEER Air-Conditioner

Another example to demonstrate how the life-cycle costs of different EEMs were calculated is the case of a more efficient air-conditioner. In this case, the base Core+ modular home included a 14 SEER air-conditioner. The total cost of the home was estimated to be $153,043, and the annual energy consumption based on BEopt simulation was 12,474 kWh.

The 14 SEER air-conditioner was then changed to a 17 SEER air-conditioner. The additional costs for this change were estimated to be $600, and the annual energy consumption was reduced to 12,175 kWh. The simple payback period was based on energy-associated costs.

Initial investment = $600
Annual energy savings = (12,474 -12,175) × 0.13 = $39

Simple payback period = initial investment / energy savings = \$600 / \$39 per year = 15.4 years.

Next, the present worth of the home's life-cycle costs for the duration of the mortgage loan was determined for each case. Exhibit 52 shows the variable quantities used to determine the present worth of the home's life-cycle costs for the 14 SEER air-conditioner. Exhibit 75 (see appendix A) shows that the present worth of mortgage, maintenance, and utility costs for the first 30 years is \$276,259. This calculation is based on a down payment of 5 percent, an interest rate of 5 percent, and a 30-year term loan for the home financing. The electricity cost was assumed to be \$0.13 per kWh, with an annual energy inflation rate of 3 percent; the maintenance cost was assumed to be 1 percent of the initial cost, with an inflation rate of 1.7 percent per year; and the discount rate was assumed to be 2.5 percent. In this example, the life-cycle cost was limited to the mortgage loan term (30 years), so one replacement cost at year 15 was included. It was also assumed that the house's energy consumption would increase by 1 percent annually due to the degradation of the equipment, appliances, and envelope materials.

Exhibit 52. Life-Cycle Cost Data for the Core+ Modular House with a 14 SEER Air-Conditioner

Name	Unit	
Term of loan	yr	30
Electricity costs	$/kWh	0.13
Initial cost	$	153,043
Down payment	%	5.0
Down payment	$	7,652
Interest rate	%	5.0
Discount rate	%	2.5
Energy inflation rate	%	3.0
General inflation rate	%	1.7
Maintenance cost	%	1.0
Annual energy consumption	kWh	12,474
Annual energy cost	$	1,622
Loan amount	$	145,391
Yearly payment	$	9,458
Replacement cost	$	9,980

kWh = kilowatt-hour.

The same financing parameters, electricity cost, energy inflation rate, maintenance costs, and inflation and discount rates were used to calculate the present worth of the life-cycle cost for the 17 SEER air-conditioner option (exhibit 53). In this example, the life-cycle cost was limited to the mortgage loan term (30 years), so only one replacement cost at year 15 was included. Exhibit 76 (see appendix A) shows that the present worth of the life-cycle cost for the first 30 years with the 17 SEER air-conditioner is \$276,078, which is \$181 less than that of the base Core+ modular house with the 14 SEER air-conditioner.

Exhibit 53. Life-Cycle Cost Data for the Core+ Modular House with a 17 SEER Air-Conditioner

Name	Unit	
Term of loan	yr	30
Electricity costs	$/kWh	0.13
Initial cost	$	153,643
Down payment	%	5.0
Down payment	$	7,682
Interest rate	%	5.0
Discount rate	%	2.5
Energy inflation rate	%	3.0
General inflation rate	%	1.7
Maintenance cost	%	1.0
Annual energy consumption	kWh	12,175
Annual energy cost	$	1,583
Loan amount	$	145,961
Yearly loan payment	$	9,495
Replacement cost	$	10,480

kWh = kilowatt-hour.

Exhibit 77 (see appendix A) compares the life-cycle cost of the 14 SEER and 17 SEER air-conditioners. Including an energy inflation rate of 3 percent and increasing the energy consumption of the house by 1 percent annually due to degradation of the equipment, appliances, and envelope materials will make the 17 SEER air-conditioner a better option than the 14 SEER air-conditioner. The life-cycle cost of the electric water heater is smaller only in the first 8 years owing to a lower initial cost. The simple payback method that resulted in 15.4 years for this case is not accurate because it does not consider the time value of money and other factors that affect life-cycle cost.

CHAPTER 7. AFFORDABILITY

Housing is usually considered affordable if no more than 30 percent of household income is devoted to housing costs, including utility consumption. Florida's population growth, combined with the state's dramatic housing boom in the mid-2000s, has led to a shrinking supply of affordable single-family homes, especially for low-income households. More than 1.4 million households in the state with incomes below 60 percent of annual median income (AMI) are cost burdened by housing, which is defined as those who spend more than 40 percent of their income on housing. This group of households includes one-half of owners and more than two-thirds of renters. With the help of life-cycle cost analysis, building materials and other accessories—such as solar photovoltaic (PV), hot water systems, etc.—can be integrated appropriately to enhance the affordability of housing. This chapter describes Florida's affordable housing context and the post-disaster recovery environment in which this Advanced Modular Housing (AMH) design can serve as a solution to both an affordable housing crisis and community recovery. The first section of this chapter discusses the characteristics of AMH design home occupants—Florida faces an ongoing shortage of affordable housing for low-income households. The next section provides insights into the affordable housing gap and the loss of lower-cost housing supply. With this background, the following section offers the AMH design as a supply-side solution to the housing shortage. The last section of this chapter discusses how AMH design can be an immediate solution to the current affordable housing shortage and for post-disaster rapid housing.

A Natural Consumer of an Affordable AMH Design Product—the Household Characteristics of Manufactured Housing Occupants

Current households in manufactured housing statewide (Shimberg Center for Housing Studies, 2020a; U.S. Census Bureau, 2020)

Currently, more than 600,000 households live in manufactured housing across Florida, of which three-quarters are owner occupied, and 44 percent are 65 years of age or older. Manufactured housing represents one of the most affordable housing options in Florida (see exhibits 54 and 55). While the statewide median income at 50 percent AMI is ~$32,000, slightly more than one-third of manufactured housing households have incomes below $32,000.

Eleven percent of manufactured housing households are renters with incomes under 50 percent of AMI. In smaller Florida counties, manufactured housing can represent the primary affordable housing option for renter households because of the relatively small supply of multifamily rental units, while the incomes range from ~$27,600 in the south-central counties to ~$31,000 in the north-central, northeast, and northern counties to ~$35,000 in the Panhandle.

Exhibit 54. Households in Manufactured Housing Statewide

	30% AMI or Less	30.01 to 50% AMI	50.01 to 80% AMI	80.01 to 120% AMI	More than 120% AMI	Grand Total	Percent of Grand Total (%)
Owner	67,903	78,696	111,428	94,336	106,378	458,741	76.1
65 or Older	31,188	45,777	61,961	48,179	50,001	237,106	39.3
Younger than 65	36,715	32,919	49,467	46,157	56,377	221,635	36.8
Renter	35,464	29,422	34,429	29,065	15,556	143,936	23.9
65 or Older	7,315	7,450	6,384	3,648	2,208	27,005	4.5
Younger than 65	28,149	21,972	28,045	25,417	13,348	116,931	19.4
Grand Total	103,367	108,118	145,857	123,401	121,934	602,677	100.0
Percent of Grand Total (%)	17.2	17.9	24.2	20.5	20.2	100.0	

AMI = annual median income.
Source: Shimberg Center for Housing Studies, 2020a

Exhibit 55. Summary: Households in Manufactured Housing Statewide

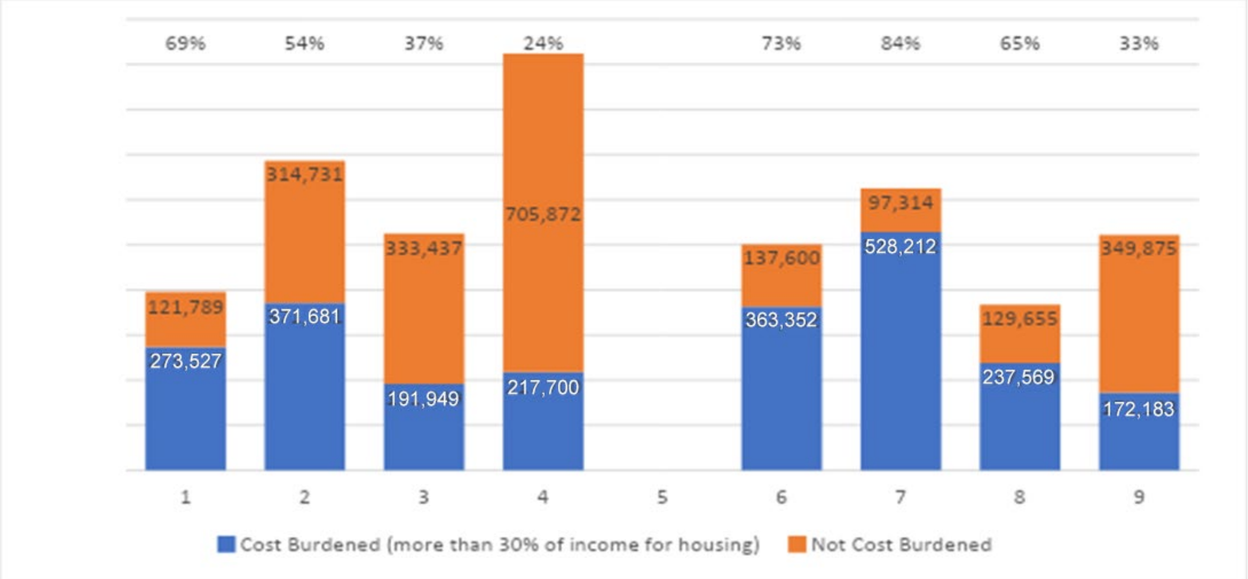
	Total HHs	Percent of Total (%)
Owner	458,741	76.1
Renter	143,936	23.9
65 or Older	264,111	43.8
0–50% AMI (All HHs)	211,485	35.1
0–50% AMI (Renters)	64,886	10.8
0–50% AMI (Owners)	146,599	24.3

AMI = annual median income. HH = household.
Source: Shimberg Center for Housing Studies, 2020a

Florida's Affordable Housing Needs

More than 2.5 million low- and moderate-income households in Florida spend more than 30 percent of their income on housing (exhibit 56). Low-income renters are the most at risk to spend more on housing.

Exhibit 56. Cost-Burdened Households by Income as a Percentage of AMI, Florida, 2017



AMI = annual median income.
Source: Shimberg Center for Housing Studies, 2020a

Florida added hundreds of thousands of rental units between 2000 and 2017 but lost units renting for $1,000 or less (in 2017 dollars) (See exhibit 57) (Shimberg Center for Housing Studies, 2019).[9]

- Net increase 2000–2017: 674,210 rental units.
- Units more than $1,000 grew by 718,166.
- Units at or less than $1,000 fell by 43,956.

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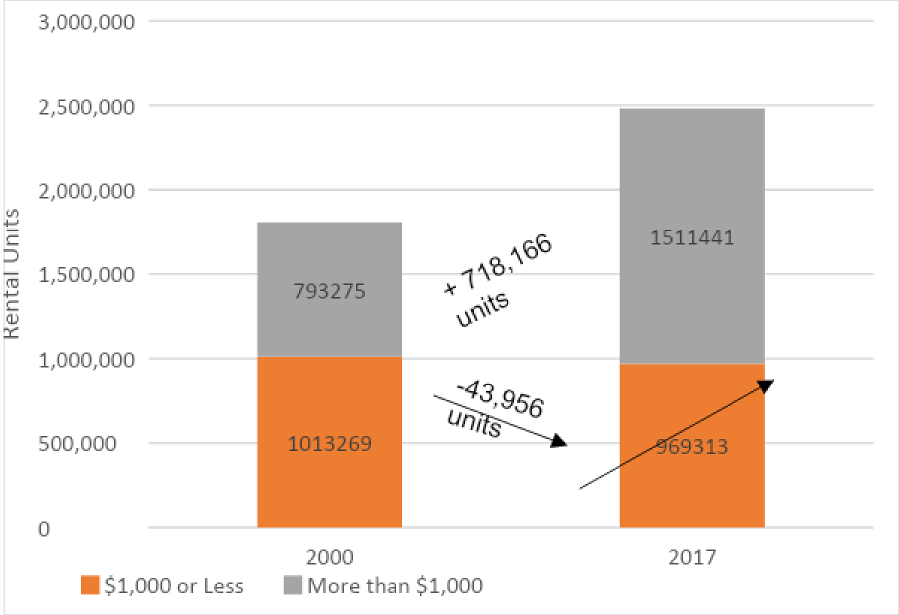
[9] Sources: Shimberg Center analysis of U.S. Census Bureau, 2000 Census and 2017a Community Survey. Year 2000 counts show units above and below $705 gross rent in nominal dollars, the equivalent of $1,000 in 2017 according to the Consumer Price Index. Excludes units with no cash rent.

Exhibit 57. Units by Gross Rent Less/More than $1,000 (2017 $), Florida, 2000 and 2017



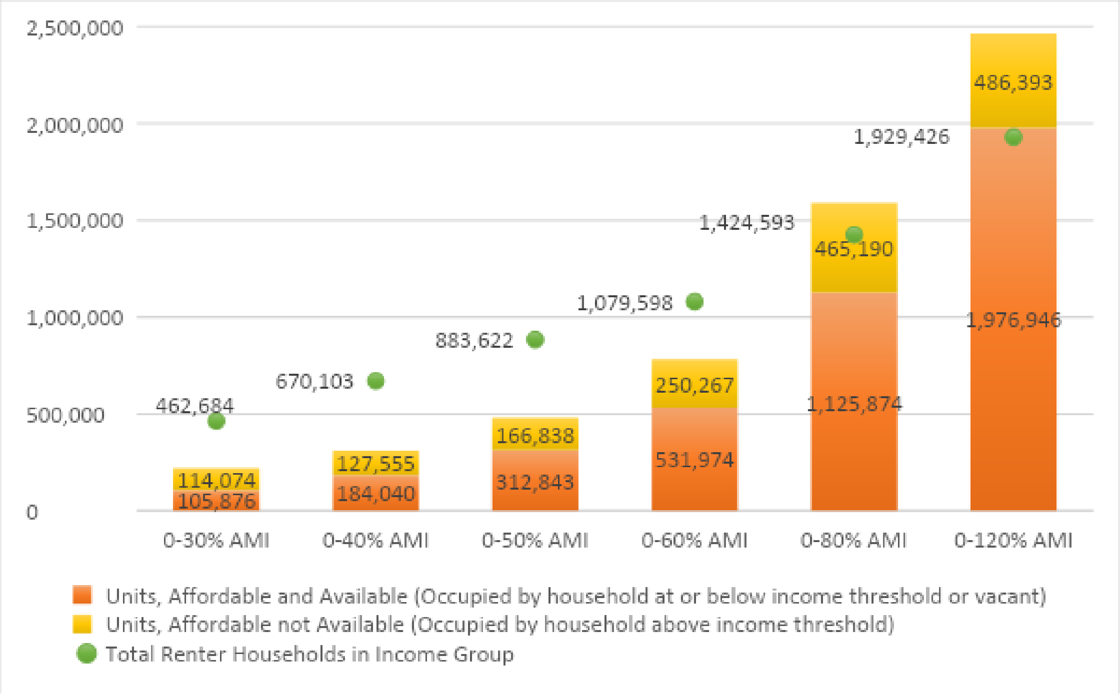
Source: Shimberg Center for Housing Studies, 2019

Tenant Characteristics—Rent

Exhibit 58. Average Tenant-Paid Gross Rent (Rent + Utilities)

AMI = Area Median Income. FHFC= Florida Housing Finance Corporation.
Source: Shimberg Center for Housing Studies, 2019

Exhibit 59. Affordable Units, Affordable and Available Units, and Renter Households by Income, Florida, 2013–2017 Estimate



Sources: Shimberg Center for Housing Studies, 2019; U.S. Census Bureau, 2017a

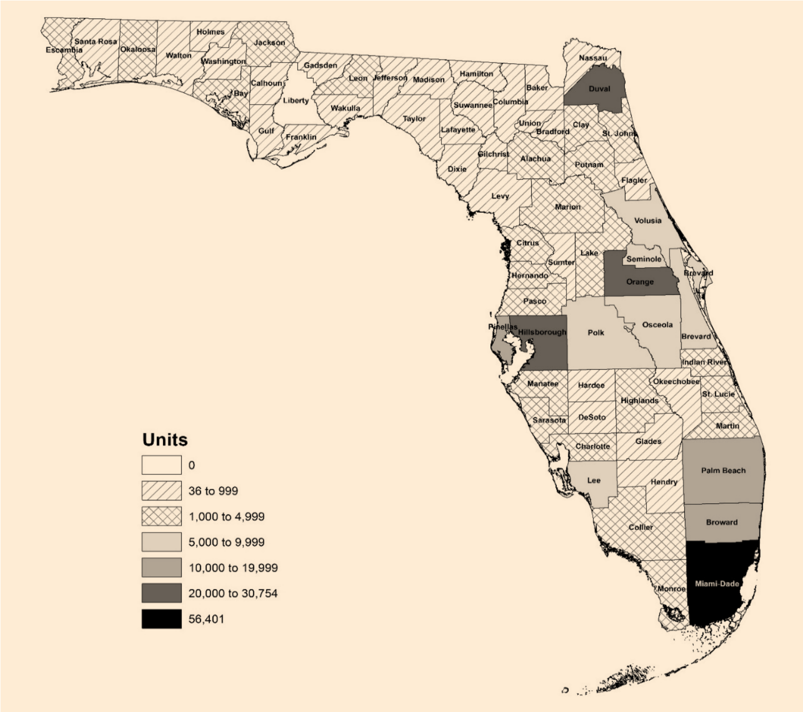
Assisted and Public Housing

Florida's public and assisted housing stock provides 286,335 units of affordable rental housing—nearly 1 in 10 rental units in the state (Exhibit 58 & 59). Public housing developments are owned by local housing authorities funded by the U.S. Department of Housing and Urban Development (HUD). Assisted housing developments may be owned by for-profit corporations, nonprofit organizations, or public agencies. They receive subsidies such as low-interest development financing or ongoing rental assistance from HUD, U.S. Department of Agriculture's Rural Development program (RD), Florida Housing Finance Corporation (Florida Housing), and local housing finance authorities (LHFAs). These two types of affordable housing can overlap, as public housing developments may also receive federal and state subsidies for preservation and redevelopment (Shimberg Center for Housing Studies, 2019).

Assisted Housing (see exhibit 60)

- Florida Housing, HUD, USDA RD, LHFAs.
- 2,528 developments, 259,085 assisted units.
- Of these, Florida Housing funded 1,620 developments and 197,021 assisted units.

Exhibit 60. Public and Assisted Housing Units by County, 2019



Source: Shimberg Center for Housing Studies, 2019

The AMH design product can serve multiple functions in Florida's current housing stock: post-disaster temporary, transitional, and permanent housing. Exhibit 61 shows multifamily units by building size (number of units), age, and rent. Multifamily units are often most vulnerable to the short- and longer-term impacts of disasters—these units are usually older and smaller—but are also often the most affordable. More than one-half of the units more than 40 years old have rents less than $1,000.

Exhibit 61. Multifamily Units: Renter and Owner Occupied

			RENTS			
UNITS BY BLDG BY YEAR BUILT	Less than $500	$500 to $999	$1,000 or More	Owner Occupied	Vacant or No Cash Rent	Grand Total
1959 or Earlier	14,271	53,228	55,209	21,327	2,289	146,324
9 or Fewer Units	6,205	33,574	28,437	9,394	877	78,487
10 to 19 Units	2,149	8,595	10,805	2,212	919	24,680
20 to 49 Units	2,220	5,311	7,364	3,926	212	19,033
50 or More Units	3,697	5,748	8,603	5,795	281	24,124
1960–1969	16,021	57,709	72,535	47,501	1,622	195,388
9 or Fewer Units	5,996	32,040	25,448	9,746	744	73,974
10 to 19 Units	815	11,738	12,850	4,183	194	29,780
20 to 49 Units	2,058	7,758	14,604	12,222	522	37,164
50 or More Units	7,152	6,173	19,633	21,350	162	54,470
1970–1979	27,106	114,691	175,693	170,267	7,404	495,161

9 or Fewer Units	11,575	59,080	68,576	46,143	3,004	188,378
10 to 19 Units	2,374	22,351	36,673	20,907	636	82,941
20 to 49 Units	2,581	17,500	34,144	45,169	1,601	100,995
50 or More Units	10,576	15,760	36,300	58,048	2,163	122,847
1980–1999	30,330	160,896	392,708	221,740	8,438	814,112
9 or Fewer Units	9,892	86,944	155,120	85,743	3,205	340,904
10 to 19 Units	4,960	33,577	95,000	37,737	1,386	172,660
20 to 49 Units	3,524	20,180	73,953	41,921	1,872	141,450
50 or More Units	11,954	20,195	68,635	56,339	1,975	159,098
2000–2018	17,699	69,660	301,424	105,923	4,664	499,370
9 or Fewer Units	4,976	27,437	73,427	35,983	2,107	143,930
10 to 19 Units	1,983	13,539	67,939	15,574	551	99,586
20 to 49 Units	3,485	11,527	65,014	19,245	525	99,796
50 or More Units	7,255	17,157	95,044	35,121	1,481	156,058
Grand Total	105,427	456,184	997,569	566,758	24,417	2,150,355

Sources: 2018 American Community Survey; Public Use Microdata Sample (PUMS); Shimberg Center for Housing Studies

Exhibit 62 shows single-family units by building size (ft^2), age, and just value. Square-foot units are often most vulnerable to the short- and longer-term impacts of disasters—these units are generally older and smaller and tend to be, not surprisingly, the most affordable. Of these square-foot units—

- 43 percent of ft^2 units more than 40 years old have just values less than $150,000.
- 60 percent of ft^2 units with just values less than $150,000 are less than 1,500 ft^2.

Exhibit 62. Single-Family Units: Renter and Owner Occupied

	JUST VALUE				
YEAR BUILT UNITS BY SIZE	Less than $100,000	$100,000 to $149,999	$150,000 to $199,999	$200,000 or More	Grand Total
1959 or Earlier	246,178	153,857	124,633	279,870	804,538
Less than 1,000 ft^2	83,812	29,680	12,328	10,306	136,126
1,000 to 1,499 ft^2	116,018	75,176	64,979	73,727	329,900
1,500 ft^2 or More	46,348	49,001	47,326	195,837	338,512
1960–1969	121,705	102,712	80,456	169,490	474,363
Less than 1,000 ft^2	30,115	7,180	2,058	1,287	40,640
1,000 to 1,499 ft^2	64,710	43,638	29,260	21,724	159,332
1,500 ft^2 or More	26,880	51,894	49,138	146,479	274,391
1970–1979	109,596	148,754	128,930	250,832	638,112
Less than 1,000 ft^2	15,467	4,807	896	1,039	22,209
1,000 to 1,499 ft^2	65,862	63,766	35,381	19,071	184,080
1,500 ft^2 or More	28,267	80,181	92,653	230,722	431,823
1980–1999	155,399	346,085	387,340	886,889	1,775,713
Less than 1,000 ft^2	27,830	9,952	2,032	2,673	42,487
1,000 to 1,499 ft^2	95,125	150,606	87,333	48,855	381,919

1,500 ft^2 or More	32,444	185,527	297,975	835,361	1,351,307
2000–2018	38,805	193,857	371,021	1,030,845	1,634,528
Less than 1,000 ft^2	4,227	1,242	433	649	6,551
1,000 to 1,499 ft^2	26,895	61,103	40,988	14,453	143,439
1,500 ft^2 or More	7,683	131,512	329,600	1,015,743	1,484,538
Grand Total	671,683	945,265	1,092,380	2,617,926	5,327,254

Sources: 2018 Florida County Property Appraisers; Shimberg Center for Housing Studies

Affordable Housing Gap

Florida faces an ongoing shortage of affordable housing for low-income households. More than 1.4 million households in the state with incomes below 60 percent of AMI spend more than 40 percent of their income on housing, including one-half of owners and more than two-thirds of renters. The problem is not limited to expensive urban areas of the state. Even in smaller, more rural counties, 40 percent of low-income owners and 53 percent of low-income renters are cost burdened (exhibit 63).

Exhibit 63. Low-Income and Cost-Burdened Households, Florida, 2019

	Owner			Renter		
County Size	Not Cost Burdened	Cost Burdened	Percent Cost Burdened (%)	Not Cost Burdened	Cost Burdened	Percent Cost Burdened (%)
Large (>825,000 population)	274,109	338,143	55	193,072	483,261	71
Medium (100,000–825,000 population)	334,436	270,215	45	148,207	287,975	66
Small (<100,000 population)	38,688	26,289	40	21,538	24,369	53
Total	647,233	634,647	50	362,817	795,605	69

Notes: Low income is 0–60 percent AMI. Cost burdened is greater than 40 percent of income.
Sources: 2019 Rental Market Study; Shimberg Center for Housing Studies

The affordable housing shortage extends to older adults and farmworker households, two groups often served by manufactured housing. Statewide, one-third of low-income, cost-burdened renter households—243,520 households in all—are headed by someone age 55 or older. Florida has an estimated 113,000 farmworkers but only 4,327 subsidized rental units for farm labor (Shimberg Center for Housing Studies, 2020b).

Loss of Lower-Cost Housing Supply

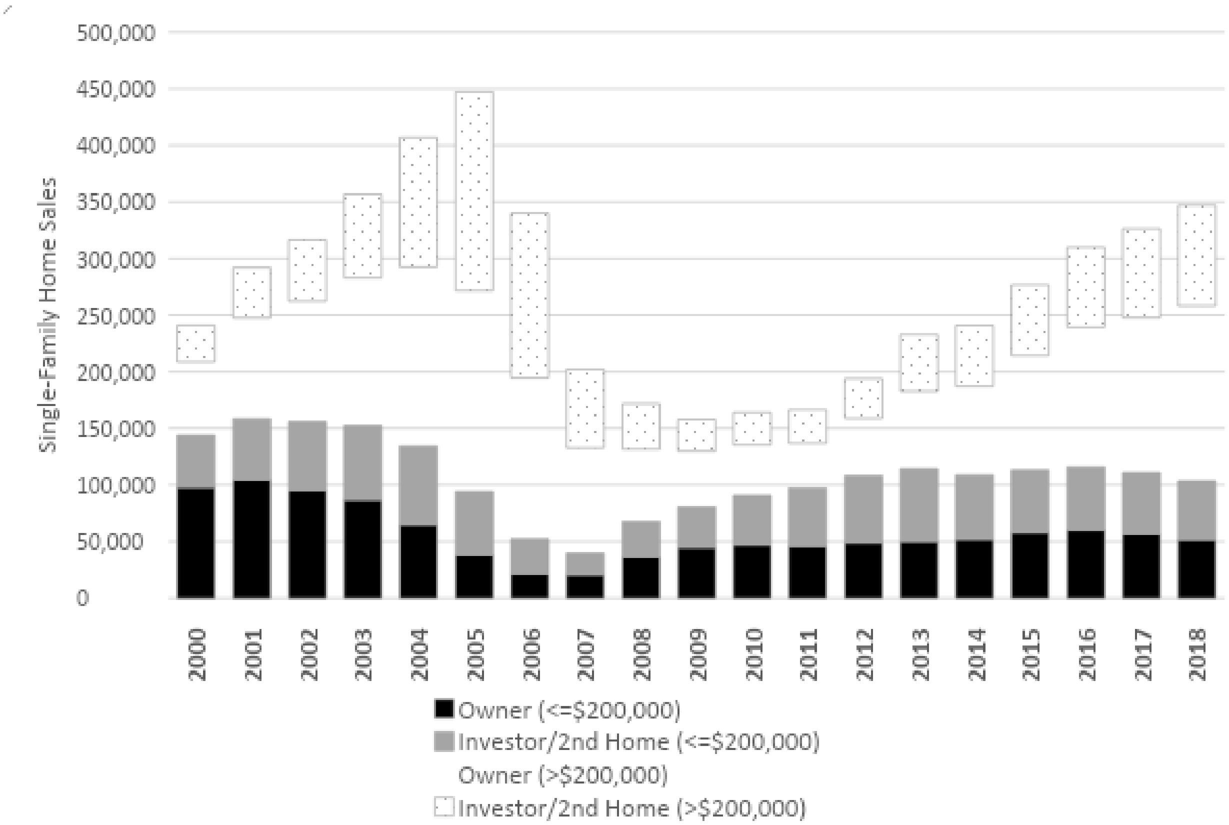
The widening affordable housing gap comes as Florida has been gaining population and losing lower-cost housing units. According to the U.S. Census Bureau, the state's population grew from 16 million people in 2000 to 21.5 million in 2019, while the number of households increased from 6.3 million to 7.9 million (U.S. Census Bureau, 2019).

The population growth, combined with Florida's dramatic housing boom in the mid-2000s, has led to a shrinking supply of lower-cost single-family homes for buyers. Exhibit 64 shows the number of single-family home sales each year from 2000 through 2018. Affordable sales are those with a price of $200,000 or less in 2018 dollars. Homes with a homestead tax exemption in the year after the sale are considered to be owner occupied. In 2000, the most common type of home sale in Florida was the purchase of a relatively affordable house by an owner occupant. Sixty percent of single-family homes sold for $136,000 or less that year, the equivalent of $200,000 in 2018 dollars. More than two-thirds of affordable sales were to owner occupants.

Affordable sales to owners began to fall as the housing market heated up in the early to mid-2000s, while affordable sales to investors and second homebuyers increased. Even more striking was the growth in unaffordable home sales. In 2000, 97,011 homes sold for more than $200,000 in 2018 dollars; in 2005, 353,065 homes sold at these prices.

As prices peaked in 2006, the number of affordable sales dropped dramatically; then, sales of all types dropped from their peak numbers. Total sales began to rise again in 2012, but most of that growth has consisted of unaffordable sales. As a result, the most common outcome is now an unaffordable home sale to an owner. Investor sales remain stronger than their pre-boom levels.

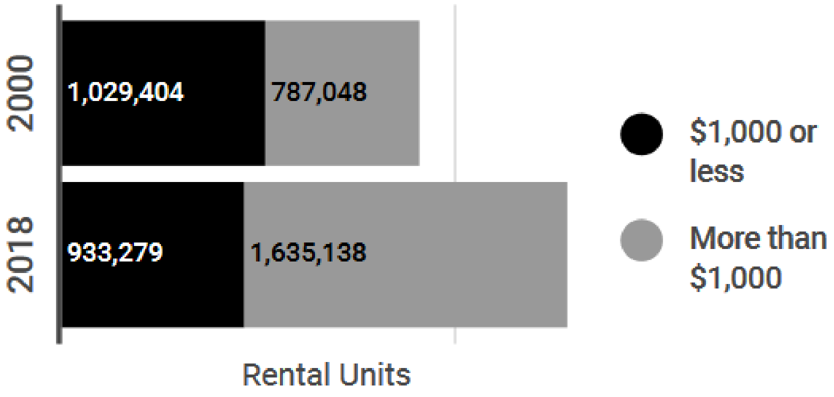
Exhibit 64. Single-Family Home Sales by Affordability and Owner Occupant Status, 2000–2018



Note: Sale prices are in 2017 dollars.
Source: Shimberg Center analysis of Florida Department of Revenue, Sales Data File

Affordable rental units also became scarcer during that time (See exhibit 65). In 2000, most rental units (57 percent) had rents less than $680, equivalent to $1,000 in 2018 dollars. From 2000 to 2018, Florida added 848,090 units with gross rents of more than $1,000 (in 2018 dollars) but lost 96,125 units with rents of $1,000 or less. As a result, the share of units with rents of $1,000 or less fell from 57 percent in 2000 to 36 percent in 2018.

Exhibit 65. Units by Gross Rent Less and More than $1,000 in Florida, 2000 and 2018



Note: Rents are in 2018 dollars.
Sources: 2018 American Community Survey; Shimberg Center analysis of U.S. Census Bureau, 2000 Census

How the AMH Design Product Is a Supply-Side Solution

Manufactured housing provides an affordable homeownership alternative compared with increasingly expensive single-family homes. Other than mobile home parks, one-half of all manufactured housing parcels have received homestead property tax exemptions, indicating that they are owner occupied. The median sales price for a manufactured home in Florida was $81,000 in 2019, compared with $250,000 for a single-family home and $169,900 for a condominium (Shimberg Center for Housing Studies, 2020b).

Manufactured housing also provides a form of naturally occurring affordable housing for renters, but this resource is underutilized in Florida. Statewide, 155,250 renters lived in manufactured housing in 2019, constituting 6 percent of the state's rental stock (U.S. Census Bureau, 2019). By comparison, the state has 285,010 units of subsidized rental housing.

Although small in number, the manufactured housing rental supply provides units that are far more affordable than other market-rate alternatives. The median gross rent for a manufactured housing unit is $722 per month, compared with $1,461 for a single-family home and $1,026–1,340 for multifamily units (U.S. Census Bureau, 2019) . In fact, the $722 median manufactured housing rent is lower than the $904 median gross rent in Florida Housing Finance Corporation's multifamily portfolio, the largest source of subsidized rental housing in the state.

Manufactured housing represents one of the most affordable housing options in Florida. Currently, more than 600,000 households live in manufactured housing across the state. Three-quarters are owner occupied, and 44 percent are 65 years of age or older. Slightly more than one-third of these households have incomes below $32,000. In smaller Florida counties, manufactured housing can represent the primary affordable housing option for renter households because of the relatively small supply of multifamily rental units. Eleven percent of manufactured housing households are renters with incomes under 50 percent of AMI (a HUD-designated income scale), and 24 percent are owners.

The development of AMH design will directly address a key problem for Florida's lower-income homeowners: the high cost of energy consumption and its contribution to the housing cost burden. Housing is usually considered affordable if no more than 30 percent of household income is devoted to housing costs, including utility consumption. In Florida, 727,000 homeowners with annual incomes less than $35,000 pay more than this percentage for their housing, including 414,000 owners with incomes less than $20,000 (U.S. Census Bureau, 2017b).[10]

Multiple Functions: Post-Disaster Temporary, Transitional, and Permanent Housing

More than 2.6 million owner and renter households declared structural damage or all damage with the Federal Emergency Management Agency (FEMA) after Hurricane Irma. Of the more than 2.6 million applicants, 2.1 million were categorized with some sort of damage (including all forms of damage); the vast majority of damage assignments, almost 1.8 million, were considered minor. More than 37,000 applicants were assigned to major or severe (including destroyed) damage categories. The statewide median income at 50 percent AMI was ~$32,000, and 60 percent of the households with major or severe damage had incomes at or less than $30,000. Of these lower-income households, owner households (more than 12,000) represented the majority of damage considered major or severe; renters composed almost 10,000 of these households. Lower-income senior households (<62 years old) composed almost 17 percent of households assigned major or severe damage, with owners the largest share. Finally, of the more than 2.6 million applicants, almost 400,000 requested temporary housing assistance (Shimberg Center for Housing Studies, 2020c).

In all, the affordable housing situation in Florida can be summed as follows—

1. The proportion of cost-burdened households within tenure and income groups is growing.
2. Cost burden is gradually increasing in higher-income categories.
3. Although the decline is small, Florida is experiencing a net loss of affordable rental properties, and the gap between demand for and supply of affordable and available rental units is growing.
4. With the primary exception of the Orlando metro area, most assisted and public multifamily units are located on Florida’s vulnerable coastlines; 73 percent of all assisted multifamily and 75 percent of HUD and Rural Development properties are in Florida’s coastal counties (Shimberg Center for Housing Studies, 2020c).
5. Disasters exacerbate the existing affordable housing problem through a combination of dislocation, physical loss of inventory, and local housing market short- and long-term impacts.

In conclusion, the AMH design can serve multiple functions, namely—

1. As affordable housing: housing prices and incomes have become unhinged, and the affordable housing “crisis” is becoming a permanent structural condition.
2. For post-disaster temporary housing, a transitional, permanent, and resilient housing solution.

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[10] According to the 2017 American Housing Survey, also produced by the Census Bureau, the median annual household income for owners of manufactured/mobile homes in Florida is $29,500.

3. To inform conventional manufactured and modular home design to improve their resilience and sustainability.

With the potential for mass customization, the AMH design can become a game changer in the affordable housing context for Florida and—with modifications to suit other regions and building code—can enable the paradigm transition that is much needed in the manufactured housing industry.

CHAPTER 8. CONCLUSION

This eight-chapter project report commenced with an introduction to the key challenges facing the U.S. housing industry and the need for Advanced Modular Housing (AMH) research in chapter 1. Chapter 2 provided a background of major U.S. hurricanes and the responses from the government and industries. Next, chapter 3 discussed the AMH design methodology and introduced the functional modules of AMH design. Chapter 4 discussed the various energy efficiency measures (EEMs), and chapter 6 discussed the life-cycle costing of Core+ modules. Chapter 7 discussed the characteristics of AMH design home occupants and provided insights into the affordable housing gap and the loss of lower-cost housing supply. In conclusion, chapter 8 discusses how the AMH design can act as a supply-side solution to the housing shortage and for post-disaster housing in Florida.

With collaboration from the modular home manufacturing industry and other stakeholders, the project team from the University of Florida developed the AMH design, the Core+, which comprises three functional units—*Core*, *Space*, and *Dwell*—that addressed the three key challenges facing the U.S. housing industry, namely, resiliency, sustainability, and affordability as well as rapid delivery of large quantities of post-disaster housing. This AMH research project addressed an approach to designing housing that can be rapidly built in factories, withstand weather events, and serve as a community asset. Using a single-family housing type suitable for the southeastern U.S., the AMH design's attributes required for post-disaster housing include appropriate structural strength and construction flexibility (resilience), high levels of energy efficiency, the potential for energy self-sufficiency (sustainability), and selection of equipment (affordability).

This project involved organizing two workshops centered on this post-disaster housing through AMH research and inviting industry leaders (modular home manufacturers, mechanical system and smart control device manufacturers) and other participants from the insurance and finance industry.

In summary, this project resulted in the following—

- The development of a scalable AMH design that focuses on energy efficiency, resilience, and affordability as a post-disaster housing option.
- Creation of Construction Documents (CDs) for the AMH design, including information on solar installation and energy storage system integration, as well as blueprints for the three functional modules Core, Space, and Dwell units.
- A thorough examination of energy systems and the Core+ module's life-cycle costs.
- The housing scarcity and the need for post-disaster housing in Florida may be addressed from the supply-side utilizing AMH design.

In addition to creating a full set of CDs, the project team worked closely with locals in North Port St. Joe, Florida, to address housing issues that may be resolved by the lot owners in the future. Both the modular home production sector and the consumers of their products will welcome the outcome of this post-disaster housing through AMH.A few recommendations are suggested below.

Sustainability, Resiliency, and Affordability as the Fundamental Basis to Modular Housing

Although passive design and energy efficiency are well integrated in modular housing design for future energy self-sufficiency, the challenges of resiliency and affordability are yet to be resolved. The AMH design has shown how all three key challenges facing the U.S. housing industry can be amicably resolved. First, the AMH design is a climate-responsive design coupled with passive energy design strategies to achieve a hyper-energy-efficient building, which, in turn, can be equipped with advanced building systems and renewable energy technologies, including solar and wind power. Second, the AMH design addressed resiliency by strengthening the individual units—the Core being most strong in structural terms—followed by Space and Dwell units. The Core+ unit design meets or exceeds all Florida building code requirements for wind loading, passive heating and cooling strategies, and systems to mitigate extended power failures, and it includes an affordable piling system that allows for easy home elevation at multiple levels to fit the needs of the site. In addition, resiliency is also embedded in this project such that the AMH design can adapt over time. Third, the AMH design mitigated the affordability challenge using life-cycle costing that included energy consumption data. This project demonstrates that this approach can inform conventional and modular home design to improve their sustainability and resiliency.

Functional Units of AMH Design: Utility and Flexibility

Unitization of modular homes to fit the specific functions (utility) and appropriate strengthening to support weather-related disasters is crucial for future-proofing. AMH design has shown how the Core unit is structurally different compared with Space and Dwell units. Besides, adding additional modules as needed provided ample flexibility to home occupants. Such utility and flexibility in modular homes should be built in and available for home occupants to choose. Furthermore, it is recommended that manufacturers embrace mass fabrication yet provide customization options with cost, energy savings, and mortgage interests and payment—essentially, user-friendly and informed selection of modular homes.

AMH Design as Affordable Supply

Utility costs make up a substantial portion of the housing cost burden for low-income households. Average utility costs are only somewhat lower for low-income homeowners than for other households, even though their means to cover these costs are far lower. The median monthly utility expenditure for all homeowners in Florida is $188. Owners with incomes of less than $20,000 pay $132 to $143 per month (U.S. Census Bureau, 2017b). Those utility costs amount to approximately one-fourth of low-income households' median housing cost, ahead of other necessary expenditures, such as property taxes and insurance.

Low-income households are more likely to occupy units with inefficient structural conditions and appliances and are less able to afford one-time investments in EEMs that result in long-term savings (Drehobl and Ross, 2016; Frederiks, Stenner, and Hobman, 2015). To address this challenge, the AMHD team propose that the development of an affordable hyper-efficient product will help level the playing field for these vulnerable households.

In conclusion, we anticipate that the development of AMH design will directly address a key problem for Florida's lower-income homeowners: the high cost of energy consumption and its contribution to the housing cost burden.

APPENDIX A. TABLES

Exhibit 66. Cost Estimate for Fabrication of the Core Unit of the Core+ Modular House

Components	Unit	Core Quantity	Total Quantity	Material (per unit)	Install (per unit)	Total Cost (per unit)	Total Material Cost	Total Install. Cost	Total Cost
Framing									
Exterior wall framing systems, 2" × 6", 16" OC	ft^2	539	539	3.16	2.03	5.19	$1,703	$1,094	$2,797
Gable end roof framing systems, 2" × 12" rafters, 24" OC, 3/12 pitch	ft^2	202	202	6.18	3.34	9.52	$1,248	$675	$1,923
Partition framing systems, 2" × 4", 24" OC	ft^2	97	97	0.99	0.8	1.79	$96	$78	$174
Partition framing systems, 2" × 4", 24" OC loft	ft^2	74	74	0.99	0.8	1.79	$73	$59	$132
Floor framing systems, 2" × 8", 16" OC	ft^2	160	160	5.15	2.64	7.79	$826	$423	$1,249
Floor framing systems, 2" × 6", 16" OC for loft	ft^2	67	67	4.52	2.54	7.06	$303	$170	$473
Exterior walls									

Fiber cement siding, lap siding, smooth texture, 5/16" thick × 6"	ft^2	539	539	1.46	1.49	2.95	$787	$803	$1,590
Non-rigid insul., batts, fbgls, kraft faced, 6" thick, R19, 15" W	ft^2	539	539	0.51	0.28	0.79	$275	$151	$426
Weather barrier, building paper, house wrap, exterior, polypropylene	ft^2	539	539	0.15	0.1	0.25	$81	$54	$135
1" rigid insulation, foil faced, both sides	ft^2	539	539	0.63	0.36	0.99	$339	$194	$533
Gypsum wallboard, wall system, 1/2" thick, taped and finished	ft^2	539	539	1.21	1.23	2.44	$652	$663	$1,315
Windows, fiberglass double-hung, 36" × 60", including grill, low E	each		0	174	33.23	207.23	$0	$0	$0
Windows, fiberglass single-hung, 36" × 60", including grill, low	each		0	190	33.23	223.23	$0	$0	$0

E									
Windows, fiberglass sliding double, 48" × 24", including grill, low E	each	1	1	100	31.66	131.66	$100	$32	$132
Windows, fiberglass sliding double, 36" × 24", including grill, low E	each	1	1	75	30.1	105.1	$75	$30	$105
Windows, fiberglass sliding double, 84" × 24", including grill, low E	each	1	1	175	31.66	206.66	$175	$32	$207
Windows, fiberglass sliding double, 120" × 24", including grill, low E	each		0	250	35	285	$0	$0	$0
Windows, fiberglass sliding double, 60" × 30", including grill, low E	each	1	1	156.25	33.23	189.48	$156	$33	$189
Door, wood, solid core birch, flush, 3' × 6'-8"	each	1	1	531.06	228.48	759.54	$531	$228	$760

Aluminum sliding door, 8' wide premium	each		0	2,238.12	400.99	2639.11	$0	$0	$0
Roofing									
Asphalt roof shingles, class A (including soffit and fascia, gutter and downspout)	SQ	2.02	2.02	228	188	416	$461	$380	$840
Blanket insulation, for ceilings, mineral wool batts, 12" thick, R38	ft^2	202	202	1.15	0.61	1.76	$232	$123	$356
Interiors									
Gypsum wallboard, wall system, 1/2" thick, taped and finished	ft^2	194	194	1.21	1.23	2.44	$235	$239	$473
Gypsum wallboard, wall system, 1/2" thick, taped and finished, loft	ft^2	74	74	1.21	1.23	2.44	$90	$91	$181
Gypsum wallboard, on ceiling, standard, 1/2" thick, taped and finished	ft^2	225	225	0.72	1.81	2.53	$162	$407	$569
Wood pocket door 3' × 6'-8"	each	2	2	606	671	1277	$1,212	$1,342	$2,554

Sliding wood-framed glass door, 8' wide economy	each		0	1,609	202	1811	$0	$0	$0
Bi-passing, flush, birch, hollow core, 4' × 6'-8" closet door	each		0	393.86	273.37	667.23	$0	$0	$0
Bi-passing, flush, birch, hollow core, 6' × 6'-8" closet door	each		0	632.42	324.05	956.47	$0	$0	$0
Lauan, flush door, hollow core, interior, 3' × 6'-8"	each		0	384.62	265.67	650.29	$0	$0	$0
14 risers pine treads stair		1	1	1,400	750	2,150	$1,400	$750	$2,150
LVP flooring	ft^2	143	143	2.73	1.74	4.47	$390	$249	$639
LVP for loft	ft^2	67	67	2.73	1.74	4.47	$183	$117	$299
Specialties									
Sinks, stainless steel, single bowl 16" × 20"	each	1	1	698.28	100.34	798.62	$698	$100	$799
Water heater, residential, electric, 40 gallons	each	1	1	1,543.3	156.6	1,699.9	$1,543	$157	$1,700
Cooking range, residential, 30" wide	each	1	1	505	61.64	566.64	$505	$62	$567

Refrigerator, residential, no frost, 10 to 12 CF, minimum	each	1	1	799	61.64	860.64	$799	$62	$861
Microwave oven, residential	each	1	1	117	115.79	232.79	$117	$116	$233
Dryer, 7.5 cu	each	1	1	799	120	919	$799	$120	$919
Washer, Energy Star, 4.5 cu	each	1	1	719	149.94	868.94	$719	$150	$869
Cabinet, kitchen, base, 2 top drawers, 2 doors below, 24" deep, 35" high, 27" wide	each	3	3	480	49.56	529.56	$1,440	$149	$1,589
Cabinet, kitchen, wall, 2 doors, 12" deep, 30" high, 27" wide	each	3	3	194	54.98	248.98	$582	$165	$747
Countertops, maple, solid, laminated 1.5" thick include backsplash	LF	11	11	117	13	130	$1,287	$143	$1,430
Mechanical									
Three-fixture bathrooms with wall-hung lavatory (includes vanity)	each	1	1	3005	1,497.20	4,502.2	$3,005	$1,497	$4,502
HVAC	each	2	2	950	750.00	1700	$1,900	$1,500	$3,400

Electrical									
200-A electric service	each	1	1	732.43	933.34	1665.77	$732	$933	$1,666
OSTWIN 6" ultra-thin LED	each	5	5	14.06	55.5	69.56	$70	$278	$348
Wiring device system economy	each	160	1,147	0.65	1	1.65	$746	$1,147	$1,893
Total cost of Core unit							$26,727	$14,993	$41,721
Percentages of materials and installation reduction for offsite construction							10%	40%	
Total cost for offsite construction without site work and installation							24,055	8,996	$33,051

CF = cubic feet. cu = cubic. HVAC = heating, ventilation, and air-conditioning. LF = linear feet. low E = low energy. LVP = luxury vinyl plank. OC = on center. SQ = square.

Source: Project team, University of Florida

Exhibit 67. Cost Estimate for Sitework and Installation of the Core Unit of the Core+ Modular House

Components	Unit	Core Quantity	Total Quantity	Total Cost (per unit)	Total Cost
Site work and excavation	ft^2	160	160	1.6	$257
Concrete footing 10" thick by 20"	ft^2	160	160	2.28	$366

wide					
Block wall system 8" thick 32" high grouted full height	ft^2	160	160	4.78	$766
Transportation less than 12' wide within 100 km	LS				$500
Crane to install (simple lift)	LS				$800
Connection to the foundation	LS				$500
PVC draining under home and misc. plumbing	ft^2	160	160	3.00	$481
Electrical services	ft^2	160	160	2.85	$457
Miscellaneous (permits, survey, dumpsters, etc.)	LS				$1,000
Total cost for site work and installation					$5,127
GC fee for site work and installation	%	20	20		$1,025
Total cost for fabrication, installation, and site work of Core unit					$39,202
Cost per ft^2 for fabrication, installation, and site work of Core unit					$244.50

GC = general contractor. LS = lump sum.
Source: Project team, University of Florida

Exhibit 68. Cost Estimate for Fabrication of the Core and Space Units of the Core+ Modular House

Components	Unit	Core Quantity	Space Quantity	Total Quantity	Material (per unit)	Install. (per unit)	Total Cost (per unit)	Total Material Cost	Total Install Cost	Total Cost
Framing										
Exterior wall framing systems, 2" × 6", 16" OC	ft^2	539	391	930	3.16	2.03	5.19	$2,938	$1,887	$4,825
Gable end roof framing systems, 2" × 12" rafters, 24" OC, 3/12 pitch	ft^2	202	237	439	6.18	3.34	9.52	$2,712	$1,466	$4,178
Partition framing systems, 2" × 4", 24" OC	ft^2	97		97	0.99	0.8	1.79	$96	$78	$174
Partition framing systems, 2" × 4", 24" OC loft	ft^2	74		74	0.99	0.8	1.79	$73	$59	$132

Floor framing systems, 2" × 8", 16" OC	**ft^2**	**160**	**193**	**353**	**5.15**	**2.64**	**7.79**	**$1,819**	**$933**	**$2,752**
Floor framing systems, 2" × 6", 16" OC for loft	ft^2	67		67	4.52	2.54	7.06	$303	$170	$473
Exterior walls										
Fiber cement siding, lap siding, smooth texture, 5/16" thick × 6"	ft^2	539	391	930	1.46	1.49	2.95	$1,357	$1,385	$2,743
Non-rigid insul., batts, fbgls, kraft faced, 6" thick, R19, 15" W	ft^2	539	391	930	0.51	0.28	0.79	$474	$260	$734
Weather barrier, building paper, house wrap, exterior, polypropylene	ft^2	539	391	930	0.15	0.1	0.25	$139	$93	$232
1" rigid insulation, foil faced, both	ft^2	539	391	930	0.63	0.36	0.99	$586	$335	$920

sides										
Gypsum wallboard, wall system, 1/2" thick, taped and finished	ft^2	539	391	930	1.21	1.23	2.44	$1,125	$1,144	$2,269
Windows, fiberglass double-hung, 36" × 60", including grill, low E	each		2	2	174	33.23	207.23	$348	$66	$414
Windows, fiberglass single-hung, 36" × 60", including grill, low E	each		2	2	190	33.23	223.23	$380	$66	$446
Windows, fiberglass sliding double, 48" × 24", including grill, low E	each	1		1	100	31.66	131.66	$100	$32	$132
Windows, fiberglass sliding double, 36" × 24", including	each	1	2	3	75	30.1	105.1	$225	$90	$315

grill, low E										
Windows, fiberglass sliding double, 84" × 24", including grill, low E	each	1		1	175	31.66	206.66	$175	$32	$207
Windows, fiberglass sliding double, 120" × 24", including grill, low E	each		1	1	250	35	285	$250	$35	$285
Windows, fiberglass sliding double, 60" × 30", including grill, low E	each	1		1	156	33	189	$156	$33	$189
Door, wood, solid core birch, flush, 3' × 6'-8"	each	1	1	2	531	228	760	$1,062	$457	$1,519
Aluminum sliding door, 8' wide premium	each			0	2,238	401	2,639	$0	$0	$0
Roofing										

Asphalt roof shingles class A (including soffit and fascia, gutter and downspout)	SQ	2.02	2.37	4.39	228	188	416	\$1,001	\$825	\$1,826
Blanket insulation, for ceilings, mineral wool batts, 12" thick, R38	ft^2	202	237	439	1.15	0.61	1.76	\$505	\$268	\$772
Interiors										
Gypsum wallboard, wall system, 1/2" thick, taped and finished	ft^2	194		194	1.21	1.23	2.44	\$235	\$239	\$473
Gypsum wallboard, wall system, 1/2" thick, taped and finished, loft	ft^2	74		74	1.21	1.23	2.44	\$90	\$91	\$181
Gypsum wallboard, on ceiling, standard, 1/2"	ft^2	225	172	397	0.72	1.81	2.53	\$286	\$719	\$1,004

thick, taped and finished										
Wood pocket door, 3' × 6'-8"	each	2		2	606	671	1,277	$1,212	$1,342	$2,554
Sliding wood-framed glass door, 8' wide economy	each			0	1,609	202	1,811	$0	$0	$0
Bi-passing, flush, birch, hollow core, 4' × 6'-8" closet door	each			0	394	273	667	$0	$0	$0
Bi-passing, flush, birch, hollow core, 6' × 6'-8" closet door	each			0	632	324	956	$0	$0	$0
Lauan, flush door, hollow core, interior, 3' × 6'-8"	each			0	385	266	650	$0	$0	$0
14 risers pine treads stair		1		1	1,400	750	2,150	$1,400	$750	$2,150
LVP flooring	ft^2	143	165	308	2.73	1.74	4.47	$841	$536	$1,377
LVP for loft	ft^2	67		67	2.73	1.74	4.47	$183	$117	$299
Specialties										

Sinks, stainless steel, single bowl, 16" × 20"	each	1		1	698	100	799	$698	$100	$799
Water heater, residential, electric, 40 gallon	each	1		1	1,543	157	1,700	$1,543	$157	$1,700
Cooking range, residential, 30" wide	each	1		1	505	62	567	$505	$62	$567
Refrigerator, residential, no frost, 10 to 12 CF, minimum	each	1		1	799	62	861	$799	$62	$861
Microwave ovens, residential	each	1		1	117	116	233	$117	$116	$233
Dryer, 7.5 cu	each	1		1	799	120	919	$799	$120	$919
Washer, Energy Star, 4.5 cu	each	1		1	719	150	869	$719	$150	$869
Cabinet, kitchen, base, 2 top drawers, 2 doors below, 24" deep, 35"	each	3		3	480	50	530	$1,440	$149	$1,589

high, 27" wide										
Cabinet, kitchen, wall, 2 doors, 12" deep, 30" high, 27" wide	each	3		3	194	55	249	$582	$165	$747
Countertops, maple, solid, laminated 1.5" thick include backsplash	LF	11		11	117	13	130	$1,287	$143	$1,430
Mechanical										
Three-fixture bathroom with wall-hung lavatory (includes vanity)	each	1		1	3,005	1,497	4,502	$3,005	$1,497	$4,502
HVAC	each	2	1	3	950	750	1,700	$2,850	$2,250	$5,100
Electrical										
200-A electric service	each	1		1	732	933	1,666	$732	$933	$1,666
OSTWIN 6" ultra-thin LED	each	5	4	9	14	56	70	$127	$500	$626
Wiring device	each	160	193	1147	0.65	1	1.65	$746	$1,147	$1,893

system economy										
Total cost for Core and Space								$36,021	$21,057	$57,078
Percentages of materials and installation reduction for offsite construction								10%	40%	
Total cost for offsite construction without site work and installation								32,419	12,634	$45,053

CF = cubic feet. cu = cubic. HVAC = heating, ventilation, and air-conditioning. LF = linear feet. low E = low-energy. LVP. = luxury vinyl plank. OC = on center. SQ = square.
Source: Project team, University of Florida

Exhibit 69. Cost Estimate for Sitework and Installation of the Core and Space Units of the Core+ Modular House

Components	Unit	Core Quantity	Space Quantity	Total Quantity	Total Cost (per unit)	Total Cost
Site work and excavation	ft^2	160	193	353	1.6	$565
Concrete footing, 10" thick by 20" wide	ft^2	160	193	353	2.28	$806
Block wall system, 8" thick by 32" high, grouted, full height	ft^2	160	193	353	4.78	$1,689
Transportation less than 12' wide within 100 km	LS					$1,000
Crane to install (simple lift)	LS					$1,000
Connection of units	LS					$1,000
PVC draining under home and misc. plumbing	ft^2	160	193	353	3.00	$1,060
Electrical services	ft^2	160	193	353	2.85	$1,007
Miscellaneous (permits, survey, dumpsters, etc.)	LS					$1,500
Total cost for site work and installation						$9,626
GC fee for site work and installation	20%					$1,925
Total cost for fabrication, installation, and site work of Core and Space units						$56,604
Cost per ft^2 for fabrication, installation, and site work of Core and Space units						$160.22

GC = general contractor. LS = lump sum.
Source: Project team, University of Florida

Exhibit 70. Cost Estimate for Fabrication of the Core+ Modular House

Components	Unit	Core Quantity	Space Quantity	Dwell Quantity	Total Quantity	Material (per unit)	Install (per unit)	Total Cost (per unit)	Total Material Cost	Total Install Cost	Total Cost
Framing											
Exterior wall framing systems, 2" × 6" wood studs, 16" OC	ft^2	539	391	1,230	2,160	3.16	2.03	5.19	$6,825	$4,384	$11,209
Gable end roof framing systems, 2" × 12" rafters, 24" OC, 3/12 pitch	ft^2	202	237	900	1,339	6.18	3.34	9.52	$8,273	$4,471	$12,745
Partition framing systems, 2" × 4" wood studs, 24" OC	ft^2	97		756	853	0.99	0.8	1.79	$844	$682	$1,527
Partition framing systems, 2" × 4", 24" OC loft	ft^2	74			74	0.99	0.8	1.79	$73	$59	$132
Floor framing systems, 2" × 8" floor joists, 16" OC	ft^2	160	193	794	1,147	5.15	2.64	7.79	$5,909	$3,029	$8,938
Floor framing systems, 2" × 6" floor joists, 16" OC for loft	ft^2	67			67	4.52	2.54	7.06	$303	$170	$473
Exterior walls											
Fiber cement siding, lap siding, smooth texture, 5/16" thick by 6" wide	ft^2	539	391	1,230	2,160	1.46	1.49	2.95	$3,153	$3,218	$6,371

Non-rigid insul., batts, fbgls, kraft faced, 6" thick, R19, 15" W	**ft^2**	**539**	**391**	**1,230**	**2,160**	**0.51**	**0.28**	**0.79**	**$1,101**	**$605**	**$1,706**
Weather barrier, building paper, house wrap, exterior, polypropylene	ft^2	539	391	1,230	2,160	0.15	0.1	0.25	$324	$216	$540
1" rigid insulation, foil faced, both sides	ft^2	539	391	1,230	2,160	0.63	0.36	0.99	$1,361	$778	$2,138
Gypsum wallboard, wall system, 1/2" thick, taped and finished	ft^2	539	391	1,230	2,160	1.21	1.23	2.44	$2,613	$2,656	$5,270
Windows, fiberglass double-hung, 36" × 60", including grill, low E	each		2		2	174	33.23	207.23	$348	$66	$414
Windows, fiberglass single-hung, 36" × 60", including grill, low E	each		2	12	14	190	33.23	223.23	$2,660	$465	$3,125
Windows, fiberglass sliding double, 48" × 24", including grill, low E	each	1			1	100	31.66	131.66	$100	$32	$132
Windows, fiberglass sliding double, 36" × 24", including grill, low E	each	1	2		3	75	30.1	105.1	$225	$90	$315
Windows, fiberglass sliding double, 84" × 24", including grill, low E	each	1		3	4	175	31.66	206.66	$700	$127	$827
Windows, fiberglass sliding double, 120" ×	each		1		1	250	35	285	$250	$35	$285

24", including grill, low E											
Windows, fiberglass sliding double, 60" × 30", including grill, low E	each	1			1	156.25	33.23	189.48	$156	$33	$189
Door, wood, solid core birch, flush, 3' × 6'-8"	each	1	1		2	531.06	228.48	759.54	$1,062	$457	$1,519
Aluminum sliding door, 8' wide premium	each			1	1	2,238.12	400.99	2,639.11	$2,238	$401	$2,639
Roofing											
Asphalt roof shingles, class A (including soffit and fascia, gutter and downspout)	SQ	2.02	2.37	9.00	13.39	228	188	416	$3,053	$2,517	$5,570
Blanket insulation, for ceilings, mineral wool batts, 12" thick, R38	ft^2	202	237	900	1,339	1.15	0.61	1.76	$1,540	$817	$2,356
Interiors											
Gypsum wallboard, wall system, 1/2" thick, taped and finished	ft^2	194		1,511	1,705	1.21	1.23	2.44	$2,063	$2,097	$4,160
Gypsum wallboard, wall system, 1/2" thick, taped and finished, loft	ft^2	74			74	1.21	1.23	2.44	$90	$91	$181
Gypsum wallboard, on ceiling, standard, 1/2" thick, taped and finished	ft^2	225	172	625	1,022	0.72	1.81	2.53	$736	$1,850	$2,586
Wood pocket door, 3' × 6'-	each	2			2	606	671	1277	$1,212	$1,342	$2,554

8"											
Sliding wood-framed glass door, 8’ wide economy	each			1	1	1,609	202	1,811	$1,609	$202	$1,811
Bi-passing, flush, birch, hollow core, 4' × 6'-8" closet door	each			2	2	393.86	273.37	667.23	$788	$547	$1,334
Bi-passing, flush, birch, hollow core, 6' × 6'-8" closet door	each			1	1	632.42	324.05	956.47	$632	$324	$956
Lauan, flush door, hollow core, interior, 3' × 6'-8"	each			4	4	384.62	265.67	650.29	$1,538	$1,063	$2,601
14 risers pine treads stair		1			1	1,400	750	2,150	$1,400	$750	$2,150
LVP flooring	ft^2	143	165	729	1,037	2.73	1.74	4.47	$2,831	$1,804	$4,635
LVP for loft	ft^2	67			67	2.73	1.74	4.47	$183	$117	$299
Specialties											
Sinks, stainless steel, single bowl 16" × 20"	each	1			1	698.28	100.34	798.62	$698	$100	$799
Water heater, residential, electric, 40 gallon	each	1			1	1,543.3	156.6	1,699.9	$1,543	$157	$1,700
Cooking range, residential, 30" wide	each	1			1	505	61.64	566.64	$505	$62	$567
Refrigerator, residential, no frost, 10 to 12 CF, minimum	each	1			1	799	61.64	860.64	$799	$62	$861
Microwave oven,	each	1			1	117	115.79	232.79	$117	$116	$233

residential											
Dryer, 7.5 ft^3	each	1			1	799	120	919	$799	$120	$919
Washer, Energy Star, 4.5 ft^3	each	1			1	719	149.94	868.94	$719	$150	$869
Cabinet, kitchen, base, 2 top drawers, 2 doors below, 24" deep, 35" high, 27" wide	each	3			3	480	49.56	529.56	$1,440	$149	$1,589
Cabinet, kitchen, wall, 2 doors, 12" deep, 30" high, 27" wide	each	3			3	194	54.98	248.98	$582	$165	$747
Countertops, maple, solid, laminated 1.5" thick, include backsplash	LF	11			11	117	13	130	$1,287	$143	$1,430
Mechanical											
Three-fixture bathroom with wall-hung lavatory (includes vanity)	each	1		1	2	3,005	1,497.20	4,502.2	$6,010	$2,994	$9,004
HVAC	each	1		3	4	1440	1,030.00	2,470	$5,760	$4,120	$9,880
Electrical											
200-A electric service	each	1			1	732.43	933.34	1,665.77	$732	$933	$1,666
OSTWIN 6" ultra-thin LED	each	5	4	12	21	14.06	55.5	69.56	$295	$1,166	$1,461
Wiring device system, economy	each	160	193	794	1,147	0.65	1	1.65	$746	$1,147	$1,893
Total cost of Core+									$78,227	$47,079	$125,306

Percentages of materials and installation reduction for offsite construction									10%	40%	
Total cost for offsite construction without site work and installation									70,404	28,247	$98,652

CF = cubic feet. cu = cubic. HVAC = heating, ventilation, and air-conditioning. LF = linear feet. low E = low-energy. LVP = luxury vinyl plank. OC = on center. SQ = square.

Source: Project team, University of Florida

Exhibit 71. Cost Estimate for Sitework and Installation of the Core+ Modular House

Components	Unit	Core Quantity	Space Quantity	Dwell Quantity	Total Quantity	Total Cost (per unit)	Total Cost
Site work and excavation	ft^2	160	193	794	1,147	1.6	$1,836
Concrete footing 10" thick by 20" wide	ft^2	160	193	794	1,147	2.28	$2,616
Block wall system 8" thick 32" high grouted full height	ft^2	160	193	794	1,147	4.78	$5,484
Transportation less than 12' wide within 100 km	LS						$1,700
Crane to install (simple lift)	LS						$2,500
Connection of the units	LS						$2,000
PVC draining under home and misc. plumbing	ft^2	160	193	794	1,147	3.00	$3,442
Electrical services	ft^2	160	193	794	1,147	2.85	$3,270
Miscellaneous (permits, survey, dumpsters, etc.)	LS						$2,500
Total cost for site work and installation							$25,348
GC fee for site work and installation	20%						$5,070
Total cost for fabrication, installation, and site work							$129,070

Components	Unit	Core Quantity	Space Quantity	Dwell Quantity	Total Quantity	Total Cost (per unit)	Total Cost
of the Core+ unit							
Cost per ft^2 for fabrication, installation, and site work of the Core+ unit							$112.49

GC = general contractor. LS = lump sum.
Source: Project team, University of Florida

Exhibit 72. Life-Cycle Cost Analysis for the Core+ Modular House with an Electric Water Heater

Year	Loan Payment	Down Payment	Replacement Cost	Maintenance	Energy Consumption	Electricity Cost	Annual Energy Cost	Total Annual Cost	NP of Annual Cost	Accrued NP of Total Cost
	($)	($)	($)	($)	(kWh/year)	($/kWh)	($)	($)	($)	($)
0		(7,652)		(17)		0.13		(7,652)	(7,652)	(7,652)
1	(9,458)			(17)	12,474	0.13	(1,670)	(11,145)	(10,874)	(18,526)
2	(9,458)			(18)	12,599	0.14	(1,738)	(11,213)	(10,673)	(29,198)
3	(9,458)			(18)	12,725	0.14	(1,808)	(11,283)	(10,478)	(39,676)
4	(9,458)			(18)	12,852	0.15	(1,880)	(11,357)	(10,288)	(49,965)
5	(9,458)			(18)	12,980	0.15	(1,956)	(11,433)	(10,105)	(60,069)
6	(9,458)			(19)	13,110	0.16	(2,035)	(11,512)	(9,927)	(69,996)
7	(9,458)			(19)	13,241	0.16	(2,117)	(11,594)	(9,754)	(79,750)
8	(9,458)			(19)	13,374	0.16	(2,202)	(11,680)	(9,586)	(89,336)
9	(9,458)			(20)	13,508	0.17	(2,291)	(11,769)	(9,424)	(98,759)
10	(9,458)		(1,700)	(20)	13,643	0.17	(2,383)	(13,561)	(10,594)	(109,354)
11	(9,458)			(20)	13,779	0.18	(2,480)	(11,958)	(9,114)	(118,467)
12	(9,458)			(21)	13,917	0.19	(2,579)	(12,058)	(8,966)	(127,433)
13	(9,458)			(21)	14,056	0.19	(2,683)	(12,162)	(8,823)	(136,256)
14	(9,458)			(22)	14,197	0.20	(2,792)	(12,271)	(8,685)	(144,941)
15	(9,458)			(22)	14,339	0.20	(2,904)	(12,384)	(8,551)	(153,491)
16	(9,458)			(22)	14,482	0.21	(3,021)	(12,501)	(8,421)	(161,912)
17	(9,458)			(23)	14,627	0.21	(3,143)	(12,623)	(8,296)	(170,208)
18	(9,458)			(23)	14,773	0.22	(3,270)	(12,750)	(8,175)	(178,384)
19	(9,458)			(23)	14,921	0.23	(3,401)	(12,883)	(8,058)	(186,442)
20	(9,458)		(1,700)	(24)	15,070	0.23	(3,538)	(14,720)	(8,983)	(195,425)
21	(9,458)			(24)	15,221	0.24	(3,681)	(13,163)	(7,837)	(203,262)
22	(9,458)			(25)	15,373	0.25	(3,829)	(13,312)	(7,732)	(210,995)
23	($,458)			(25)	15,527	0.26	(3,984)	(13,467)	(7,631)	(218,626)
24	(9,458)			(25)	15,682	0.26	(4,144)	(13,627)	(7,534)	(226,160)
25	(9,458)			(26)	15,839	0.27	(4,311)	(13,795)	(7,441)	(233,601)

26	(9,458)			(26)	15,997	0.28	(4,485)	(13,969)	(7,351)	(240,952)
27	(9,458)			(27)	16,157	0.29	(4,666)	(14,150)	(7,265)	(248,217)
28	(9,458)			(27)	16,319	0.30	(4,854)	(14,339)	(7,182)	(255,399)
29	(9,458)			(28)	16,482	0.31	(5,049)	(14,535)	(7,103)	(262,502)
30	(9,458)			(28)	16,647	0.32	(5,253)	(14,739)	(7,027)	(269,528)

NP = net price.

Source: Project team, University of Florida

Exhibit 73. Life-Cycle Cost Analysis for the Core+ Modular House with a Solar Water Heater

Year	Loan Payment	Down Payment	Replacement Cost	Maintenance Cost	Electricity Consumption	Electricity Cost	Annual Electricity Cost	Total Annual Cost	NP of Annual Cost	Accrued NP of Total Cost
	($)	($)	($)	($)	(kWh/year)	($/kWh)	($)	($)	($)	($)
0		(7,777)		(42)		0.13		(7,777)	(7,777)	(7,777)
1	(9,612)			(43)	10,771	0.13	(1,442)	(11,097)	(10,827)	(18,604)
2	(9,612)			(43)	10,879	0.14	(1,500)	(11,156)	(10,619)	(29,222)
3	(9,612)			(44)	10,987	0.14	(1,561)	(11,217)	(10,416)	(39,639)
4	(9,612)			(45)	11,097	0.15	(1,624)	(11,281)	(10,220)	(49,859)
5	(9,612)			(46)	11,208	0.15	(1,689)	(11,347)	(10,029)	(59,888)
6	(9,612)			(46)	11,320	0.16	(1,757)	(11,416)	(9,844)	(69,732)
7	(9,612)			(47)	11,434	0.16	(1,828)	(11,488)	(9,664)	(79,396)
8	(9,612)			(48)	11,548	0.16	(1,902)	(11,562)	(9,490)	(88,886)
9	(9,612)			(49)	11,663	0.17	(1,978)	(11,640)	(9,320)	(98,206)
10	(9,612)			(50)	11,780	0.17	(2,058)	(11,720)	(9,156)	(107,362)
11	(9,612)			(51)	11,898	0.18	(2,141)	(11,804)	(8,996)	(116,358)
12	(9,612)			(51)	12,017	0.19	(2,227)	(11,891)	(8,842)	(125,200)
13	(9,612)			(52)	12,137	0.19	(2,317)	(11,982)	(8,692)	(133,892)
14	(9,612)			(53)	12,258	0.20	(2,410)	(12,076)	(8,547)	(142,438)
15	(9,612)		(4,200)	(54)	12,381	0.20	(2,508)	(16,374)	(11,306)	(153,744)
16	(9,612)			(55)	12,505	0.21	(2,609)	(12,276)	(8,269)	(162,014)
17	(9,612)			(56)	12,630	0.21	(2,714)	(12,382)	(8,137)	(170,151)
18	(9,612)			(57)	12,756	0.22	(2,823)	(12,492)	(8,010)	(178,161)
19	(9,612)			(58)	12,884	0.23	(2,937)	(12,607)	(7,886)	(186,047)
20	(9,612)			(59)	13,013	0.23	(3,055)	(12,726)	(7,767)	(193,813)
21	(9,612)			(60)	13,143	0.24	(3,178)	(12,851)	(7,651)	(201,465)
22	(9,612)			(61)	13,274	0.25	(3,306)	(12,980)	(7,539)	(209,004)
23	(9,612)			(62)	13,407	0.26	(3,440)	(13,114)	(7,432)	(216,436)
24	(9,612)			(63)	13,541	0.26	(3,578)	(13,254)	(7,328)	(223,763)
25	(9,612)			(64)	13,676	0.27	(3,723)	(13,399)	(7,227)	(230,991)

26	(9,612)			(65)	13,813	0.28	(3,873)	(13,550)	(7,131)	(238,121)
27	(9,612)			(66)	13,951	0.29	(4,029)	(13,707)	(7,037)	(245,158)
28	(9,612)			(67)	14,091	0.30	(4,191)	(13,871)	(6,948)	(252,106)
29	(9,612)			(68)	14,232	0.31	(4,360)	(14,041)	(6,861)	(258,967)
30	(9,612)			(70)	14,374	0.32	(4,536)	(14,218)	(6,778)	(265,745)

NP = net price.

Source: Project team, University of Florida

Exhibit 74. Comparison of Life-Cycle Cost of Electric and Solar Water Heaters

	Accrued NP of Total Cost	
Year	Electric WH ($)	Solar WH ($)
0	(7,652)	(7,777)
1	(18,526)	(18,604)
2	(29,198)	(29,222)
3	(39,676)	(39,639)
4	(49,965)	(49,859)
5	(60,069)	(59,888)
6	(69,996)	(69,732)
7	(79,750)	(79,396)
8	(89,336)	(88,886)
9	(98,759)	(98,206)
10	(109,354)	(107,362)
11	(118,467)	(116,358)
12	(127,433)	(125,200)
13	(136,256)	(133,892)
14	(144,941)	(142,438)
15	(153,491)	(153,744)
16	(161,912)	(162,014)
17	(170,208)	(170,151)
18	(178,384)	(178,161)
19	(186,442)	(186,047)
20	(195,425)	(193,813)
21	(203,262)	(201,465)
22	(210,995)	(209,004)
23	(218,626)	(216,436)
24	(226,160)	(223,763)
25	(233,601)	(230,991)
26	(240,952)	(238,121)
27	(248,217)	(245,158)
28	(255,399)	(252,106)
29	(262,502)	(258,967)
30	(269,528)	(265,745)

NP = net price. WH = water heater.
Source: Project team, University of Florida

Exhibit 75. Life-Cycle Cost Analysis for the Core+ Modular House with a 14 SEER Air-Conditioner

Year	Loan Payment	Down Payment	Replacement Cost	Maintenance Cost	Electricity Consumption	Electricity Cost	Annual Electricity Cost	Total Annual Cost	NP of Annual Cost	Accrued NP of Total Cost
	($)	($)	($)	($)	(kWh/year)	($/kWh)	($)	($)	($)	($)
0		(7,652)		(100)		0.13		(7,652)	(7,652)	(7,652)
1	(9,458)			(101)	12,474	0.13	(1,670)	(11,230)	(10,956)	(18,608)
2	(9,458)			(103)	12,599	0.14	(1,738)	(11,299)	(10,754)	(29,362)
3	(9,458)			(105)	12,725	0.14	(1,808)	(11,370)	(10,559)	(39,921)
4	(9,458)			(107)	12,852	0.15	(1,880)	(11,445)	(10,369)	(50,289)
5	(9,458)			(109)	12,980	0.15	(1,956)	(11,523)	(10,184)	(60,474)
6	(9,458)			(110)	13,110	0.16	(2,035)	(11,603)	(10,006)	(70,479)
7	(9,458)			(112)	13,241	0.16	(2,117)	(11,687)	(9,832)	(80,311)
8	(9,458)			(114)	13,374	0.16	(2,202)	(11,774)	(9,664)	(89,975)
9	(9,458)			(116)	13,508	0.17	(2,291)	(11,865)	(9,501)	(99,476)
10	(9,458)			(118)	13,643	0.17	(2,383)	(11,959)	(9,343)	(108,819)
11	(9,458)			(120)	13,779	0.18	(2,480)	(12,058)	(9,190)	(118,009)
12	(9,458)			(122)	13,917	0.19	(2,579)	(12,160)	(9,041)	(127,050)
13	(9,458)			(124)	14,056	0.19	(2,683)	(12,266)	(8,898)	(135,947)
14	(9,458)			(126)	14,197	0.20	(2,792)	(12,376)	(8,759)	(144,706)
15	(9,458)		(9,980)	(129)	14,339	0.20	(2,904)	(22,470)	(15,515)	(160,221)
16	(9,458)			(131)	14,482	0.21	(3,021)	(12,610)	(8,494)	(168,715)
17	(9,458)			(133)	14,627	0.21	(3,143)	(12,734)	(8,368)	(177,084)
18	(9,458)			(135)	14,773	0.22	(3,270)	(12,863)	(8,247)	(185,331)
19	(9,458)			(137)	14,921	0.23	(3,401)	(12,997)	(8,130)	(193,461)
20	(9,458)			(140)	15,070	0.23	(3,538)	(13,136)	(8,017)	(201,477)
21	(9,458)			(142)	15,221	0.24	(3,681)	(13,281)	(7,907)	(209,385)
22	(9,458)			(145)	15,373	0.25	(3,829)	(13,432)	(7,802)	(217,187)
23	(9,458)			(147)	15,527	0.26	(3,984)	(13,589)	(7,701)	(224,887)
24	(9,458)			(150)	15,682	0.26	(4,144)	(13,752)	(7,603)	(232,490)
25	(9,458)			(152)	15,839	0.27	(4,311)	(13,921)	(7,509)	(239,999)

26	(9,458)			(155)	15,997	0.28	(4,485)	(14,097)	(7,419)	(247,418)
27	(9,458)			(157)	16,157	0.29	(4,666)	(14,281)	(7,332)	(254,749)
28	(9,458)			(160)	16,319	0.30	(4,854)	(14,472)	(7,248)	(261,998)
29	(9,458)			(163)	16,482	0.31	(5,049)	(14,670)	(7,169)	(269,167)
30	(9,458)			(165)	16,647	0.32	(5,253)	(14,876)	(7,092)	(276,259)

NP = net price.

Source: Project team, University of Florida

Exhibit 76. Life-Cycle Cost Analysis for the Core+ Modular House with a 17 SEER Air-Conditioner

Year	Loan Payment	Down Payment	Replacement Cost	Maintenance Cost	Electricity Consumption	Electricity Cost	Annual Electricity Cost	Total Annual Cost	NP of Annual Cost	Accrued NP of Total Cost
	($)	($)	($)	($)	(kWh/year)	($/kWh)	($)	($)	($)	($)
0		(7,682)		(105)		0.13		(7,682)	(7,682)	(7,682)
1	(9,495)			(107)	12,175	0.13	(1,630)	(11,232)	(10,958)	(18,640)
2	(9,495)			(108)	12,297	0.14	(1,696)	(11,299)	(10,755)	(29,395)
3	(9,495)			(110)	12,420	0.14	(1,764)	(11,369)	(10,558)	(39,952)
4	(9,495)			(112)	12,544	0.15	(1,835)	(11,442)	(10,366)	(50,319)
5	(9,495)			(114)	12,669	0.15	(1,909)	(11,518)	(10,181)	(60,499)
6	(9,495)			(116)	12,796	0.16	(1,986)	(11,597)	(10,000)	(70,500)
7	(9,495)			(118)	12,924	0.16	(2,066)	(11,679)	(9,825)	(80,325)
8	(9,495)			(120)	13,053	0.16	(2,150)	(11,765)	(9,656)	(89,981)
9	(9,495)			(122)	13,184	0.17	(2,236)	(11,853)	(9,491)	(99,472)
10	(9,495)			(124)	13,316	0.17	(2,326)	(11,945)	(9,332)	(108,803)
11	(9,495)			(126)	13,449	0.18	(2,420)	(12,041)	(9,177)	(117,981)
12	(9,495)			(128)	13,583	0.19	(2,518)	(12,141)	(9,027)	(127,008)
13	(9,495)			(130)	13,719	0.19	(2,619)	(12,245)	(8,882)	(135,890)
14	(9,495)			(133)	13,856	0.20	(2,725)	(12,352)	(8,742)	(144,633)
15	(9,495)		(10,480)	(135)	13,995	0.20	(2,834)	(22,944)	(15,842)	(160,475)
16	(9,495)			(137)	14,135	0.21	(2,949)	(12,581)	(8,475)	(168,950)
17	(9,495)			(140)	14,276	0.21	(3,068)	(12,702)	(8,348)	(177,297)
18	(9,495)			(142)	14,419	0.22	(3,191)	(12,828)	(8,225)	(185,522)
19	(9,495)			(144)	14,563	0.23	(3,320)	(12,959)	(8,106)	(193,629)
20	(9,495)			(147)	14,709	0.23	(3,454)	(13,095)	(7,992)	(201,620)
21	(9,495)			(149)	14,856	0.24	(3,593)	(13,237)	(7,881)	(209,501)
22	(9,495)			(152)	15,004	0.25	(3,737)	(13,384)	(7,774)	(217,276)
23	(9,495)			(154)	15,154	0.26	(3,888)	(13,538)	(7,672)	(224,947)
24	(9,495)			(157)	15,306	0.26	(4,045)	(13,697)	(7,573)	(232,520)
25	(9,495)			(160)	15,459	0.27	(4,208)	(13,863)	(7,477)	(239,997)

26	(9,495)			(162)	15,614	0.28	(4,377)	(14,035)	(7,386)	(247,383)
27	(9,495)			(165)	15,770	0.29	(4,554)	(14,214)	(7,297)	(254,680)
28	(9,495)			(168)	15,927	0.30	(4,737)	(14,400)	(7,213)	(261,893)
29	(9,495)			(171)	16,087	0.31	(4,928)	(14,594)	(7,132)	(269,025)
30	(9,495)			(174)	16,248	0.32	(5,127)	(14,796)	(7,054)	(276,078)

NP = net price.

Source: Project team, University of Florida

Exhibit 77. Comparison of Life-Cycle Cost of 14 and 17 SEER Air-Conditioners

Year	14 SEER	17 SEER
	Accrued NP of Total Cost	
0	$ (7,652)	$ (7,682)
1	$ (18,608)	$ (18,640)
2	$ (29,362)	$ (29,395)
3	$ (39,921)	$ (39,952)
4	$ (50,289)	$ (50,319)
5	$ (60,474)	$ (60,499)
6	$ (70,479)	$ (70,500)
7	$ (80,311)	$ (80,325)
8	$ (89,975)	$ (89,981)
9	$ (99,476)	$ (99,472)
10	$ (108,819)	$ (108,803)
11	$ (118,009)	$ (117,981)
12	$ (127,050)	$ (127,008)
13	$ (135,947)	$ (135,890)
14	$ (144,706)	$ (144,633)
15	$ (160,221)	$ (160,475)
16	$ (168,715)	$ (168,950)
17	$ (177,084)	$ (177,297)
18	$ (185,331)	$ (185,522)
19	$ (193,461)	$ (193,629)
20	$ (201,477)	$ (201,620)
21	$ (209,385)	$ (209,501)
22	$ (217,187)	$ (217,276)
23	$ (224,887)	$ (224,947)
24	$ (232,490)	$ (232,520)
25	$ (239,999)	$ (239,997)
26	$ (247,418)	$ (247,383)
27	$ (254,749)	$ (254,680)
28	$ (261,998)	$ (261,893)
29	$ (269,167)	$ (269,025)
30	$ (276,259)	$ (276,078)

NP = net price.

Source: Project team, University of Florida

APPENDIX B. CHARRETTE 1 OUTCOME

Charrette Agenda

December 13, 2019
FIBER Conference Room
10:00–2:00

10:00–10:45 Presentations

10:45–11:30 Scope of Research—Determining values

A series of three primary project goals and 12 measurable subthemes will be presented, with case study examples for each. These case studies will form the basis of design explorations during the charrette. The goal of this first exercise is to agree on the overall themes and subthemes and the approach to optimization based on these categories.

11:30–11:45 Determining teams and dividing measures

Break out into three or four teams, and divide the case studies. Each team is to design a manufactured house based on the three themes and subthemes and selected case studies. The goal is to design a manufactured house within the constraints of certain technologies, processes, etc.

11:45–1:30 Round 1 design (Lunch)

Within teams, design the house—plan, section, elevation, materials, perspective, installation, etc. Explore the possibilities.

1:30–2:00 Report out and next steps

Research Themes

Efficiency: Deploy climatic-based design coupled with passive energy design strategies to achieve a hyper-energy-efficient building that can be equipped and updated with advanced building systems and renewable energy technologies. The focus is on creating maximum efficiency. Sub-themes include solar, wind, materials, and technologies.

Resources: Develop integrated design, fabrication, and installation operations that overcome shortages of skilled craftspeople with effective automation and the substitution of scarce materials with renewables. The focus will be on how the design of a manufactured house can stir innovation across the sector. Subthemes include material (taxonomic exploration), assembly (structure/enclosure/space), and logistics (C2C).

Resilience: In environments of increased risk, this design will focus on rapidly installed manufactured housing that increases the capacity for structures to withstand or adapt to sudden and prolonged change due to climate change and storm damage. Subthemes include rapid deployment, risk factors, longevity and durability, and adaptability.

APPENDIX C. CHARRETTE 2 OUTCOME

HUD Advanced Modular Housing Design (AMHD) Project
CHARRETTE #2: User Experience
February 24, 2020, 2:00–5:00

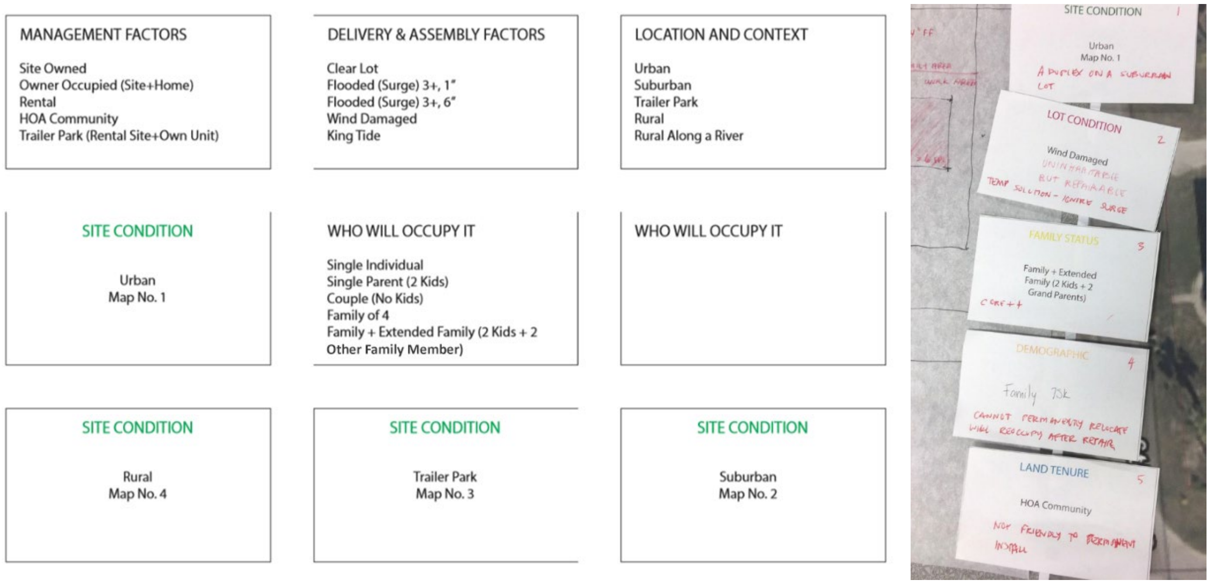
Charrette Purpose

Manufactured housing, by definition, starts with standardization. However, a "home" is often considered a reflection of the person or family who occupies it. It can be designed, sited, transformed, decorated, or augmented in countless ways to reflect the resident's needs, site conditions, or environmental risks. How can AMHD maximize standardized efficiencies while responding to the varied needs of users? This charrette will explore the varied user demands of AMHD through a series of scenario exercises.

Charrette Design

To test the flexibility of AMHD, charrette 2 was designed to put AMHD in a number of different environmental, social, and operational conditions and quickly test them through a scenario exercise. Each team chose at random a "hand" of five cards that made up the criteria for their scenario (exhibit 78). Each scenario contained a location, description of the site and lot condition, family status, land tenure, and demographics, so the teams should provide an answer to solve the problem of each scenario. Throughout solving the problem, the team could analyze and evaluate the effectiveness of the alternative design.

Exhibit 78. Hands of Cards



MANAGEMENT FACTORS

Site Owned
Owner Occupied (Site+Home)
Rental
HOA Community
Trailer Park (Rental Site+Own Unit)

DELIVERY & ASSEMBLY FACTORS

Clear Lot
Flooded (Surge) 3+, 1"
Flooded (Surge) 3+, 6"
Wind Damaged
King Tide

LOCATION AND CONTEXT

Urban
Suburban
Trailer Park
Rural
Rural Along a River

SITE CONDITION

Urban
Map No. 1

WHO WILL OCCUPY IT

Single Individual
Single Parent (2 Kids)
Couple (No Kids)
Family of 4
Family + Extended Family (2 Kids + 2 Other Family Member)

WHO WILL OCCUPY IT

SITE CONDITION

Rural
Map No. 4

SITE CONDITION

Trailer Park
Map No. 3

SITE CONDITION

Suburban
Map No. 2

SITE CONDITION 1

Urban
Map No. 1
A DUPLEX ON A SUBURBAN LOT

LOT CONDITION 2

Wind Damaged
UNINHABITABLE BUT REPAIRABLE
TEMP SOLUTION - IGNORE SURGE

FAMILY STATUS 3

Family + Extended Family (2 Kids + 2 Grand Parents)
CORE++

DEMOGRAPHIC 4

Family 75k
CANNOT PERMANENTLY RELOCATE WILL REOCCUPY AFTER REPAIR

LAND TENURE 5

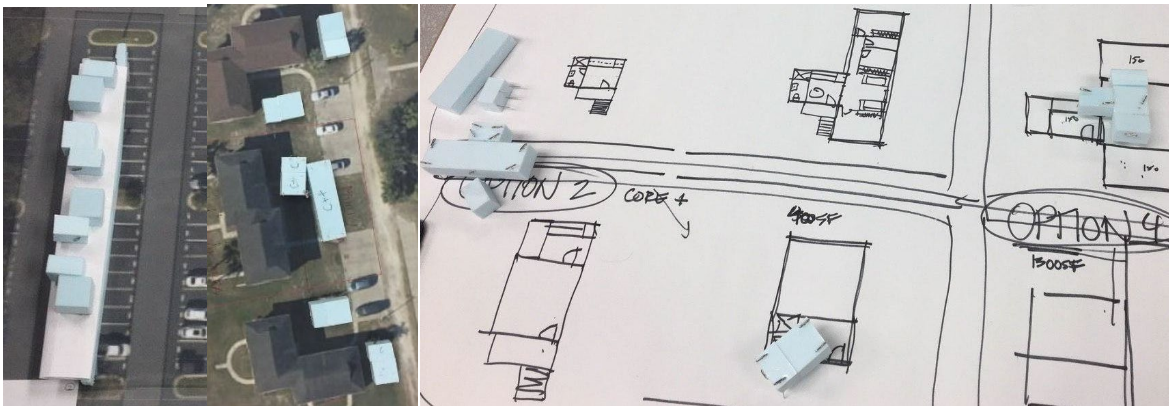
HOA Community
NOT FRIENDLY TO PERMANENT INSTALL

Each team then played out the delivery, assembly, and operation of AMHD, given the particular circumstance. For example, in the case of delivery, they considered time, money, site accessibility, and equipment. The teams came up with the design alternatives for the AMHD units and played with various configurations of units to determine the flexibility level of AMHD, advantages, disadvantages, and limitations of the presented design. Teams used drawings and models to show the results.

The AMHD Model—What Teams Started With

Each team was given a set of AMHD drawings, a printed location plan, and precut volumes to assemble models of their solutions as shown in exhibits 79 to 98. Teams used three different sizes of precut volumes referred to as Core, Core+, and Core++.

Exhibit 79. Precut Volumes



Source: Project team, University of Florida

Charrette Process

2:00–2:15	Introduction to the team and guests
2:15–2:45	Short presentations by students as part of Dr. Sharston's design studio
2:45–3:00	Summary of charrette 1 results
3:00–3:15	Introduction to the current schematic design of AMHD
3:15–3:30	Discussion of charrette process and objectives to test AMHD design
3:30–4:30	Break into five teams, each taking on a predetermined series of scenarios: • Site considerations that affect the position of AMHD • Post- and pre-disaster conditions that affect the delivery of AMHD • Land tenure type that affects the management of the AMHD • Demographics of the people who will occupy the AMHD • Size of the family who will occupy the AMHD
4:30–5:00	Teams report out and discuss next steps

Team Reports

At the end of the charrette, each team presented the process of design, design priority based on given cards, challenges, and findings.

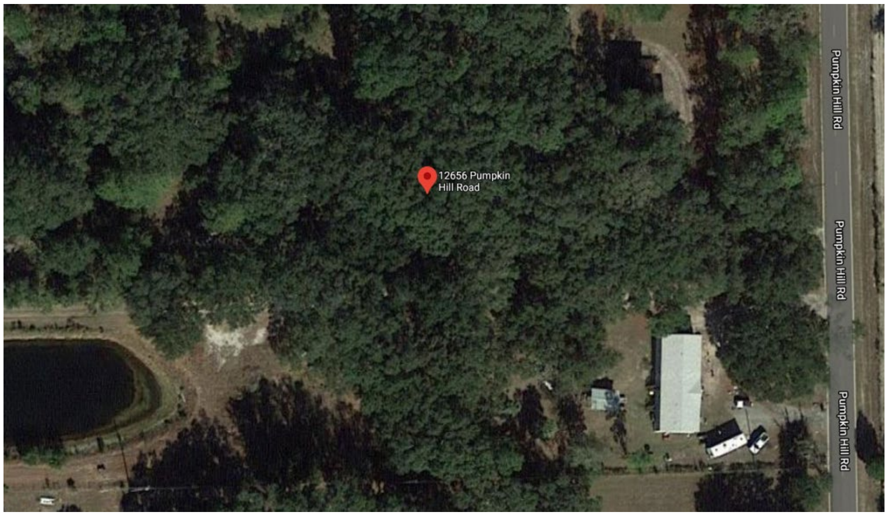
Team 1

Scenario and Condition

Address: 12656 Pumpkin Hill Rd., Jacksonville, FL 32226

- Wooded Site (Unpaved)
- Up to 3-ft Surge (Category 3 Storm)
- 6+-ft Surge (Category 5 Storm)
- Federal Emergency Management Agency (FEMA) Flood Zone: × (Area of Minimal Flood Hazard)
- High Tide Vulnerability: Low
- Annual Median Income (AMI): $74,424

Exhibit 80. Team 1 Location



Source: Project team, University of Florida

Card Information

SITE CONDITION:
  - Rural

LOT CONDITION:
  - Flooded (Surge) 3+

FAMILY STATUS:
  - Single parent (2 kids)

DEMOGRAPHIC:
  - 32k

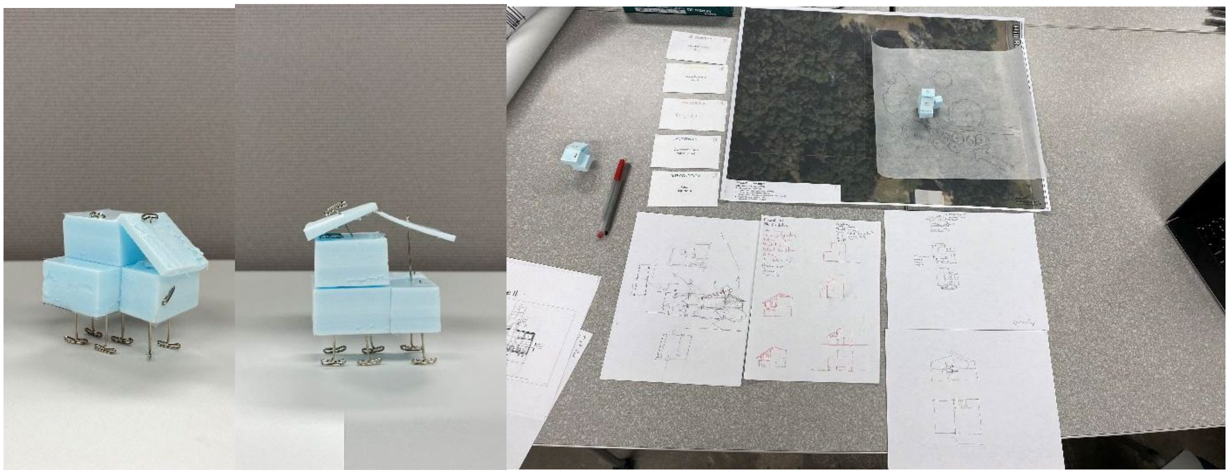
LAND TENURE:
  - Owner Occupied (Site + Home)

Design Approach

Assumptions ranked by priority:

1. Lot Condition—The flooded site required a strategy to mitigate flooding within the structure. This factor led to the design of an elevated building to prevent water intrusion.
2. Family Status—Family size dictated the size of the unit. A unit with at least three rooms was suitable for a family of three. This planning involved combining a Core module and two Core+ modules. The Core module would provide the necessary mechanical equipment, and the two Core+ modules would allow for flexibility within the space.
3. Demographics—The demographics also limited the size of the unit and the number of modules to be used. Keeping the unit affordable was necessary because of the low income of the family to occupy it.
4. Land Tenure—The owner-occupied site and home provided some flexibility in building placement and orientation on the site. The building was oriented to reduce solar gain and provide shading within the home. A reduction in solar gain would also contribute to reduced cooling costs.
5. Site Condition—The rural site condition also provided some flexibility in terms of approach to the building and the use of natural conditions to provide additional shading and reduce solar gain. The wooded site would also assist in breaking harsh winds on the site and reducing the load on the building.

Exhibit 81. Team 1 Unit Configurations



Source: Project team, University of Florida

Summary

The conditions chosen led to the design of a single-family modular unit suitable for a low-income family of three on a rural site. The modules were elevated and stacked to create a two-story building. To maximize usable space in the building without adding more modules, the team suggested the addition of a hinged roof that would ship attached to the module and later be opened once the three modules were assembled. The roof would also assist in ventilating and shading the building.

With an elevation of more than 6 ft and a pile foundation, the building would be protected from floods and have reduced vulnerability to future storms. The use of solar panels on the hinged roof and overhangs to provide shading maximized the unit's energy efficiency and could provide a self-sufficient building. The natural ventilation that the hinged roof facilitates would also help reduce energy consumption and cool the space naturally.

Exhibit 82. Team 1 Presentation

Source: Project team, University of Florida

Team 2

Scenario and Condition

Address: 2701 Hodges Blvd., Jacksonville, FL 32224

- Paved and Unpaved Sites
- Unaffected (Category 3 Storm)
- Up to 3-ft Surge (Category 5 Storm)
- FEMA Flood Zone X (Area of Minimal Flood Hazard)
- High Tide Vulnerability: Low
- AMI: $44,238

Exhibit 83. Team 2 Location

Source: Project team, University of Florida

Card Information

SITE CONDITION:

- Suburban

LOT CONDITION:

- Flooded (Surge) - 3+, 6"

FAMILY STATUS:

- Family of 4

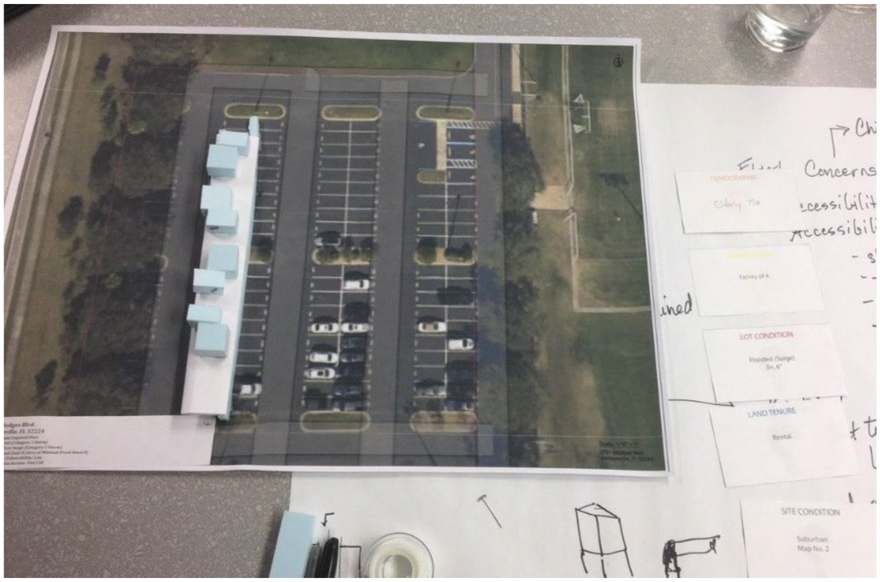
DEMOGRAPHIC:

- 75k: Senior

LAND TENURE:

- Rental

Exhibit 84. Team 2 Final Model



Source: Project team, University of Florida

Design Approach

Assumptions ranked by priority:

1. Demographics—Not permanent housing, can affect to move on . . . only Core and Core+.
2. Accessibility in flood area—Raised entire neighborhood on a shaped platform (fewer ramps per unit) consolidated services.
3. Lot condition—Raised groups of houses on precast concrete with spans—stocked items that can be stockpiled.
4. Family status—Assumed grandparents plus two grandchildren—grandchildren sleep in the loft, Core+ is for grandparents + living room.
5. Land tenure—Temporary solution—to be disassembled and moved because abode is temporary; focus on being assembled and disassembled.
6. Site condition—Parking lot—assumed people are here because of access to utilities—created a temporary “neighborhood.”

Summary

The family status of the scenario was “family of four”; however, the team created a more complicated scenario with three families, so they designed a community that included four families or four units. The most important issue, in this case, was providing utilities for all units. Hence, the teams tried to locate all units on a single slab or base to make a compact community and bring the utilities with single lines instead of scattering the units. Hence, the community can provide utility from the closest lines. Based on the family size and demands, each unit can contain either Core, Core+, or Core++.

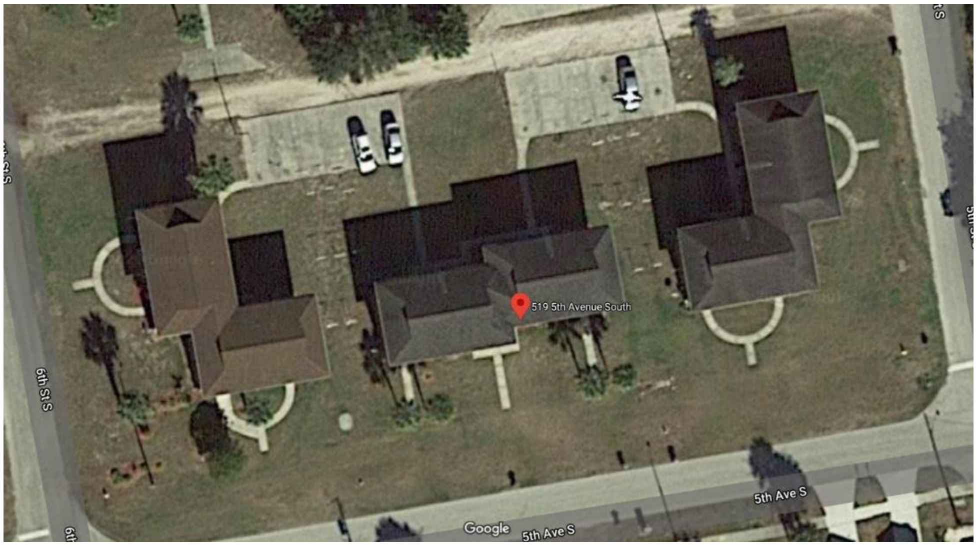
Team 3

Scenario and Condition

Address: 519 5th Avenue S., Jacksonville Beach, FL 32250

- Multifamily Housing Site
- 6+-ft Surge (Category 3 storm)
- 9+-ft Surge (Category 5 Storm)
- FEMA Flood Zone X (0.2 Annual Chance Flood Hazard)
- High Tide Vulnerability: Low
- AMI: $46,964

Exhibit 85. Team 3 Location



Source: Project team, University of Florida

Card Information

SITE CONDITION:

- Urban

LOT CONDITION:

- Wind Damage

FAMILY STATUS:

- Family + Extended (2 Kids + Grandparents)

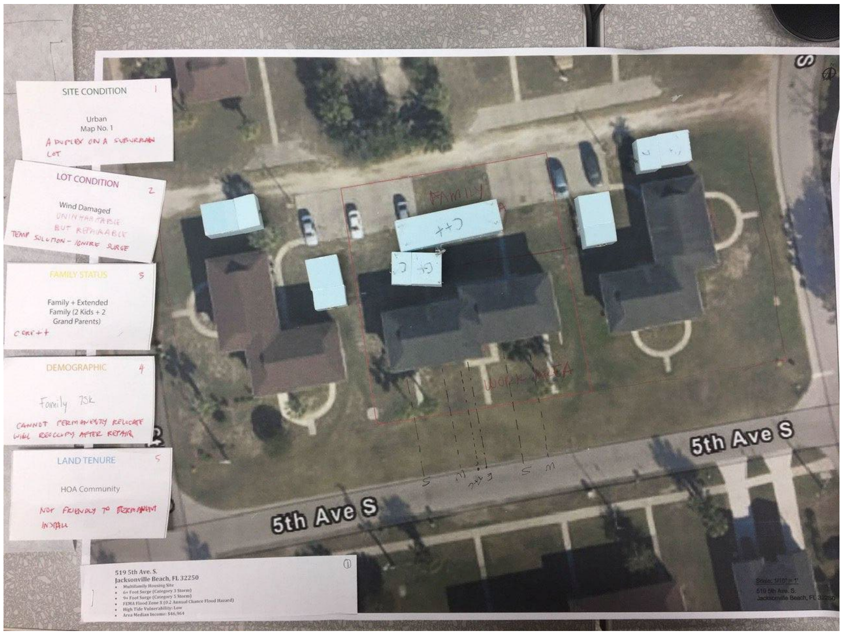
DEMOGRAPHIC:

- 75k

LAND TENURE:

- Homeowner Association (HOA) Community

Exhibit 86. Team 3 Final Model



Source: Project team, University of Florida

Design Approach

Assumptions ranked by priority:

1. Site condition—A duplex on a suburban lot.
2. Lot condition—Uninhabited, but repairable—temporary solution: ignore surge, which means the damage was not so bad, and they could repair it by fixing some damage to the roof, exterior wall, and windows. It takes approximately 6 months to fix it.
3. Family status—A family form of parents, two kids, and grandparents, which means in a normal situation, this family needs at least three bedrooms. For the first stage and probably just for a week, they can live in the Core, but after that time in the first month, adding Core + and Core++ to the unit is necessary.
4. Demographics—The family must repair; they own a house and move there because it will be expensive to relocate permanently—will recover after repair—in this way, they can rent the unit or buy it and resell it after moving to their house.
5. Land tenure—Not a friendly environment. Because it is an HOA community, they care a lot about the beauty of the neighborhood, so the family will be careful about the location of Core and other units.

Summary

The team started with finding the best way to bring utilities to the site. Two options were available, one of which was the shortest way and the other could create a nice location for the unit. Another challenging issue was accessibility to the unit. The north and south sides of the existing building were considered the best places; however, the southern yard was accepted as the best option because it could create a more private place for residence and labor.

- Step 1: Locate access
- Step 2: Locate utilities
- Family-driven solution
- More sanitary
- Higher floor at (±12″ PAU[11])

The most difficult challenge was placing the unit in an appropriate location to avoid creating a noisy environment for the HOA community.

Limitation:

- Setbacks
- HOA community

In this case, the model responded very well to the challenge by providing three steps in scheduling and an expandable area.

Schedule:

- Core—1st week
- Core+—2nd week (bunk beds)
- Core++—End of the month

Recommendations for Improvement

AMHD, as it currently is designed, has enough space; however, the design does not include space for stairs. The project team proposed using a flat roof so that units could be stacked, redesigning the kitchen to make it more flexible, etc.

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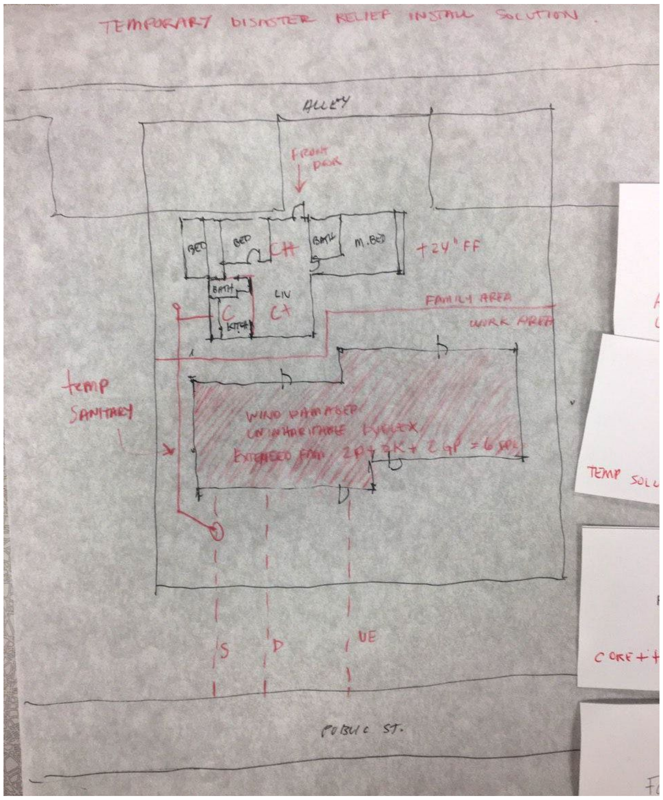
[11] pre-assembled unit

Exhibit 87. Team 3 Solution



Source: Project team, University of Florida

Team 4

Scenario and Condition

Address: 508 Trout River Dr., Jacksonville, FL 32208

- Post-Disaster Site
- Up to 3-ft Surge (Category 3 Storm)
- 9+-ft Surge (Category 5 Storm)
- FEMA Flood Zone X (0.2 Annual Chance Flood Hazard)
- High Tide Vulnerability: Low
- AMI: $27,823

Exhibit 88. Team 4 Location

Source: Project team, University of Florida

Card Information

SITE CONDITION:
- Urban—FEMA flood zone X

LOT CONDITION:
- Clear lot

FAMILY STATUS:
- Single person

DEMOGRAPHIC:
- Individual 25k

LAND TENURE:
- Site owned

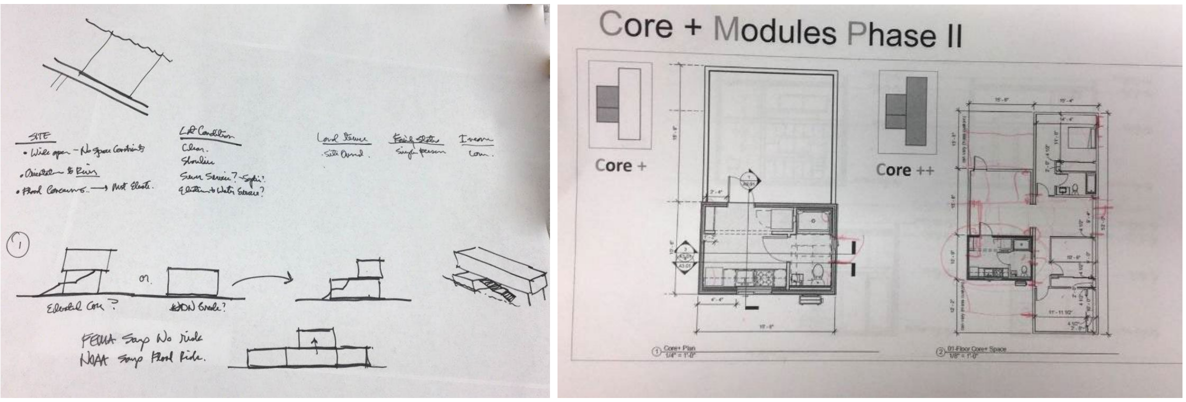
Design Approach

Assumptions ranked by priority:
1. Site condition—Because it is in a flood zone.
2. Demographics—Low income.
3. Family status.
4. Lot condition.
5. Land tenure.

Summary

Although this site is in FEMA flood zone X and has a 0.2 annual chance of flood hazard, the first and most important concern with this site is storm surge. The site is on the shoreline, which increases the risk and power of storm surges. Based on the Core idea, the team presented four options:

Exhibit 89. Team 4 Design Process

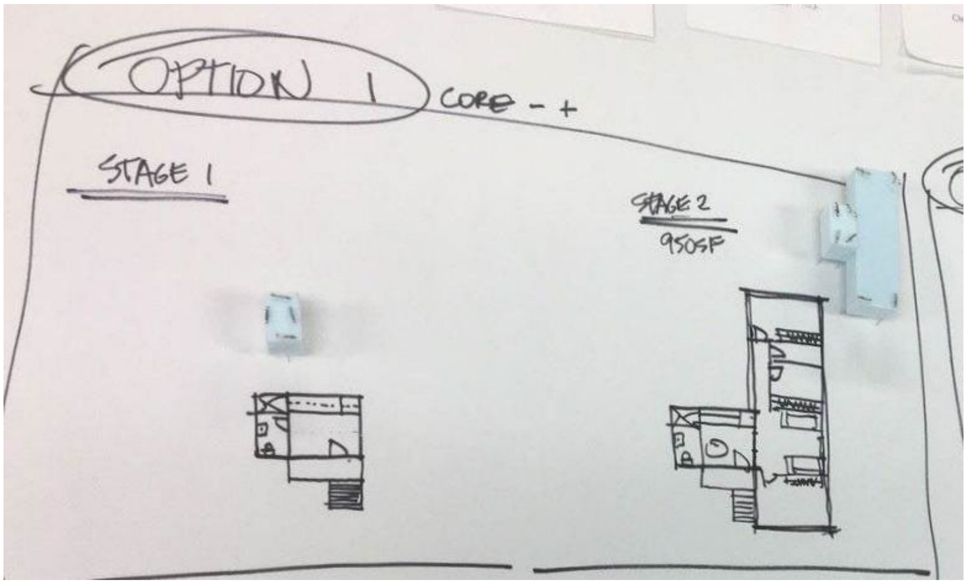


Source: Project team, University of Florida

Option 1

There are two stages in this option. The first stage is immediately after the disaster, and it could include only the Core, which contains more important needs, such as a kitchen, toilet, etc., and is called Core -. Then, in stage 2, the owner can expand her home by adding Core+. Stage 2 is approximately 950 ft^2.

Exhibit 90. Team 4 Option 1

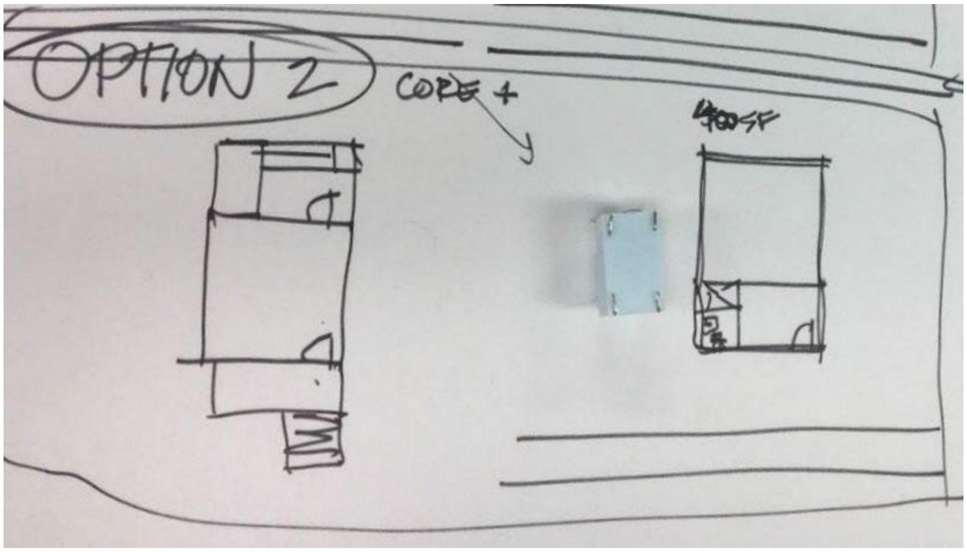


Source: Project team, University of Florida

Option 2

This option includes just the Core, which has a 400-ft^2 area.

Exhibit 91. Team 4 Option 2

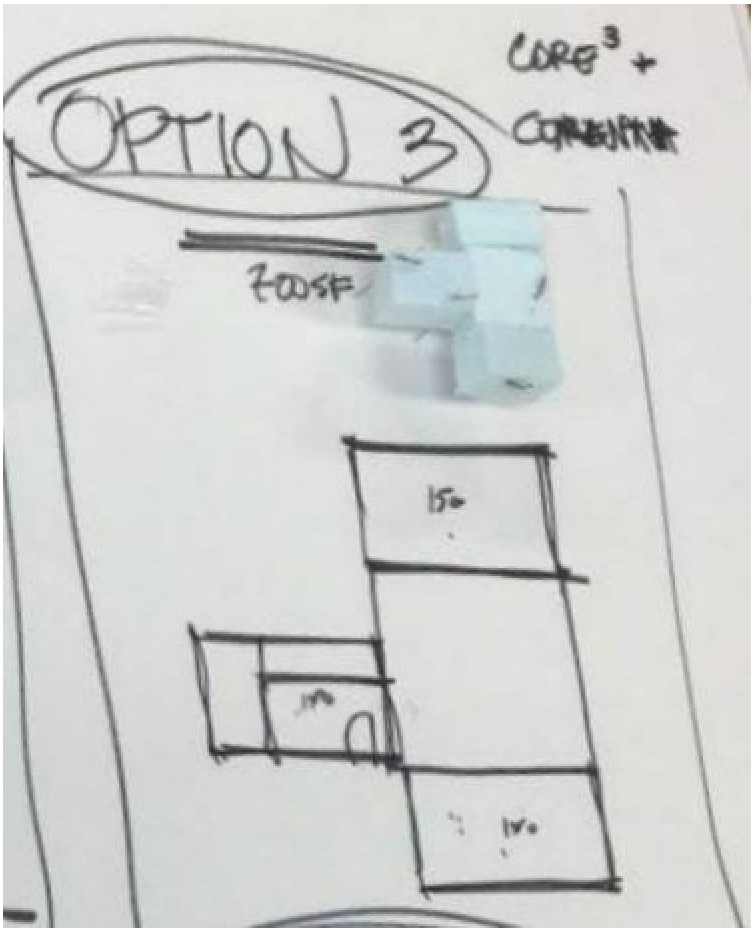


Source: Project team, University of Florida

Option 3

This option is the combination of Core_, Core, and Core+, and its area is approximately 700 ft^2. (The team initially referred to the units as Core_, Core, and Core +, but eventually changed the names to Core, Space, and Dwell, and the combination of those would be Core+.)

Exhibit 92. Team 4 Option 3

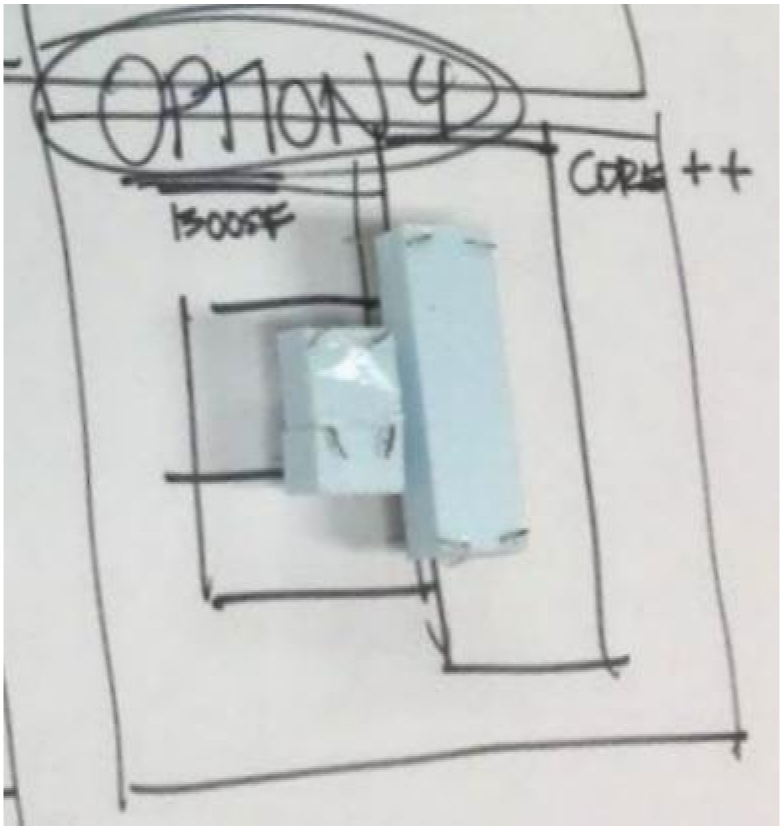


Source: Project team, University of Florida

Option 4

Option 4 is the largest, which is Core ++ and is approximately 1,300 ft^2.

Exhibit 93. Team 4 Option 4



Source: Project team, University of Florida

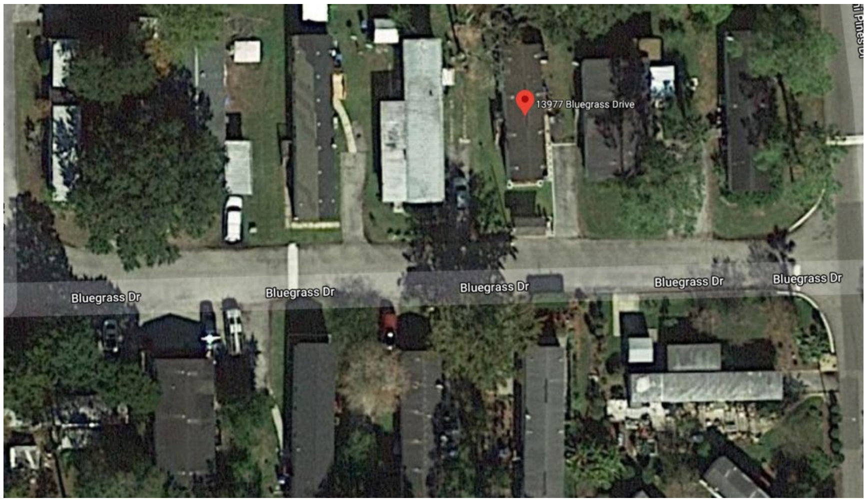
Team 5

Scenario and Condition

Address: 13977 Bluegrass Dr., Jacksonville Beach, FL 32250

- Trailer Park
- Unaffected (Category 3 Storm)
- 6+-ft Surge (Category 5 Storm)
- FEMA Flood Zone X (Area of Moderate Flood Hazard)
- High Tide Vulnerability: Low
- AMI: $44,238

Exhibit 94. Team 5 Location



Source: Project team, University of Florida

Card Information

SITE CONDITION:

- Trailer Park

LOT CONDITION:

- High tide

FAMILY STATUS:

- Couple (no kids)

DEMOGRAPHIC:

- 55k

LAND TENURE:

- Trailer park (rental site + own unit)

Design Approach

Assumptions ranked by priority:

1. Land tenure—Trailer park (rental site + own unit): consider disassembly and removable temporary housing for future use.
2. Lot condition—King tide: the house is in FEMA Flood Zone X and has a 6+-ft surge. The house is at king tide, so the lot condition must consider the risk for flood and storm strength caused by rising sea levels, and inclement weather conditions combine to exacerbate flooding risks.
3. Demographics—Seniors, $55k: The demographics limited the number of modules for owners' purchasing affordability and potential financing issues with the bank.
4. Family status—Couple (no kids): The family status of a couple with no kids determines the size of this design.
5. Site condition—Trailer park Map No. 3

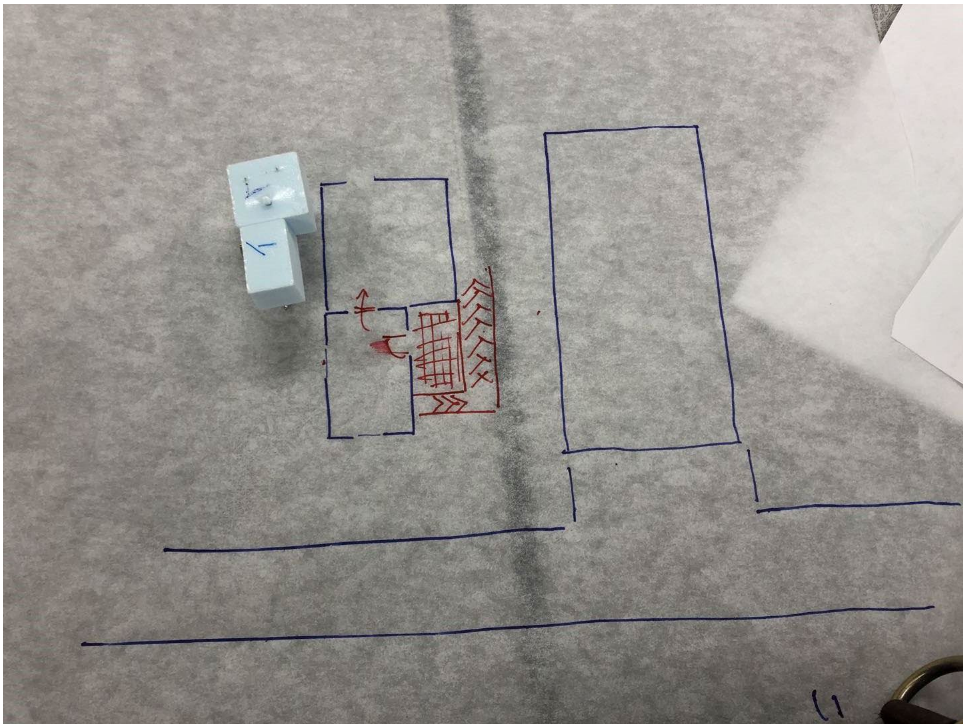
Exhibit 95. Team 5 Location and Consumption

Source: Project team, University of Florida

Summary

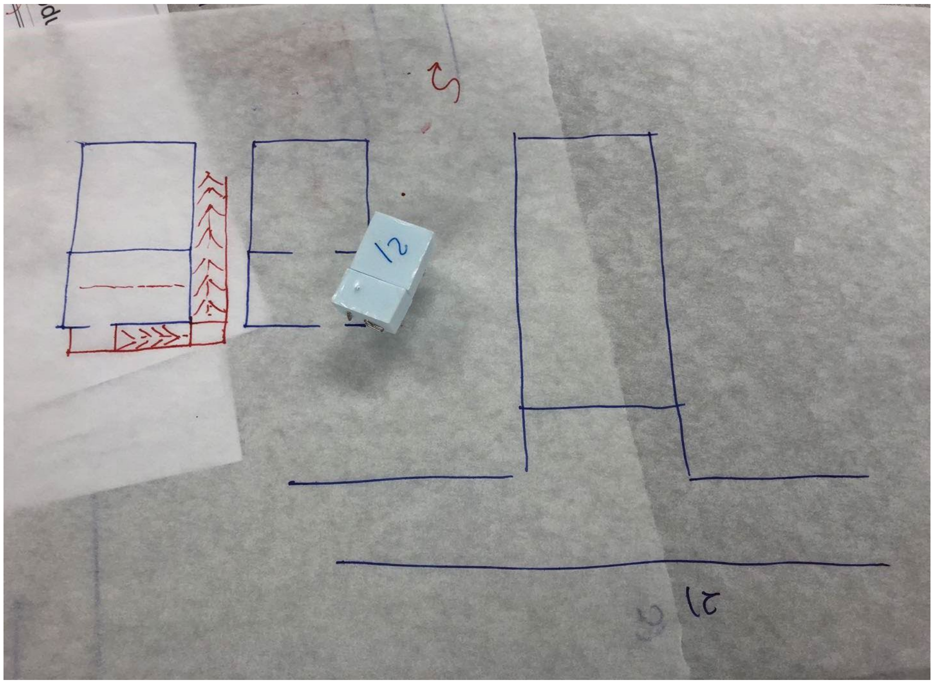
The owner is a family of two with low income, seniors, $32k/year, so this housing design includes no more than three units, considering affordability. Three design options include three types of the Core+ model. The lot condition is king tide, and the site is in FEMA Flood Zone X and has a 6+-ft surge, so the floor height is 10 ft above ground. Stairs are designed to meet 2010 ADA accessible Design 504.1-504.7 requirements. Based on the Core idea, the following three options are provided:

Exhibit 96. Team 5 Option 1: Core+ Model



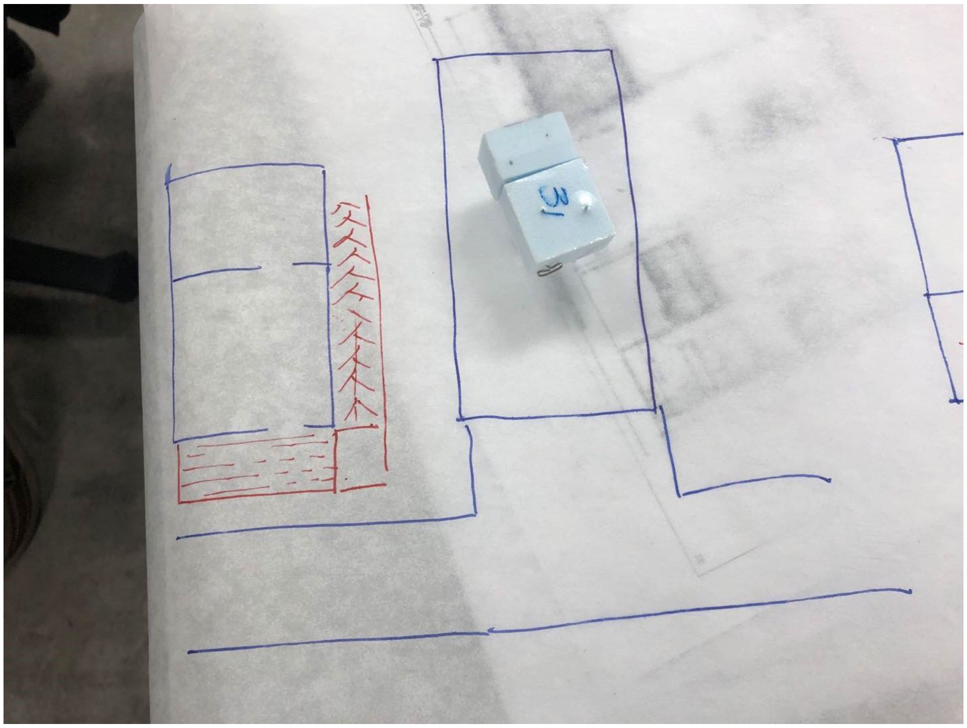
Source: Project team, University of Florida

Exhibit 97. Team 5 Option 2: Core+ Model



Source: Project team, University of Florida

Exhibit 98. Team 5 Option 3: Core+ Model



Source: Project team, University of Florida

APPENDIX D. CHARRETTE 3 OUTCOME

August 7, 2020
HUD Advanced Modular Housing Design (AMHD) Project: Actionable Items Form
Charrette 3
Design Development Phase

Architecture Room (Room 1) Discussion Topic

- Consider the connection of utilities to the Core.
- Dealing with materials choices: wood framing, steel, cross-laminated timber (CLT).
- Review connections and interfacing between units.
- Temporal issues: disaster to manufacturing to delivery.
- Varying Core unit relationships to avoid a monolithic appearance.

Energy and Services Room (Room 2) Discussion Topic

- Option 3—individual heating, ventilation, and air-conditioning (HVAC) units manufactured with each component—is likely the best solution.
- Keep options 1 (VRF[12]) and 3 for evaluation.
- Need to consider DHW[13] systems: solar, heat pump, point of use.
- Ventilation: need a concept that matches the modular building build-out.
- Location of bathrooms and bedrooms to optimize utilities and services.
- Need to consider photovoltaic (PV) and energy storage

Materials and Manufacturing Room (Room 3) Discussion Topic

- Current factory practice is wood studs, not metal studs.
- Industry is not familiar with CLT, one plant in the United States (Alabama).
- Industry suggests building five Core units on a 70-ft chassis to accelerate production.
- Materials cost 10 percent less for modular compared with site-built homes.
- Factory labor is one-third of materials cost.
- Water tightness is a concern, with multiple modules installed at different times.
- Interconnections between Core, Space, and Dwell must be defined and detailed for structure and utilities.

Room 1: Core+ Concept

Participants

- University of Florida (UF): Jeffrey Carney, Ryan Sharston, Forough Foroutan, Bill O'Dell, and Madhya Sam
- HUD: Jagruti Rekhi and Luis Borray
- Other: Frank Wells

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[12] variable refrigerant flow

[13] domestic hot water

Agenda

The charrette met in a Zoom meeting room, and after the participants were divided into breakout rooms, the leader for “Breakout Room 1” provided a brief introduction that defined the goal and main criteria for the projects. The goal for the group discussion introduced by the leader was to dig into the overall objectives of the Core+ concept and how it can be improved to achieve through the design.

The driving goal behind the Core+ design was introduced as follows:

- Rapid deployment.
- Mass fabrication balanced with site variabilities and individual choice.
- Energy efficiency.
- Tectonics and materials that can establish a long-term resilient community.

Then, specific questions were posed to the participants to obtain input and feedback.

1. What are the specific techniques and technologies suggested for unit connections?
2. Is it feasible to have different construction systems for each different unit?
3. What are the considerations for HVAC and plumbing system connections between volumes?
4. Units have external walls until they are enclosed. Are there concerns about leaks, transmission?

Group Discussion

Rapid installation post-storm, responsive design

- Lot clearing and pre-cleanup at the site could take a couple of weeks, which could be addressed by different site selections, such as parking lots.
- Depending on where the unit is located and how quick the response is, what are the utility conditions, and how would this affect installation time?
- Construction systems for each unit have been predefined as a CLT system for the Core, panelizing for the Space, and volumetric for the Dwell. Because the panelizing system will add more onsite construction work with more labor force, it was suggested that the volumetric system would be an option in terms of rapidity and post-disaster construction.
- Strong support for early installation, but questions emerge about whether the Core unit could be installed at a temporary location while the site is being prepped. Possible parking lots of a mall or other?
- Discussion about whether it is necessary for the Core unit to be deployed or if it should be connected with Core+ from the start. There is little advantage not to include both; all expenses are in the first unit. The only downside is transportation volume.

Workforce issues influence construction systems

- The available workforce should be a significant driver of the type of construction system. There are few skilled trades, especially after a storm. They tend to work for wealthier markets. Professionalizing the workforce in a factory setting is good but does not help immediately after a storm because people need more training.

Constructability—Roofline and slope—Avoid complexity

- Wells cited a modular product with a Lego-like assembly.

- It should be considered that every time Space is added to the Core, the need for labor in joining the units incurs expense.
- A split-system HVAC is the system defined for the project, which can be installed on site or in the manufacturing process.
- Reconfigure roofs to be a shed. Avoid inside corners.

Financial mechanisms

- Financial instruments for the initial purchase of the units in terms of rapidity would be another aspect of attention that would be very different based on the project unit being permanent or temporary. It is also important to consider the different stages of delivery times.
- It is difficult to obtain a mortgage on a manufactured home because it is treated as personal property, not real property. However, there is an established, although not frequently-used, FHA Title I mortgage insurance program for manufactured homes treated as personal property (i.e., chattel). This is a type of mortgage insurance available for the purchase of the manufactured home (personal property), lot on which the manufactured home will be situated (real property), or both.
- Because they are built according to HUD code instead of local residential code, they are generally of lower-quality material. They will not accrue value over time and will not be considered as an equity-building proposition for the homeowner.

Process

- Consider another round of research to understand post-disaster and transitional housing circumstances and the relationship between the prospective delivery of units, such as the Core, and the circumstances on the ground once they are delivered. Finance, policy, and construction.
- The way the house will deal with the community is important. It is important to consider the community's acceptance of the project or if there will be difficulty getting houses placed.
- The intention of the project for permanency influences the designs in that the housing would provide the ability to reconstruct with permanent housing.
- Concern about temporary siting that becomes permanent.

Room 2: Energy

Leader: Ravi Srinivasan

Participants

- UF: Ravi Srinivasan, Jiaxuan Li, Research Assistant and Notetaker, Mahtab Kouhirostamkolaei, and Lauren Shinnow
- HUD: Mike Blanford

LG Solar: Kevin Priest, Jacob Gribbon, Victoria Sanville

Agenda

The charrette met in a Zoom meeting room, and after the participants were divided into breakout rooms, the leader for “Breakout Room 2” provided a brief introduction that defined the goal and main criteria for the projects. The goal for the group discussion introduced by the leader was to dig into the energy and services, including energy performance, technology, generation, storage, and modeling of the Core++ model in terms of HVAC, lighting and daylighting, ventilation, energy recovery, DHW, and appliances through results of simulation models.

The building energy models of the Core+PLUS were introduced as follows:

- HUD Benchmark Model (HUD Best Practices, NREL Report 2016)
- IECC-2018 Model
- Hyper-Efficient Model (Improvement over IECC-2018)
- Net Zero Energy-Capable Model (optimal balance with renewables)

Different steps of the process were defined as follows:

1. Identify Building Energy Model Inputs for Benchmark, IECC-2018, Hyper-Efficient, and Net Zero Energy-Capable Models.
2. Estimate Cooling and Heating Capacities of the Building Design (using eQUEST software).
3. Estimate Building Energy Use (using BEopt software).
4. Compare Energy Savings over Benchmark, IECC-2018, Hyper-Efficient, and Net Zero Energy-Capable Models.
5. Recommend High-Performance HUD AMHD Core+ Designs based on Cost Impact.

Considering different specificities and regulations, model design, and site variabilities, model simulation inputs were set up differently for both the Core+Space model and the Core+Space+Dwell model, including the following:

- NREL Report 2016 for HUD benchmark model.
- IECC-2018 regulations with location set up as Charleston, South Carolina, located in U.S. Environmental Protection Agency (EPA) climate zone 3.

The primary objectives of the three different units were explored as follows:

- Core is a solid, storm-resistant, structurally robust unit that can be delivered immediately, which has a kitchen, a bathroom, and a sleeping space.
- Space is a modular assembly with maximum flexibility and a flat frame system that can be open as a porch or eighter with modular pieces that could close it down to be a closed part of the house. Space could be delivered with the Core or may be added later.
- Dwell is a full-size mobile unit that completes the model.

The primary comparison of different BEopt model simulation results was explored as follows:

- EUI is calculated by dividing the total energy consumed by the building in 1 year (measured in kBtu or gigajoules [GJ]) by the total gross floor area of the building (energy divided by square footage).
- Percentage energy savings is calculated when comparing different inputs for the same model.
- Cooling energy, heating energy, and lighting energy are noted for comparison.

Specific questions were posed to the participants to obtain input and feedback.

1. What energy efficiency measures (EEMs) can be applied to the IECC-2018 model to move toward a 50-percent reduction over the HUD Benchmark?
2. How does the installer resolve the connectivity issues (in services) as the owner expands from Core+Space to Core+Space+Dwell?

Discussion

During the discussion, the participants brought up some crucial points of consideration and some specific questions to be answered.

- Members of the research team run real-time modeling and make recommended changes on the basis of discussions on mechanical ventilation, lighting, appliances, etc.
- What EEMs[14] can be applied to the IECC-2018 model to move toward a 50-percent reduction over the HUD Benchmark?
- The HUD Benchmark model (NREL Report 2016; Beiter, Elchinger. and Tian Tian, 2016) is set up as a baseline for the project, and the goal is to explore several opportunities to move toward 50-percent energy savings over the HUD Benchmark. After introducing IECC-2018, savings from the model output are clear. The heating setpoint is set as 70°F based on IECC recommendations.
- Energy Star-rated energy efficiency appliances can be selected for optimal energy consumption.
- What EEMs can be applied to the IECC-2018 model to move toward a 50-percent reduction over the HUD Benchmark? Discuss EEMs/opportunities in HVAC systems, DHW (solar WH), energy storage, renewables, and others. Real-time modeling and results will be obtained based on changes.
- As all building components are one-piece volume matrixes and prefabricated, Jacob at LG Solar provides three conceptual options for HVAC + connections, depending on which way the split system will go and the type of indoor unit.
- The first option is VRF + VAV[15] dampers with 2 tons (min). Module 1 will be the Core, the base module for living. Module 2 is for the Space, and module 3 is for the Dwell. The benefit of this is if we want to look at adding on other modules, we can have one duct unit in module 1 serving the Core and Space and add on later for the Dwell if required. The benefit of this product in conjunction with VRF is that it still allows the VRF product to modulate up and down based on the thermal comfort in the space, which offers a means of control ability using one indoor unit. Dampers open and close based on the thermal comfort needed for the small space, which can perform fast without recirculation. The benefits of option 1: (1) it is cost effective for a single indoor unit to maintain, (2) it provides thermal comfort control for all spaces, and (3) it has the flexibility to add on additional modules cost effectively.
- The lowest capacity is 2 tons, which is at the VRF commercial side, and we can start the unit with 1 ton of load for the 405 ft^2 module. If we have the unit prebuilt at a certain facility, we can create a spool sheet that tells the installation contractor where to put each component. Thus, module 3 can have a spool sheet with supply grills, with return registers already installed and ready to go. Thus, when the Dwell arrives on site, we set that Dwell unit to the Space and Core, anchor it down, open it up, and then run it to the

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[14] energy-efficient mortgage

[15] variable air volume

certain place we need to in the project. The ventilation for fresh air needs to be discussed based on the residential regulations.

- Depending on the project and cost, running the small side into a space is easier. Option 2 will run the same cost as option 1—depending on the tonnage, capability, square footage, and Btus needed—and we can come up with a wall-mounted option or a four-way concept option. Based on the AHRI[16] standard, option 1 is approximately 17 SEER. Option 2 is close to 18 SEER. We could achieve higher efficiency if calculated on the basis of actual project conditions instead of the HRI condition. We will have dehumidification in the space.
- The third option is a mini-split factory assembled, which is a traditional residential split unit. In this unit, how the electrical work could get together must be considered. The uncertainty of the third option is the ability to preinstall the outdoor unit on the first module, or it will be done on site. When working with the designer, options 1 and 2 will avoid this question by pre-attaching the outdoor unit onto the module and running the pre-test. All outdoor units in option 3 are 115 V. Sizes are 9,000 Btu or 12,000 Btu.
- Mike suggested making the two bathrooms close to each other in the design.
- Ravi brought up the point that, based on the simulation output, the water heating output is high. What can we do to reduce it? Mike commented that, depending on how you set up the modules, it may be relatively easy to pump gray water. If gray water [17]comes out of the house, you can set up a tank to capture it to use for the garden. Considering the size of the house, the reuse of gray water is a challenge. Ravi suggested considering a water sewerage system and a black water[18] sewerage system.

Room 3: Material and Assembly

Leader: Stephen Bender

Participants

- UF: Abdol Chini, Maryam Kouhirostami, and Hamid Esmaeillou
- HUD: Regina Gray
- Clayton Homes: Gavin Mabe
- Palm Harbor Homes: Mike Draper and Sean Levy
- Jacobsen Homes: Dusty Rhodes

Agenda

The charrette met in a Zoom meeting room, and after the participants were divided into breakout rooms, the leader for "Breakout Room 3" provided a brief introduction that defined the goal and main criteria for the projects. The goal for the group discussion introduced by the leader was to dig into the overall objectives of material selection, module manufacturing issues, high-speed manufacturing, and mobilizing manufacturers to supply components post-disaster.

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[16] Air-Conditioning, Heating, and Refrigeration Institute

[17] Grey water, also spelled gray water, is water that already has been used domestically, commercially, and industrially.

[18] Black water in a sanitation context denotes wastewater from toilets, which likely contains pathogens that may spread by the fecal–oral route.

Considerations

Review the research goal: the design of a hyper-efficient and energy self-sufficient home that can cope with future severe weather events while also providing basic services needed for families during post-disaster recovery. It will address the design of housing that can be rapidly built in factories, cope with future major events, and become a major community asset.

- Compile material possibilities.
- Consider intrinsic and extrinsic.
- Innovate material systems.
- Develop selection criteria.

Material: Spectrum of Lightness |
Heavy < > Light
Multi-duty (thermal-environmental-structural)
    Manufacture
    Fabrication
    Transport
    Durability
    Modular manufacturing issues

1. Assembly: Spectrum of Solidity

    Layered < > Solid
    Flexible < > Determined

    Reduce the number of—
    parts (elements)
    attachments/joints
    operations
    = (-) Time
    = (-) Cost
    = (+) Durability
    Consider assembly and disassembly (sequence):
    Replacement
    Renovation
    Recycling
    High-speed manufacturing
2. Logistics: Spectrum of simplicity | Logistics is typically considered in the context of transportation only. However, we may propose that logistics is a pervasive consideration in manufactured housing.

    Volumetric < > Panelized
    Cellular < > Open
    Mobilizing supply post-disaster

Specific questions were posed to the participants to obtain input and feedback.

1. What types of materials are often used by factories?
2. Is there any modularity to the factory system?
3. If there are any other ways of manufacturing, does it mean building a new factory?

4. How would the model be built in the factory?
5. Will the building be built while the chassis is on it?
6. What would be the foundation type?
7. How can the design deal with the systems, such as plumbing?

Discussion

During the discussion, the participants brought up some crucial points of consideration and some specific questions to be answered.

- The weight of the material does come into play. However, cost and structure are more important. In fact, industry cost is one of the important aspects of choosing materials. Thus, there should be a good balance of light material and structure. Industry is using foam board, but there is no structure in it. Factories use all stick builds. In addition, material selection has not changed much over the years. SIP [structural insulated panels] as a wired premade panel is difficult to install and was a failed experiment in industry.
- Materials: LSD[19] | Foamboard | Thermo sheet | Thermo plot | Thermal ply.
- Foam application is problematic due to the scope of materials overlap.
- Switching to cold-formed steel is not conceivable in the current system. In a recent factory trial, the cold-formed system tooling cost would have required adding a second shift, which was not feasible for the manufacturer.
- Material systems use light-gauge metal framing and lighter-weight sheathing and remove the structural capacity from the integrated system using spray-applied closed-cell foam. The panels are not prewired, and spraying foam could happen after wiring the wall section. It is a very moisture-resistant system that is also highly insulated and unified in the structure.
- Environmental aspects of the material are another consideration.
- The construction process in factories first starts with the frame and wall construction process and then rolls down the center of the building so that more than one activity can take place; one could have cabinets installed at the same time that the roof is being installed, so it is an assembly line-type production. The entire structure of the home is finished, and before it rolls out of the building, the tile work and that kind of stuff gets done.
- The station has some flexibilities, but the process has been set for a long time, so switching some things out is not easy. Instead, it could require a new facility.
- The design explores hybrid, which means it should be able to do some volumetric components and is very easily transformable.
- The industry receives FEMA's order and then runs the batches, so the plants prefer building lots of things simultaneously instead of running one and disrupting the flow. The factory facilities will build a range of models, but not all. In some cases, they do not have the facilities to build very entry-level homes or very custom-designed homes. That is often done at two different factories. In another case, factories build any model from high end to entry level—in fact, whatever the customer wants—so their lines are not segregated.
- The proposed Core+Space module design is very similar to the Chariot Park model, except it has a chassis attached, so it is very deliverable.

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[19] limit state design

- Some factories have only one line, so whatever the building is, it has to go all the way through that line. Thus, if they have a gap in the line, there is a problem. Based on the complexity of the product, they dictate which facility will build that.
- Considering the factory lines, Core+Space should be built together because of the size.
- The Core is a rigid box with no chassis. Making it flat and level is a problem, so they will build a dummy chassis.
- The chassis is an expense, but it also is necessary and has a suspension. The unit—with the possible exception of Dwell—does not need that component which will help reduce the cost. The units come via flatbed truck and are transferred to the site by truss crane. In many cases, if the Core is designed properly, it is possible to use adapted man craft cranes. If it is light enough, it is possible to use an extended-reach forklift, resulting in a much easier delivery process.
- Flooring that is 76 ft long—five at a time—is on the same chassis to be brought to the site. Take them outside and unload them. Put them in a "function test" area to test the water system, electrical, and plumbing. Pull them off the chassis, and put them on the flatbed. Once they get tested, then they are ready to be shipped.
- Originally, the Core is designed with parapet walls around the top because it might be easier to put them together and possibly stack them for storage. The problem might be not just the static load but the wind load. Thus, storage is going to be more challenging.
- A helical coil is a good choice for the foundation. However, it is necessary to check the resistance by locality. Industry divides it into on-frame modular and off-frame modular. Both may depend on the locality. In addition, HUD needs to approve homes with no chassis.
- Designing a frame that creates a connection between the ground and the units above enables the distance between soil and structure to be occupied with something that can deal with lateral forces. Design a K-frame system that allows the sheer to the ground; then, the system is fine. It can be made in station inexpensively or made by the supplier.
- Design a utility wall to include all systems to save time; thus, each unit will come with its own separate system. The electrical crosses over like a plug-in and will reduce the time when setting the units together. In addition, the unit can have both the dry and wet sides together but separate sanitary/domestic.
- The design tries to build more of the complete components offline. This way, the construction process needs more automation and can provide more flexibility.
- Wall height variation is fine to be built in factories.
- The cost of material for a prefabricated house is 10 percent less than that of onsite construction. The labor cost is 33 percent less as well.

APPENDIX E. CHARRETTE 4 OUTCOME (NPSJ WORKSHOP)

Led by the University of Florida's Florida Resilient Cities (FRC) program, partnering with the Florida A&M University Architecture program and the North Port St. Joe (NPSJ) Project Area Coalition (PAC), the May 2021 workshop leveraged ongoing university research (including the HUD-funded Advanced Modular Housing Design [AMHD] project) and outreach efforts to provide innovative housing, landscape, and public policy solutions to residents of NPSJ. Teams of university students, faculty, subject matter experts, practitioners, invited guests, and community members investigated and proposed solutions to community challenges across four main themes:

- Land tenure, policy, regulation, and finance.
- Modular housing design options for new construction.
- Stormwater, drainage, and ecological challenges.
- Mixed-use development on Martin Luther King Boulevard.

The workshop provided opportunities for specific lot owners and resident input on myriad design and policy challenges. The outcomes include a stronger relationship with stakeholders, collaborative connections between interdisciplinary problems, and introductions to future funders and organizations that will assist with capacity building and implementation of projects for community resilience.

Objectives

The NPSJ workshop's first main goal was to develop actionable ideas and projects that would rebuild the neighborhood. Connecting affordable housing design, public policy, flood mitigation, and urban development issues that often are considered separately into a comprehensive overview was another goal, as well as helping community members see opportunities to improve their homes, lots, and neighborhoods through their own actions. Finally, giving the community members a chance to express their concerns and be heard and understood by the decisionmakers and funders who often do not hear from them was a valuable objective to achieve in this workshop.

Workshop Schedule

Due to COVID-19, the workshop was held online using Zoom. The workshop engaged community stakeholders, elected officials, policymakers, and funders through a series of interactive events:

- Saturday Community Meetings—May 1, 8, and 15, 1:00–3:00. The PAC hosted meetings for community members to bring their specific projects, concerns, and ideas to the table. These sessions allowed community members to interact with the teams to make their voices heard.
- Team Presentations—Monday, May 3, 4:00–6:00. These sessions featured short presentations focused on each theme for the community to learn about the four topics of the workshop and potential remedies that the teams will consider.
- Working Sessions—Thursday and Friday, 9:00–12:00. Work sessions allowed teams to work while incorporating stakeholder concerns, researching solutions, and developing designs and proposals. These sessions gave faculty and students time to hear from individual community members, discuss ideas with outside experts, and propose new ideas.

- Implementation Workshop—Friday, May 21, 12:00–2:00. The team hosted an online forum to present the workshop results, garner feedback, and engage potential partners in the future development and funding of projects.

Modular Housing Design Options for New Construction

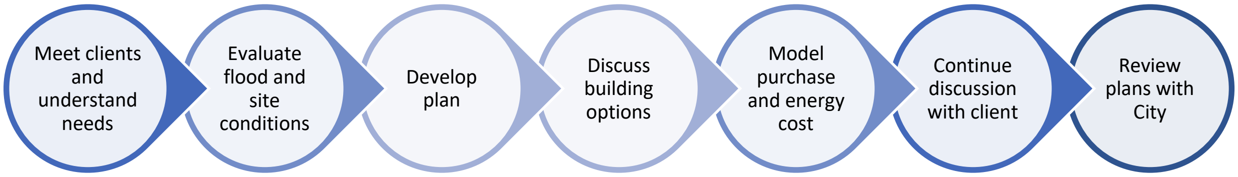
The modular housing team applied Core+ in the workshop to address housing challenges in NPSJ. The team's vision was to identify the modular housing design options that can meet community members' needs for housing that is affordable, rapidly constructed, resilient, and energy efficient.

AMHD Team's Objectives

The AMHD team aimed to work on site-specific housing concerns and opportunities for a new single-family modular home. In this workshop, AMHD was able to use the Core+ model to design, specify, and price the home at six sites suggested by community members. It was also important to work with NPSJ clients to fit the home to their space needs, site conditions, and budgets, which resulted in refining the design.

It was also an important goal for the team to coordinate with the city to ensure that the home met all local zoning and building codes and to work with external funders, including HUD, to determine a future for the Core+ model in NPSJ.

Design Process



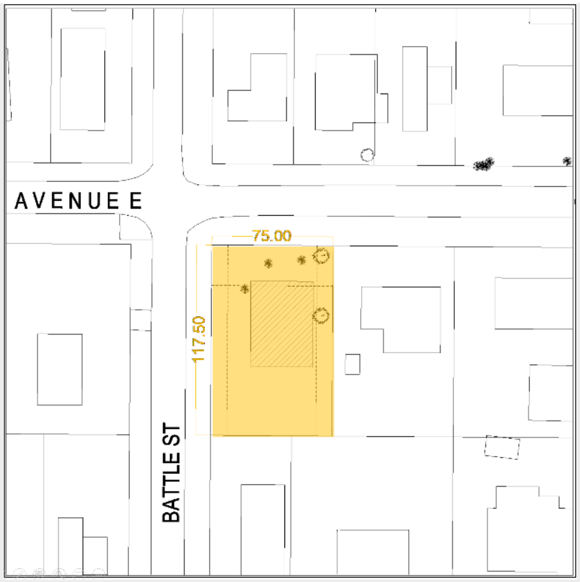
The design development started with conversations with community members as potential clients to understand their needs. Six potential sites were suggested by the community members (exhibit 99). The design team evaluated the flood zone and other site conditions and then developed specific plans shaped by Core+ for each of the six sites (exhibits 100 to 111).

Various building options were discussed with the community members. The team received valuable feedback from community members and lot owners. Each site had different orientations and specifications, and the owner's requirements were modeled to estimate cost and energy consumption.

Exhibit 99. Six Study Sites Selected by North Port St. Joe, Where the Team Tested the Core+ Model

Source: Google Maps

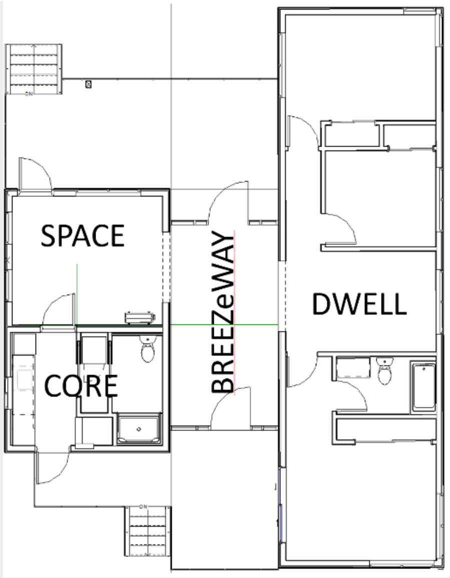
Site 1: 403 BATTLE ST



Site Description:

The site is located in Gulf County, Sandy Quinn district, at Battle Street and Avenue E, with the parcel number 05927-000R. It is placed longitudinally in a north-south orientation, with the dimensions of 75 ft length and 117.5 ft width, and the lot size is 0.2 acre.

The site is occupied by one building, constructed in 1965, which is a single-family house with a total area of 1,839 ft^2. The flood zone is A, and the site is north facing. It is located at the corner of the street, with a wide lot and no alley.



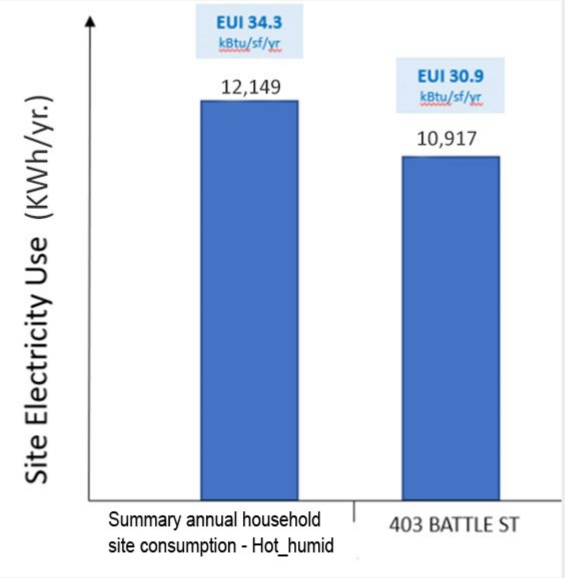
Design Recommendations:

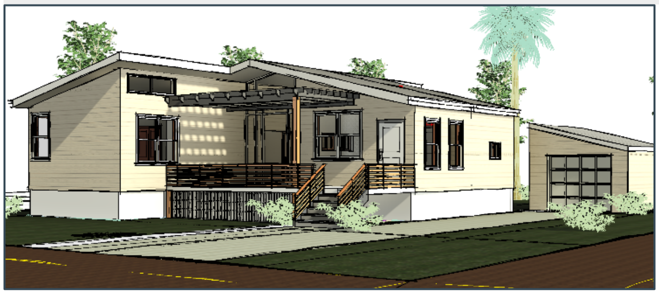
- Large front porch
- Backyard deck
- Single-car garage
- Breezeway between units
- Energy savings: $162/ year

Exhibit 100. Cost Estimation for Applying Core+ at Site Number 1

Cost of Units	Deck Cost	Breezeway Cost	One-Car Garage Detached Cost	Covered Porch Cost	Deck skirting cost	Driveway/Walkway Cost	Parging and Paint Cost	Total Cost
$131,000	$10,516	$8,775	$20,000	$8,100	$2,016	$4,340	$1,225	**$185,972**

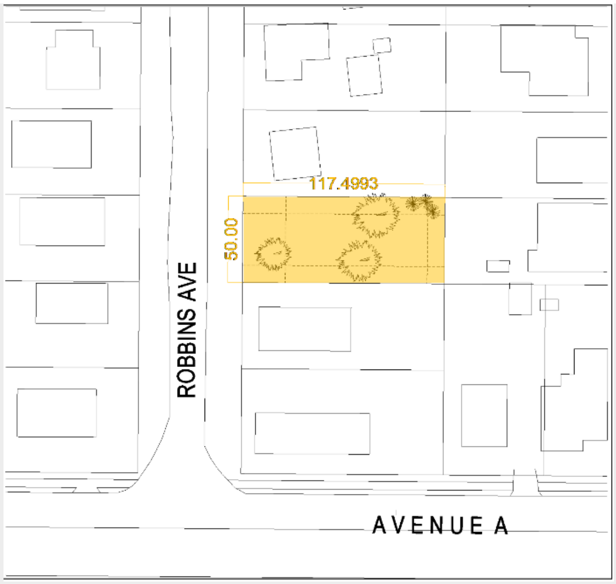
Exhibit 101. The Comparison of Energy Consumption of Core+ with a Regular House at the Same Site





EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. sf = square feet.

Site 2: 115 ROBBINS AVE



Site Description:

The site is placed on Robbins Avenue and is near the intersection of Robbins Avenue and Avenue A, with three lots distance, with the parcel number 04618-000R. It is placed transversally in an east-west orientation, with the dimensions of 117.5 ft length and 50.00 ft width, and the lot size is 0.13 acre.

The site is vacant, and the flood zone is X. It is a mid-block with a narrow lot and no alley.

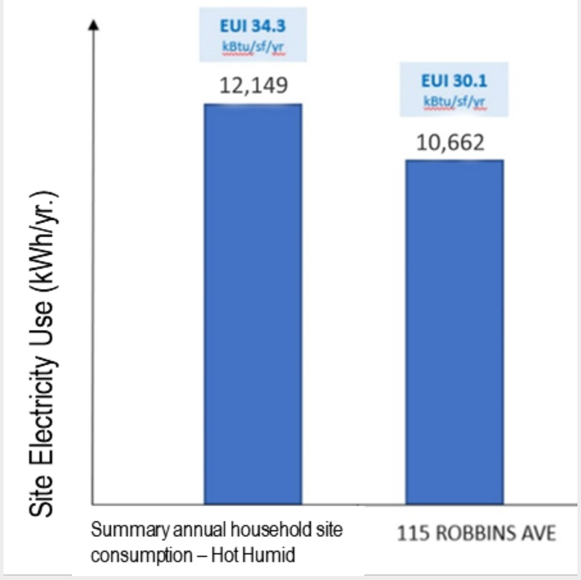
Design Recommendations:

- Larger front porch and backyard deck
- 3-ft elevation is sufficient for flood recommendation —
- Energy savings: $196/year

Exhibit 102. Cost Estimation for Applying Core+ at Site Number 2

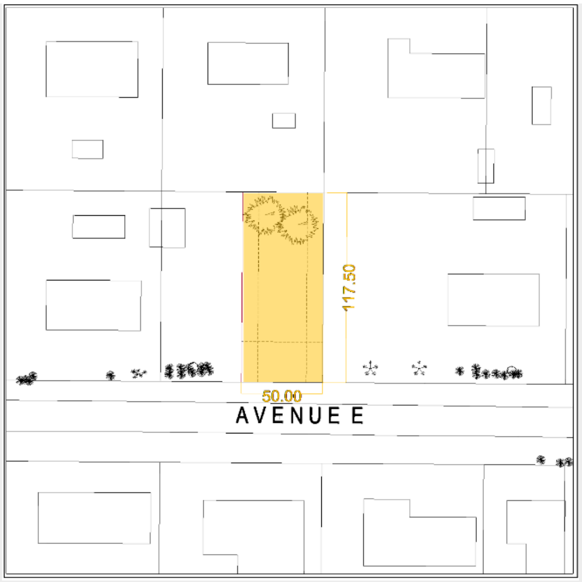
Cost of Units	Deck Cost	Deck Skirting cost	Driveway/Walkway Cost	Parging and Paint cost	Total Cost
$131,000	$7,986	$1,716	$2,170	$1,092	**$143,967**

Exhibit 103. The Comparison of Energy Consumption of Core+ with a Regular House at the Same Site



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. sf = square feet.

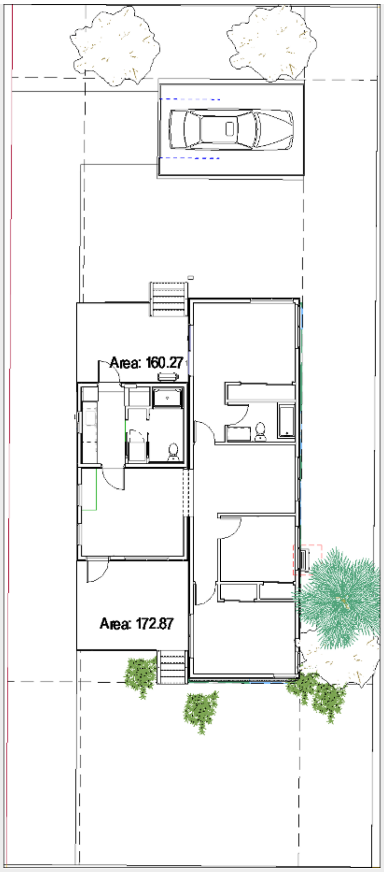
Site 3: 311 AVE E



Site Description:

The site is located on Avenue E, with the parcel number 05921-000R. It is placed longitudinally in a north-south orientation, with the dimensions of 117.5 ft length and 50 ft width, and the lot size is 0.13 acre. The site is vacant. Buildings occupy all other lots surrounding the site.

The site flood zone is X, and it is south facing. It is a mid-block, narrow lot with no alley.



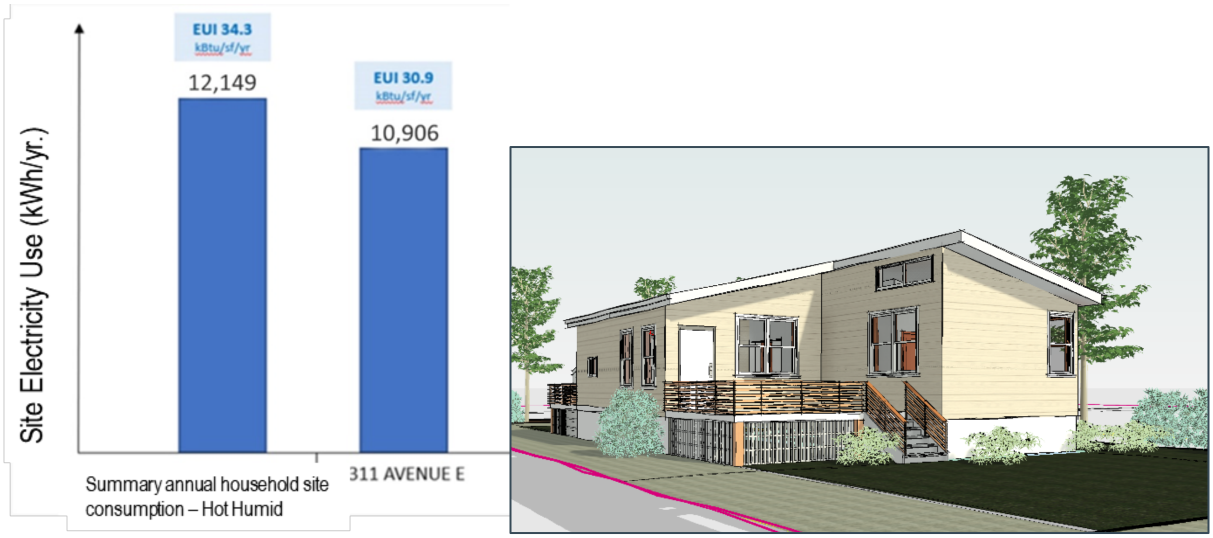
Design Recommendations:

- Front porch and backyard deck
- Backyard one-car garage
- Energy savings: $170/year

Exhibit 104. Cost Estimation for Applying Core+ at Site Number 3

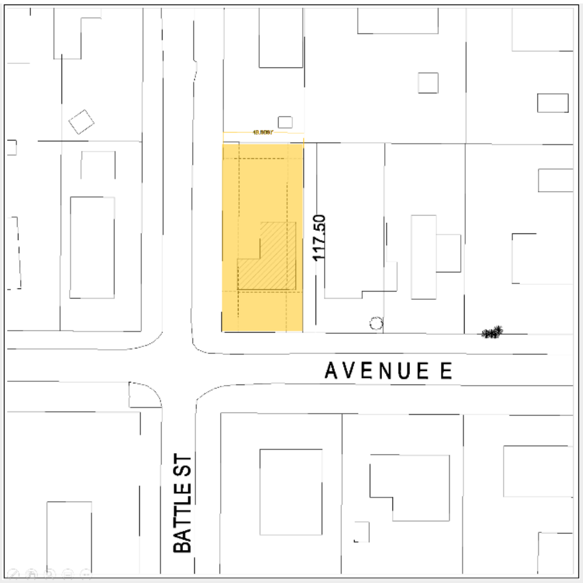
Cost of Units	Deck Cost	Deck Skirting Cost	Driveway/Walkway Cost	Parging and Paint Cost	Total Cost
$131,000	$9,994	$1,860	$6,727	$1,053	**$ 150,634**

Exhibit 105. The Comparison of Energy Consumption of Core+ with a Regular House at the Same Site



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. sf = square feet.

Site 4: 301 AVE E



Site Description:

The site is located on the northeast side of the intersection of Battle Street and Avenue E, with the parcel number 05914-000R. The Avenue E width is roughly 19 ft, and that of Battle Street is 20 ft. It is placed longitudinally in a north-south orientation, with the dimensions of 117.5 ft length and 50.0 ft width, and the lot size is 0.13 acre.

The site is occupied by one building, constructed in 1970, which is a single-family house with a total area of 1,192 ft^2.

The flood zone is A, and the site is south facing, located at the corner of the street with a narrow lot and no alley.

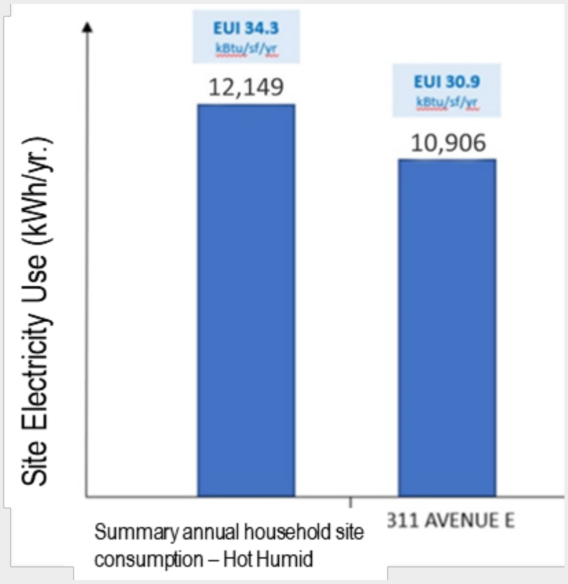
Design Recommendations:

- Front porch
- Backyard deck
- Backyard one-car garage
- Energy savings: $170/year

Exhibit 106. Cost Estimation for Applying Core+ at Site Number 4

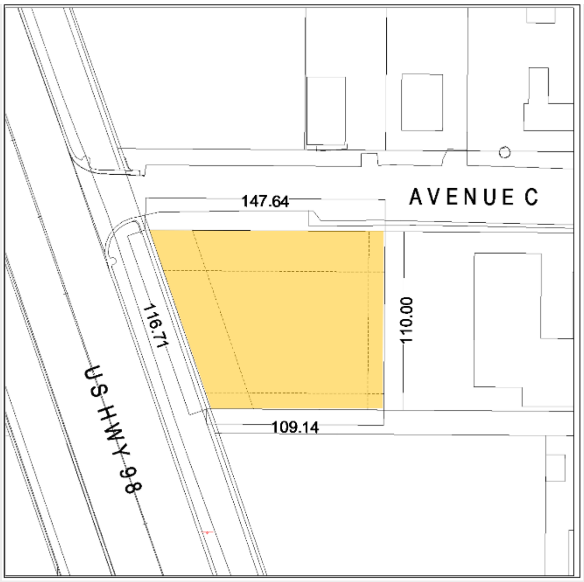
Cost of Units	Deck Cost	Deck Skirting Cost	Driveway/Walkway Cost	Parging and Paint Cost	Total Cost
$131,000	$10,693	$1,860	$1,934	$1,053	**$ 146,540**

Exhibit 107. The Comparison of Energy Consumption of Core+ with a Regular House at the Same Site



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. sf = square feet.

Site 5: 144 AVE C



Site Description:

The site is located at the intersection of Avenue C and Monument Avenue, with the parcel number 05724-050R. Its dimensions are 110.0 ft, 109.14 ft, 147.64 ft, and 116.71 ft, and the site area is 0.330 acre.

The site is vacant, and the flood zone is AE. It is north facing and adjacent to US HWY 98, with a wide lot that has access to an alley.

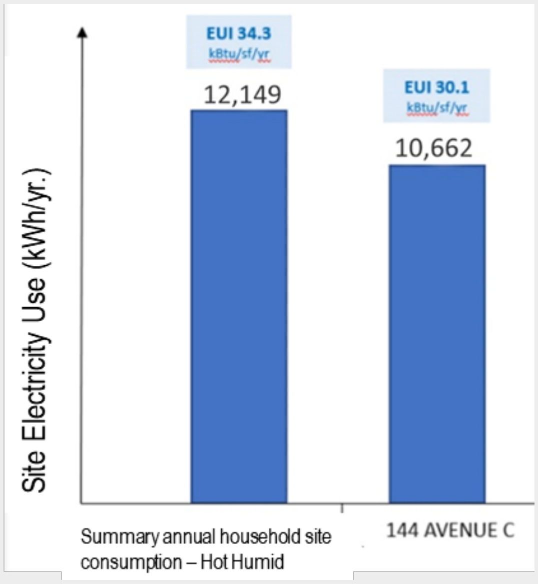
Design Recommendations:

- Front porch
- Backyard deck
- Backyard one-car garage
- Energy savings: $196/year

Exhibit 108. Cost Estimation for Applying Core+ at Site Number 5

Cost of Units	**Deck Cost**	**One-Car Garage Detached**	**Deck Skirting Cost**	**Fence Cost**	**Driveway/ Walkway Cost**	**Parging and Paint Cost**	**Total Cost**
$131,000	$12,429	$20,000	$2,784	$2,925	$3,081	$878	**$173,097**

Exhibit 109. The Comparison of Energy Consumption of Core+ with a Regular House at the Same Site

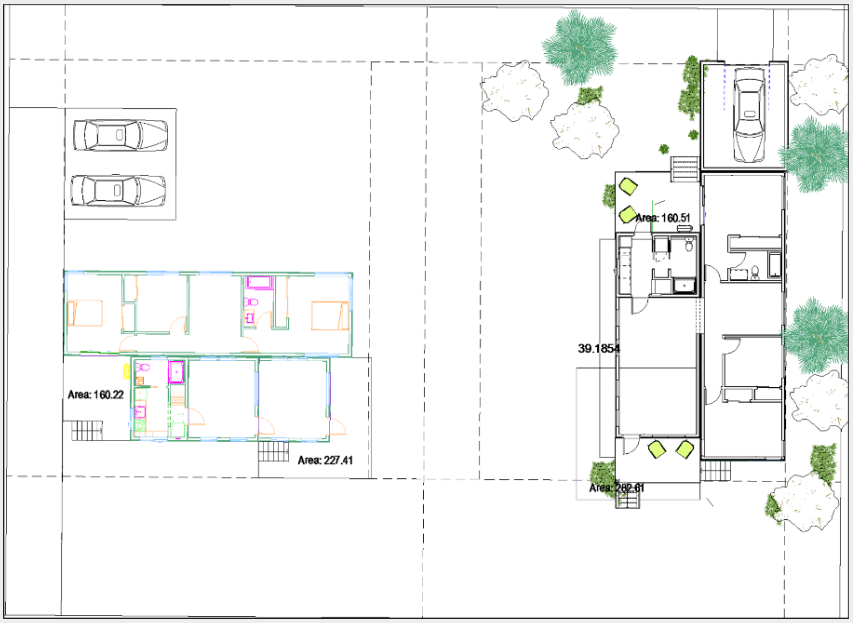


EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. sf = square feet.

Site 6: AVE A

Site Description:

The site dimensions are 150 ft length and 110 ft width, and the lot size is 0.37 acre. The site is vacant and south facing. It is a mid-block site, with a medium-size (75 ft) lot and access to an alley. The flood zone is A



Design Recommendations:

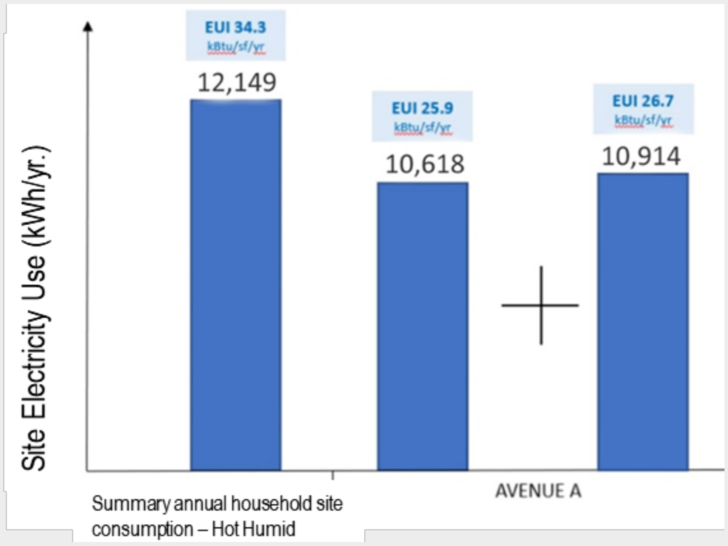
- Front porch
- Backyard deck
- Added space
- Garage
- Energy savings: $364/year

Exhibit 110. Cost Estimation for Applying Core+ at Site Number 6

Cost of Units	**Deck Cost**	**One-Car Garage, Detached**	**Larger Space Cost**	**Deck Skirting Cost**	**Additional CMU Courses for Crawl Space**	**Crawl Space Cost ($500 per course)**	**Driveway/ Walkway Cost**	**Parging and Paint Cost**	**Total Cost**
$131,000	$11,628	$20,000	$22,050	$3,915	3	$1,500	$6,064	$1,550	$197,707

CMU = concrete masonry unit.

Exhibit 111. The Comparison of Energy Consumption of Core+ with a Regular House at the Same Site



EUI = energy use intensity. kBtu = kilo British Thermal Unit. kWh/yr = kilowatt-hours per year. sf = square feet.

Workshop Outcomes

The NPSJ workshop of May 2021 led Modular Housing, Housing Policy, Stormwater and Landscape, and Mixed-Use Development groups on MLK Blvd. to work toward an overall vision for North Port St. Joe. The collaborative sessions with community members and the ability to work between groups led to a better understanding of community goals, challenges, and strengths. Each group responded to the community's goals and challenges with an overall design solution and future steps.

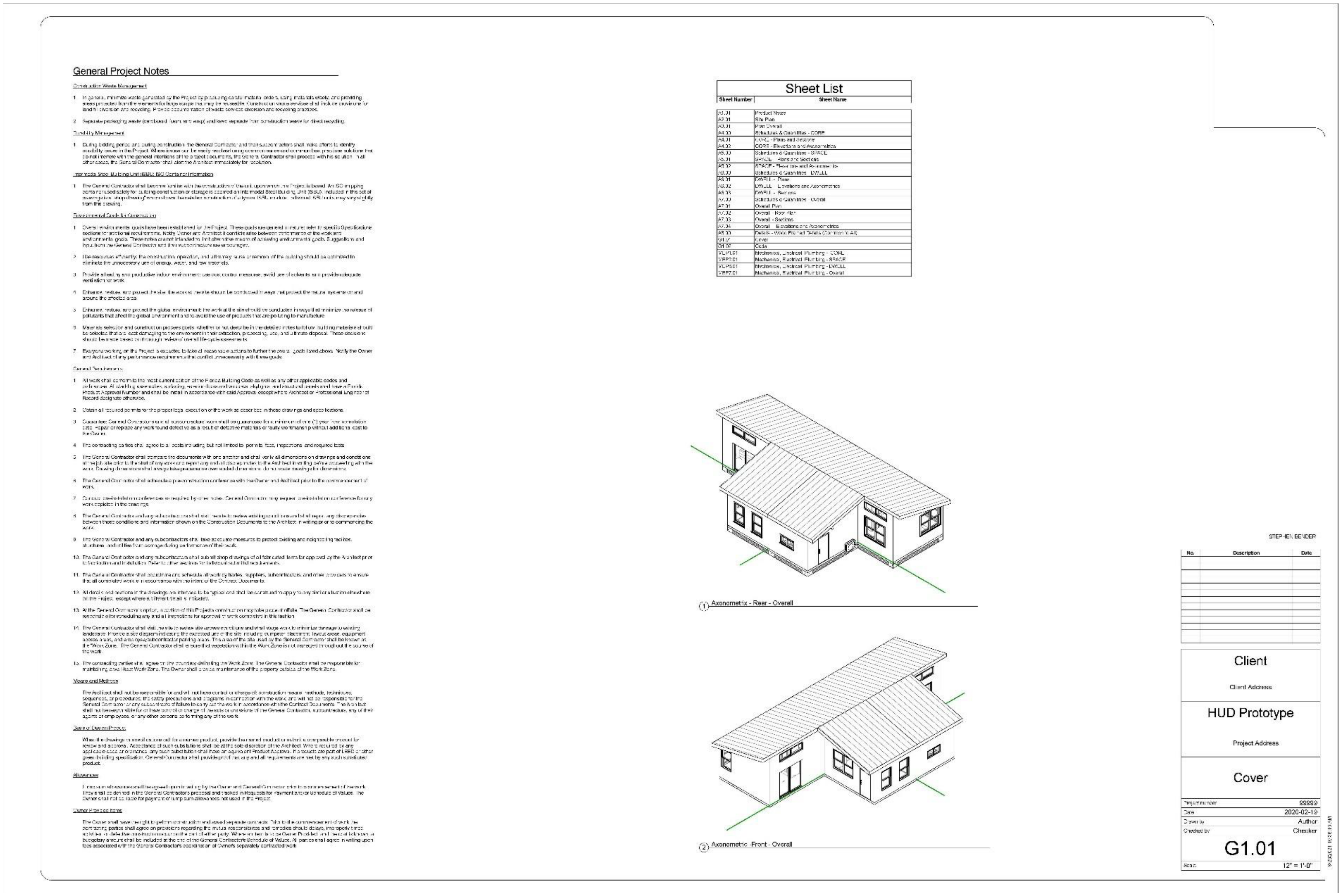
The Modular Housing group proposed a Core+ housing design that addresses long-term resiliency and affordability issues. Core+ could be considered the first essential step to address community housing challenges, with potential for future development by the lot owners. The next steps for modular housing are to coordinate with the City of Port St. Joe to ensure that housing design meets all local zoning and building codes and to work with external funders, including HUD, to determine a path forward for the Core+ model in North Port St. Joe.

The Housing Policy group extensively researched policies and programs that addressed property ownership, maintenance, and repairs issues. The specific focus was on wealth building, parcel redevelopment, land development codes, and overall resilience post-Hurricane Michael. By building trust with the North Port St. Joe Project Area Coalition, community residents, and other housing-related experts, the team provided a list of objectives that could begin tailoring to individual and family-specific needs, both immediate and long term. The objectives ranged from building repair to adding new housing stock, revitalizing the Washington recreation center, and addressing inconsistencies between the land development code and neighborhood character. The next steps for the housing policy group are to provide further details regarding the various funding programs and insurance options and to prioritize certain projects using an implementation timeline.

The Stormwater and Landscape group identified opportunities for green infrastructure improvements in North Port St. Joe to reduce residential flooding, enhance community open space, and improve water quality. The group developed a three-tier strategy that includes developing stormwater capture and treatment at the neighborhood, street, and parcel scales. The total project stormwater capacity is 7.05 million gallons. The design has the potential to improve water quality through nutrient and other pollutant load reduction. Next steps include moving forward with the overall stormwater master plan for North Port St. Joe and continuing conversations with potential funders.

The Martin Luther King Boulevard Mixed-Use Development group focused on redevelopment through walkability, improved streetscapes, identifying key small businesses, and working in parallel with stormwater strategies that will create public space for events and gatherings. Overall, the group demonstrated that an investment in physical and social infrastructure could activate and support the North Port St. Joe community. The MLK Mixed-Use Development plan focuses on walkability, civic anchors, small business development, gathering spaces, gentle density, and regional connections. The next steps are to work with local collaborators and potential state and federal funders.

APPENDIX F. CONSTRUCTION DOCUMENTS



General Project Notes

Sheet Number	Sheet Name
A1.01	Product Notes
A2.01	Site Plan
A3.01	Plan Overall
A4.00	Schedules & Quantities - CORE
A4.01	CORE - Plans and Sections
A4.02	CORE - Elevations and Axonometrics
A5.00	Schedules & Quantities - SPACE
A5.01	SPACE - Plans and Sections
A5.02	SPACE - Elevations and Axonometrics
A6.00	Schedules & Quantities - DWELL
A6.01	DWELL - Plans
A6.02	DWELL - Elevations and Axonometrics
A6.03	DWELL - Sections
A7.00	Schedules & Quantities - Overall
A7.01	Overall Plan
A7.02	Overall - Roof Plan
A7.03	Overall - Sections
A7.04	Overall - Elevations and Axonometrics
A8.00	Details - Wood Framed Details (Common to All)
G1.01	Cover
G1.02	Code
MEP1.01	Mechanical, Electrical, Plumbing - CORE
MEP2.01	Mechanical, Electrical, Plumbing - SPACE
MEP6.01	Mechanical, Electrical, Plumbing - DWELL
MEP7.01	Mechanical, Electrical, Plumbing - Overall

1 Axonometric - Rear - Overall

2 Axonometric - Front - Overall

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Cover

Project number 99999
Date 2020-02-19
Drawn by Author
Checked by Checker

G1.01

Scale 12" = 1'-0"

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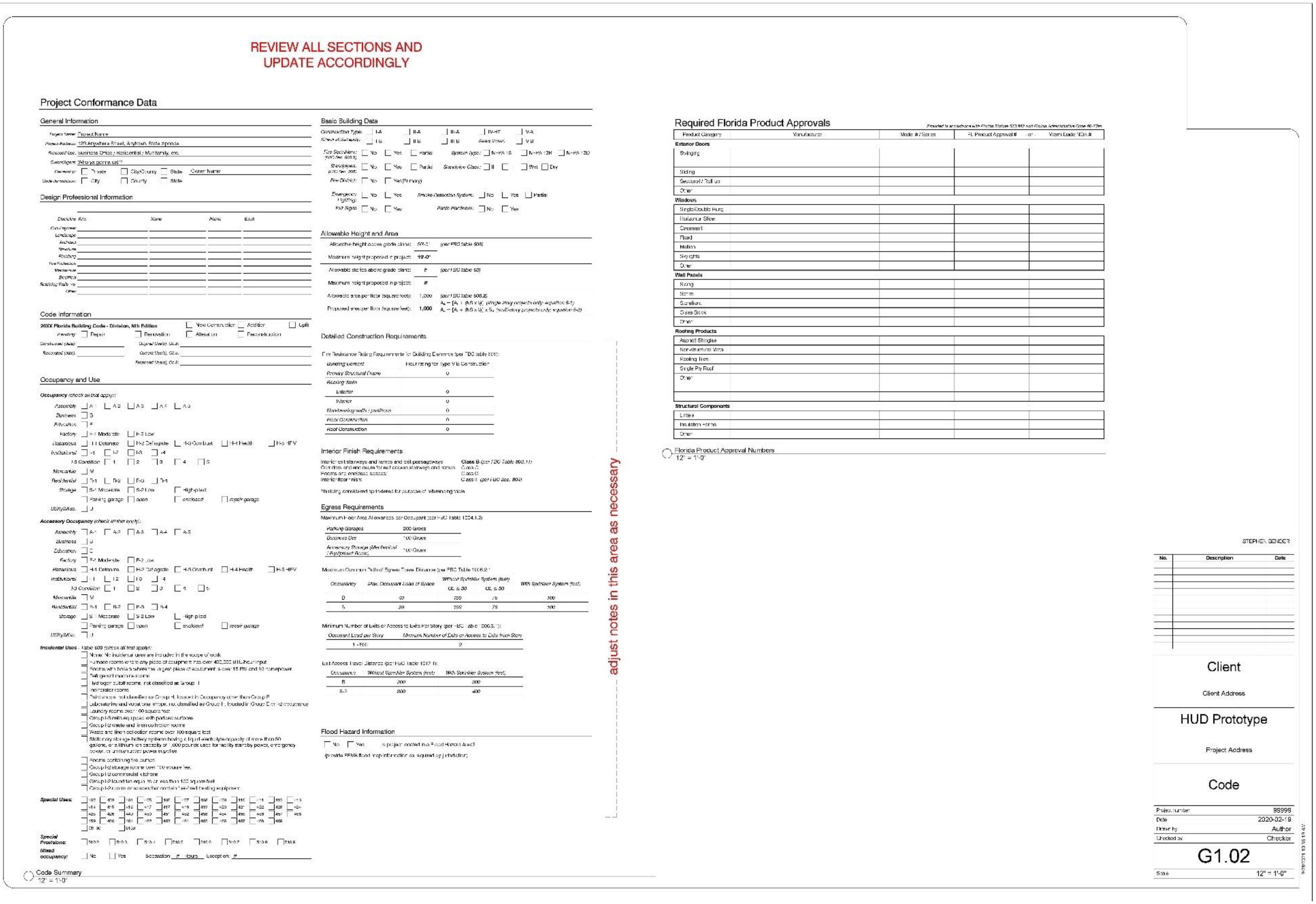

REVIEW ALL SECTIONS AND
UPDATE ACCORDINGLY

Project Conformance Data

General Information

Project Name: Project Name
Project Address: 123 Anywhere Street, Anytown, State zipcode
Proposed Use: Business Office / Residential / Multifamily, etc.
Owner/Agent: Who ya gonna call?
Ownership: ☐ Private ☐ City/County ☐ State Owner Name
Code Jurisdiction: ☐ City ☐ County ☐ State

Design Professional Information

Discipline	Firm	Name	Phone	Email
Civil Engineer				
Landscape				
Architect				
Structural				
Plumbing				
Fire Protection				
Mechanical				
Electrical				
Retaining Walls etc				
Other				

Code Information

20XX Florida Building Code - Division, Nth Edition ☐ New Construction ☐ Addition ☐ Upfit
Existing: ☐ Repair ☐ Renovation ☐ Alteration ☐ Reconstruction
Constructed (date): ______ Original Use(s), Ch. 3: ______
Renovated (date): ______ Current Use(s), Ch. 3: ______
Proposed Use(s), Ch. 3: ______

Occupancy and Use

Occupancy (check all that apply):
Assembly ☐ A-1 ☐ A-2 ☐ A-3 ☐ A-4 ☐ A-5
Business ☐ B
Education ☐ E
Factory ☐ F-1 Moderate ☐ F-2 Low
Hazardous ☐ H-1 Detonate ☐ H-2 Deflagrate ☐ H-3 Combust ☐ H-4 Health ☐ H-5 HPV
Institutional ☐ I-1 ☐ I-2 ☐ I-3 ☐ I-4
I-3 Condition ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Mercantile ☐ M
Residential ☐ R-1 ☐ R-2 ☐ R-3 ☐ R-4
Storage ☐ S-1 Moderate ☐ S-2 Low ☐ High-piled
☐ Parking garage ☐ open ☐ enclosed ☐ repair garage
Utility/Misc. ☐ U

Accessory Occupancy (check all that apply):
Assembly ☐ A-1 ☐ A-2 ☐ A-3 ☐ A-4 ☐ A-5
Business ☐ B
Education ☐ E
Factory ☐ F-1 Moderate ☐ F-2 Low
Hazardous ☐ H-1 Detonate ☐ H-2 Deflagrate ☐ H-3 Combust ☐ H-4 Health ☐ H-5 HPV
Institutional ☐ I-1 ☐ I-2 ☐ I-3 ☐ I-4
I-3 Condition ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Mercantile ☐ M
Residential ☐ R-1 ☐ R-2 ☐ R-3 ☐ R-4
Storage ☐ S-1 Moderate ☐ S-2 Low ☐ High-piled
☐ Parking garage ☐ open ☐ enclosed ☐ repair garage
Utility/Misc. ☐ U

Incidental Uses - Table 509 (check all that apply):
- ☐ None: No incidental uses are included in the scope of work
- ☐ Furnace rooms where any piece of equipment has over 400,000 BTU/hour input
- ☐ Rooms with boilers where the largest piece of equipment is over 15 PSI and 10 horsepower
- ☐ Refrigerant machine rooms
- ☐ Hydrogen cutoff rooms, not classified as Group H
- ☐ Incinerator rooms
- ☐ Paint shops, not classified as Group H, located in Occupancy other than Group F
- ☐ Laboratories and vocational shops, not classified as Group H, located in Group E or I-2 occupancy
- ☐ Laundry rooms over 100 square feet
- ☐ Group I-3 cells equipped with padded surfaces
- ☐ Group I-2 waste and linen collection rooms
- ☐ Waste and linen collection rooms over 100 square feet
- ☐ Stationary storage battery systems having a liquid electrolyte capacity of more than 50 gallons, or a lithium ion capacity of 1,000 pounds used for facility standby power, emergency power, or uninterrupted power supplies
- ☐ Rooms containing fire pumps
- ☐ Group I-2 storage rooms over 100 square feet
- ☐ Group I-2 commercial kitchens
- ☐ Group I-2 laundries equal to or less than 100 square feet
- ☐ Group I-2 rooms or spaces that contain fuel-fired heating equipment

Special Uses:
☐ 402 ☐ 403 ☐ 404 ☐ 405 ☐ 406 ☐ 407 ☐ 408 ☐ 409 ☐ 410 ☐ 411 ☐ 412 ☐ 413
☐ 414 ☐ 415 ☐ 416 ☐ 417 ☐ 417 ☐ 418 ☐ 419 ☐ 420 ☐ 421 ☐ 422 ☐ 423 ☐ 424
☐ 425 ☐ 426 ☐ 449 ☐ 450 ☐ 451 ☐ 452 ☐ 453 ☐ 454 ☐ 455 ☐ 456 ☐ 457 ☐ 458
☐ 459 ☐ 460 ☐ 461 ☐ 462 ☐ 463 ☐ 464 ☐ 465 ☐ 466 ☐ 467 ☐ 468 ☐ 468
☐ Ch. 30 ☐ 3109

Special Provisions: ☐ 510.2 ☐ 510.3 ☐ 510.4 ☐ 510.5 ☐ 510.6 ☐ 510.7 ☐ 510.8 ☐ 510.9

Mixed occupancy: ☐ No ☐ Yes Separation # Hours Exception: #

Code Summary
12" = 1'-0"

Basic Building Data

Construction Type: ☐ I-A ☐ II-A ☐ III-A ☐ IV-HT ☐ V-A
(Check all that apply) ☐ I-B ☐ II-B ☐ III-B Heavy Timber ☐ V-B
Fire Sprinklers: (FBC Sec. 903.3) ☐ No ☐ Yes ☐ Partial System type: ☐ NFPA 13 ☐ NFPA 13R ☐ NFPA 13D
Standpipes: (FBC Sec. 905) ☐ No ☐ Yes ☐ Partial Standpipe Class: ☐ II ☐ ☐ Wet ☐ Dry
Fire District: ☐ No ☐ Yes(Primary)
Emergency Lighting: ☐ No ☐ Yes Smoke Detection System: ☐ No ☐ Yes ☐ Partial
Exit Signs: ☐ No ☐ Yes Panic Hardware: ☐ No ☐ Yes

Allowable Height and Area

Allowable height above grade plane: 60'-0" (per FBC table 504)
Maximum height proposed in project: 19'-0"
Allowable stories above grade plane: # (per FBC table 504)
Maximum height proposed in project: #
Allowable area per floor (square feet): 1,000 (per FBC table 506.2)
Proposed area per floor (square feet): 1,000
$A_a = [A_t + (NS \times I_f)]$ (single story projects only: equation 5-1)
$A_a = [A_t + (NS \times I_f)] \times S_a$ (multi-story projects only: equation 5-2)

Detailed Construction Requirements

Fire Resistance Rating Requirements for Building Elements (per FBC table 601):

Building Element	Hour rating for Type V B Construction
Primary Structural Frame	0
Bearing Walls	
Exterior	0
Interior	0
Nonbearing walls / partitions	0
Floor Construction	0
Roof Construction	0

Interior Finish Requirements

Interior exit stairways and ramps and exit passageways	**Class B** (per FBC Table 803.11)
Corridors and enclosure for exit access stairways and ramps	Class C
Rooms and enclosed spaces:	Class C
Interior floor finish:	Class II (per FBC Sec. 804)

*building considered sprinklered for purpose of referencing table

Egress Requirements

Maximum Floor Area Allowances per Occupant (per FBC Table 1004.1.2)

Parking Garages	200 Gross
Business Use	100 Gross
Accessory Storage (Mechanical / Equipment Room)	100 Gross

Maximum Common Path of Egress Travel Distance (per FBC Table 1006.2.1)

Occupancy	Max. Occupant Load of Space	Without Sprinkler System (feet)		With Sprinkler System (feet)
		OL ≤ 30	OL ≤ 30	
B	49	100	75	100
S	29	100	75	100

Minimum Number of Exits or Access to Exits Per Story (per FBC Table 1006.3.1):

Occupant Load per Story	Minimum Number of Exits or Access to Exits from Story
1 - 500	2

Exit Access Travel Distance (per FBC Table 1017.2):

Occupancy	Without Sprinkler System (feet)	With Sprinkler System (feet)
B	200	300
S-2	300	400

Flood Hazard Information

☐ No ☐ Yes Is project located in a Flood Hazard Area?
(provide FEMA flood map information as required by jurisdiction)

adjust notes in this area as necessary

Required Florida Product Approvals

Provided in accordance with Florida Statute 553.842 and Florida Administrative Code 9B-72

Product Category	Manufacturer	Model # / Series	FL Product Approval # -or-	Miami-Dade NOA #
Exterior Doors				
Swinging				
Sliding				
Sectional / Roll up				
Other				
Windows				
Single/Double Hung				
Horizontal Slider				
Casement				
Fixed				
Mullion				
Skylights				
Other				
Wall Panels				
Siding				
Soffits				
Storefront				
Glass Block				
Other				
Roofing Products				
Asphalt Shingles				
Non-structural Metal				
Roofing Tiles				
Single Ply Roof				
Other				
Structural Components				
Lintels				
Insulation Forms				
Other				

Florida Product Approval Numbers
12" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client
Client Address

HUD Prototype
Project Address

Code

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

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Scale	12" = 1'-0"

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PRODUCT NOTES

OWNER SUPPLIED ITEMS
Refer to separate schedule for any owner supplied items.

EARTHWORK, TERMITE CONTROL, CONCRETE, MASONRY, METALS, EARTHWORK
Refer to Structural Drawings.

CARPENTRY

1. NOTICE TO WOOD PRODUCT SUPPLIERS: The Owner prefers to purchase wood products that are certified according to the guidelines of the Forest Stewardship Council (FSC). The Owner also prefers not to use any tropical wood or wood products. If any tropical wood or wood products are supplied, they must be FSC certified. Please provide the country of manufacture of each product expected to be supplied, as well as a list of FSC certified products that are available.
2. Refer to Structural Drawings for structural framing/lumber requirements.
3. Provide BLOCKING in walls for mounting kitchen and bathroom casework and accessories.
4. All framed wall cavities shall have FIREBLOCKING installed in concealed spaces of stud walls and partitions including furred spaces at ceiling and floor levels, at all interconnections between concealed vertical and horizontal spaces such as those that occur at soffits, drop ceilings, cove ceilings, and at openings around vents, pipes, ducts, chimneys, and fireplaces at ceiling and floor levels.
5. PRESERVATIVE TREATMENT: ACQ, except that lumber that is not in contact with the ground and is continuously protected from liquid water may be treated according to AWPA C31 with inorganic borate (SBX). Refer to Structural Drawings for additional requirements.
6. TREAT ITEMS INDICATED ON DRAWINGS, AND THE FOLLOWING: wood cants, nailers, curbs, equipment support bases, blocking, stripping, and similar members in connection with roofing, flashing, vapor barriers, and waterproofing. Wood sills, sleepers, blocking, furring, stripping, and similar concealed members in contact with masonry or concrete. Wood framing members less than 18 inches above grade. Wood floor plates that are installed over concrete slabs directly in contact with earth.
7. INTERIOR STANDING AND RUNNING TRIM, OPAQUE FINISH: 3/4 inch (U.N.O.) smooth medium density fiberboard (MDF) formaldehyde-free, pre-primed. Square edge profile with eased corner.
8. HDPE Plastic: 0.375 inch HD polyethylene sheet material, recycled preferred (black) or "Natural" (white).

BUILDING INSULATION

1. EXTERIOR WALLS (interior side): NeoFast PLUS system, EX 2.5 Engineered Insulated ribbed foam panel system incorporating a drainage plane, wiring and utility chases, and molded attachment studs, with an additional layer of 1" of Rigid Board Insulation. http://neofast.com/. Add a layer of rigid board insulation, EPS or XPS, with minimum R-value of 5 where indicated in drawings.
2. INTERIOR CEILING: NeoFast system, EX 2.5 Engineered insulated ribbed foam panel system incorporating a drainage plane, wiring and utility chases, and molded attachment studs. http://insofast.com/
3. INTERIOR WALLS/ACOUSTICAL CONTROL: Dense Spray-Applied Cellulose or glass fiber batts containing minimum 25% post-consumer recycled content.
4. INTERIOR CEILING: glass fiber batts containing minimum 25% post-consumer recycled content, non-combustible, fire block rated.
5. INTERIOR WALLS / ACOUSTICAL INSULATION: glass fiber batts containing minimum 25% post consumer recycled content, non-combustible, fire block rated.
6. CONCEALED COMBUSTIBLE SPACES: all combustible concealed spaces shall be filled with non-combustible insulation.
7. FOAM SEALANT: for filling small gaps (<1/2 inch) use minimal expansion closed-cell polyurethane insulating foam sealant. Named product: "GREAT STUFF Gaps & Cracks" by Dow. For filling large gaps and holes (>1/2 inch) use insulating foam sealant with greater insulation properties. Named product: "GREAT STUFF Big Gap Filler". For sealing windows and doors use a one component, minimal-expanding, low pressure-build, flexible polyurethane foam. Named product: "GREAT STUFF PRO Window & Door Insulating Foam Sealant". [Environmental alternative foam sealant named product: "XtraFoam" minimal expanding foam sealant family: http://premierindustrial.net/index.html]

CLADDING
—

ROOF SYSTEM

1. ROOF SYSTEM COATING: LANCO Ultra Siliconizer RC-905 (100% Acrylic Silicone Roof Membrane) for sealing surfaces in a monolithically way. Designed for concrete surfaces, metal, wood, asphalt membranes and EPDM. May be applied with roller, brush or spray - airless. Use Lanco Red Oxide Primer on rusted metal. Before application of elastomeric coating SBU be sure that water does not stand on roof surface. For level corrections use Lanco Ultra Level self-leveling underlayment according to label instructions. Rusty metal must be cleaned with a wire brush and primed with Lanco Gray Oxide Primer, a rust inhibitive metal primer. Cracks, seams, and flashing must be clean and dry. With a putty knife, apply Lanco Siliconizer Crack Filler and Fiber Glass Patching Weave over cracks, seams, flashing, screws and any other standing objects. Be certain all surfaces are properly rinsed and dry prior to applying coating.

JOINT SEALANTS

1. GENERAL: Minimize use of sealants, caulks and adhesives through proper installation of building components and proper lapping of flashing, building paper and trim.
2. EXTERIOR GENERAL USE: single component polyurethane conforming to ASTM C920, Type S, Class 25, Grade NS; one part silicone sealant, VOC content maximum 15 grams/liter. Acrylic/silicone water-based sealant, VOC content maximum 31 grams/liter.
3. EXTERIOR CONCEALED JOINTS AND UNDER THRESHOLDS: one part butyl rubber caulk conforming to FS TT-S-001657, Type I.
4. EXTERIOR CONCEALED JOINTS: between two assembled rigid surfaces in compression: polyisobutylene sealant tape conforming to AAMA 804.1.
5. EXTERIOR AND INTERIOR HORIZONTAL JOINTS subject to pedestrian traffic: two-part polyurethane conforming to ASTM C920, Class 25, Type M, self-leveling; zero-VOC, one-part polyurethane, VOC content maximum 45 grams/liter.
6. INTERIOR NON-WET AREAS: one component acrylic latex water based sealant conforming to ASTM C834, VOC content maximum 42 grams/liter.
7. INTERIOR WET AREAS: one part, mildew resistant silicone rubber conforming to ASTM C920, Type S, Class 25, Grade NS.
8. Provide joint sealants, backings, and other related materials that are compatible with one another and with joint substrates under conditions of service and application, as demonstrated by sealant manufacturer, based on testing and field experience.
9. Provide and install sealant backings of material and type that are non staining; are compatible with joint substrates, sealants, primers, and other joint fillers; and are approved for applications indicated by sealant manufacturer based on field experience and laboratory testing.
10. SLIP JOINTS: provide and install back up filler made of compressible closed cell polyethylene or its equivalent that will not bond to the sealant used to cover it.
11. Comply with recommendations in ASTM C1193 "Standard Guide for Use of Joint Sealants" for use of joint sealants as applicable to materials, applications, and conditions indicated.
12. COLOR:
    - Sealants used with exposed masonry shall match color of mortar joints.
    - Sealants used with unpainted concrete shall match color of adjacent concrete.
    - Sealants used with factory colored systems shall match system. Use manufacturer's sealants where required.
    - Color of sealants at other locations shall be light gray or aluminum, unless specified otherwise.
    - Interior caulking shall be light gray or white, unless specified otherwise.
13. Clean out all joints immediately before installing joint sealants.
14. All holes and gaps in wall cavities shall be sealed against the movement of air, including furred spaces at ceiling and floor levels, at all interconnections between concealed vertical and horizontal spaces such as those that occur at soffits, drop ceilings, cove ceilings, and at openings around vents, pipes, ducts, chimneys, and fireplaces at ceiling and floor levels. Penetrations from attic spaces into wall cavities shall be fully sealed with an approved caulk or sealant. All joints and penetrations through the floor, including plumbing pipes, conduits, chases, wiring, ductwork, and at floor-wall joints, shall be fully sealed with an approved caulk. Where large openings are created (such as at bathtub drains), rigid materials shall be used in conjunction with sealants to close and seal the openings.
15. ISOLIMATE SEAL: expanding foam sealant tape, 1 1/2" thick x 1" wide expanding foam sealant tape for metal roof closure.
16. BACKER ROD: closed cell backer rod.

DOORS AND DOOR HARDWARE

1. Exterior doors must meet design pressure (Wind Loads) as indicated in Structural Drawings.
2. EXTERIOR FLUSH DOORS: HM doors and frames by CECO, Curries, or similar. Butt frame type, 4 3/4" frame depth (single rabbet frame), insulated door leafs at exterior locations. Include stock and deadlock preparation. (or equivalent product with FL PA#)
3. EXTERIOR FLUSH-GLAZED SLIDING DOORS: Mr. Glass Doors and Windows Inc., series MG-1000 aluminum sliding door, (no nail fin) impact rated, insulated, standard non-recessed hardware (FL Product Approval # 19092.1)
4. INTERIOR FLUSH DOORS: Masonite International Corporation, masonite hardboard flush interior door, primed smooth, white.
5. LOCKSETS, DEADBOLTS: Commercial (A-Series) locks, levers, and deadbolts finish 626.
6. SWINGING DOOR HARDWARE: full mortise residential hinges, 3.5 x 3.5 x 0.365 gauge minimum steel - brushed chrome finish.

WINDOWS

1. Windows must meet design pressure (Wind Loads) as indicated in Structural Drawings. Windows shall be provided with tempered glass where required by code. Groupings of windows shall be mulled together with manufacturer supplied components.
2. WINDOWS, single hung: Mr. Glass Doors and Windows Inc. series MG 200 aluminum single hung window, flush frame (no nail fin) impact rated, insulated, no grill, primed for paint (or equivalent product with FL Product Approval # 20062.1)

GYPSUM WALL BOARD

1. GYPSUM SYSTEMS: gypsum wall board (GWB) with smooth plaster finish OR drywall with Magnum LEVEL COAT at Contractor's option.
2. Provide "L-bead", Zip Bead, Tear Away L-Bead", Control Joint Deep V", or similar where GWB contacts dissimilar materials, exposed edges, window and door frames. Provide backer rod and sealant at joints.
3. Provide Fry Reglet "Reveal Base" (4" DRMB-50-400) at bottom of walls throughout as indicated in drawings. Do not install in bathrooms, closets, or storage rooms.
4. Provide "Control Joint Deep V" or similar where joints are indicated in the drawings, at different substrates, or where required to ease large areas of GWB.

FLOORING

1. FLOOR COATING: urethane coating clear high gloss, water based.
2. Contractor shall protect installed finish flooring from damage for the duration of the construction phase. Damaged floor shall be refinished or replaced at the Contractor's expense.

PAINT AND FINISH

1. All exterior and interior surfaces shall receive the painter's finish except those scheduled to receive other surface treatment (tile, natural finish, shot blasting, etc.) and coordinated factory finish surfaces. Remove hardware and hardware accessories, plates, machined surfaces, lighting fixtures and similar items already installed that are not to be painted. Top, bottom, and sides of all doors to be painted; coordinate paint color with adjacent wall finish.
2. NOTE TO PAINT PRODUCT SUPPLIERS: the Owner prefers to purchase coatings and sealants with low emissions of volatile organic compounds (VOCs).
3. SEALANTS: Refer to "Joint Sealants" section.
4. PAINTS, COATINGS, AND PRIMERS APPLIED TO INTERIOR WALLS & CEILINGS: one (1) coat of primer and two (2) coats of finish paint products that comply with Green Seal Standard GS-11, Paints shall be applied in sheens/colors as selected by Owner.
    - Exterior metal surfaces: semi-gloss
    - Exterior panel siding: satin
    - Exterior running trim: satin
    - Exterior doors indicated for opaque finish: gloss
    - Interior exposed steel ceilings (marked as open): flat interior
    - Exposed steel beams: semi-gloss interior
    - Exposed steel walls: semi-gloss
    - Interior finished gypsum wall board walls: eggshell
    - Interior finished gypsum wall board ceilings: flat interior
    - Doors indicated for opaque finish: semi-gloss
    - Interior running trim indicated for opaque finish: semi-gloss
    - Interior running trim indicated for clear finish: satin
5. SBU panels not indicated for exterior treatment are to be painted.

SPECIAL CONSTRUCTION

1. SBU shipping containers: quality pre-used ISO shipping containers in quantities and configurations shown in documents to be PROVIDED BY OWNER.

CABINETS

1. BASE AND WALL CABINETS: solid wood face frame style cabinets. Doors and drawer fronts: solid wood stile and rails, reveal overlay face style. Hardware: manufacturer's standard units complying with BHMA A156.9 of type, size, style, material, and finish as selected by Architect.
2. COUNTERTOPS AND BACKSPLASHES: provided by Owner

FURNISHINGS
—

PLUMBING

1. GENERAL: select low flow, water efficient plumbing fixtures. Avoid polyvinyl chloride (PVC) pipe for water delivery and drain systems.
2. Submit Plumbing fixture products and locations for Architect's approval prior to ordering.
3. WASTE PIPE: PVC.
4. SUPPLY PIPE: polyethylene pipe (XPE) with Viega PEX crimp MANABLOC (or similar).
5. SINKS: needs selection.
6. LAVATORIES: needs selection.
7. BATHTUBS/SHOWERS: needs selection.
8. DISPOSAL UNIT: needs selection.
9. TOILETS: needs selection.
10. WATER HEATER: 40-gallon, needs selection.

MECHANICAL

1. HVAC: See Manual J and Energy Form.
2. MINISPLIT UNITS: Mitsubishi Electric, M-series wall-mounted heat pump systems in sizes indicated in Mechanical drawings.
3. Provide proper combustion venting for furnaces and water heaters. Coordinate water heater requirements with plumbing contractor.
4. OUTSIDE AIR: Provide and install Panasonic "WhisperComfort" spot ERV ceiling mounted heat ventilators in sizes indicated in Mechanical drawings.
5. AIR TRANSFER DEVICES: Tamarack "AirShare" ventilator model AS1.
6. EXHAUST VENT GRILLS AND CAPS: Seiho vent caps, model SFX-4 (4") with screen, aluminum, clear anodized.
7. PREOCCUPANCY FLUSH: flush conditioned areas of home for 48 hours (non-consecutive if necessary) with interior doors, windows, and exterior doors open using exhaust fans operating at highest flow rates.

ELECTRICAL

1. GENERAL: select energy-efficient electrical fixtures for Architect's approval for the following general fixture types as shown in Electrical drawings.
2. EXHAUST FANS: Panasonic "WhisperCeiling" ceiling-mount ventilation fans in sizes as indicated in drawings. Provide Intermatic Timer EI600 electronic auto shutoff 5/10/15/30 minutes.
3. CEILING FANS: ceiling fan with light kits as scheduled or as selected by Architect.
4. ELECTRICAL FIXTURES, INTERIOR: as indicated in Electrical drawings. Recessed lighting, fluorescent strip lighting, shower lights and exhaust fans and all switching and receptacles by contractor. Other electrical fixtures to be provided by Owner installed by Contractor.
5. ELECTRICAL FIXTURES, RECESSED LIGHTING: LED low-profile fixtures as scheduled.
6. EXTERIOR WALL MOUNT FIXTURES: lighting by Bamford mfg #: GB-2000, ENERGY STAR, IES full cutoff type, white finish (26w compact fluorescent bulb included), glide lock mount, frosted glass lens. Provided by and installed by Contractor.
7. ELECTRICAL FIXTURES OTHER: as indicated in Electrical drawings; provided by Owner, installed by Contractor.
8. Provide multiple station SMOKE DETECTORS in all sleeping rooms and outside each separate sleeping area in the immediate vicinity of the bedrooms, except where the alterations or repairs do not result in the removal of interior wall or ceiling finishes exposing the structure, unless there is an attic, crawl space, or basement available which could provide access for hard wiring and interconnection without the removal of interior finishes.
9. Provide one CARBON MONOXIDE SENSOR/ALARM on each floor. Locate to meet requirements of FBC.
10. EQUIPMENT AND APPLIANCES: Architect will provide a schedule of equipment and appliances for the calculation of loads.

Required Florida Product Approvals

Provided in accordance with Florida Statute 553.842 and Florida Administrative Code 9B-72

Product Category	Manufacturer	Model # / Series	FL Product Approval # - or - Miami-Dade NOA #
Exterior Doors			
Swinging			
Sliding			
Sectional / Roll-up			
Other			
Windows			
Single/Double Hung			
Horizontal Slider			
Casement			
Fixed			
Mullion			
Skylights			
Other			
Wall Panels			
Siding			
Soffits			
Storefront			
Glass Block			
Other			
Roofing Products			
Asphalt Shingles			
Non-structural Metal			
Roofing Tiles			
Single Ply Roof			
Other			
Structural Components			
Lintels			
Insulation Forms			
Other			

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

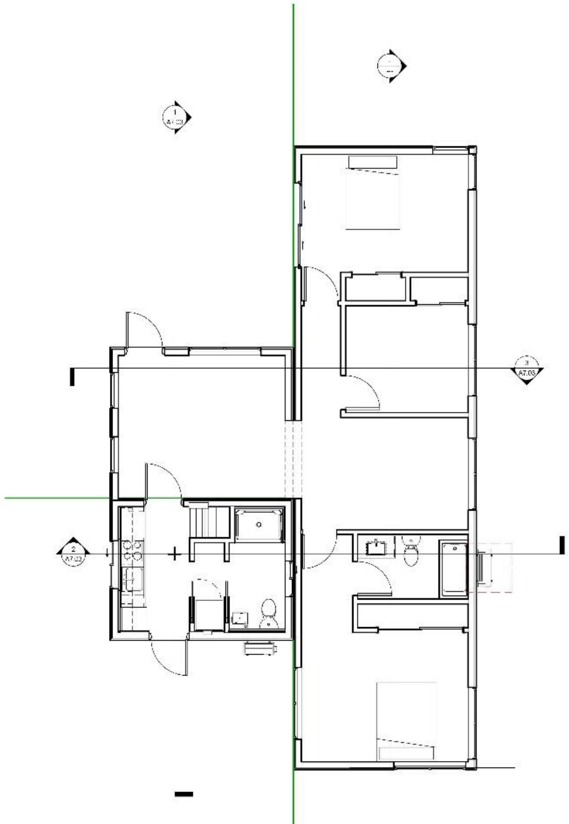
Product Notes

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A1.01

Scale 12" = 1'-0"

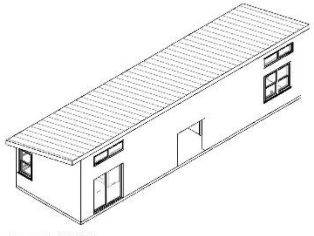
9/28/2021 10:34:25 AM



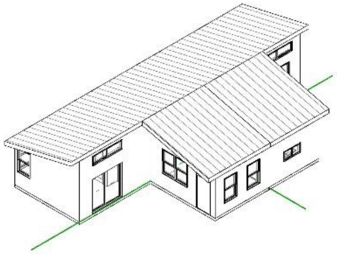
① 01-Floor Plan - Overall
1/4" = 1'-0"

③ Axonometric 1 - CORE

④ Axonometric 2 - SPACE



② Axonometric 3 - DWELL



⑤ Axonometric -Front - Overall Connection

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Plan Overall

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A3.01

Scale	1/4" = 1'-0"

9/28/2021 10:34:43 AM

Quantity Takeoff - CORE - Exterior Envelope & Partitions

Family and Type	Width	Length	Finish Height	Area: GWB, Insulation, Paint	Footage - LGMF	Structural Material	Volume	Type	Phase Created
Exterior Walls									
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	9' - 4 5/8"	10' - 5 5/16"	65 SF	47' - 5 25/32"	Metal Stud Layer	10.53 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	5 5/8"	8' - 0"	1 SF	11 25/32"	Metal Stud Layer	0.22 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	2' - 9 1/2"	8' - 0"	20 SF	14' - 6 3/8"	Metal Stud Layer	3.28 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	4' - 3 1/2"	8' - 0"	26 SF	21' - 2 1/8"	Metal Stud Layer	4.69 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	5' - 2 3/8"	8' - 0"	33 SF	24' - 7 5/32"	Metal Stud Layer	5.45 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	4 3/8"	3' - 6"	0 SF	3 9/32"	Metal Stud Layer	0.06 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: Int. Partition 2" stud + GWB	2"	7' - 8 1/4"	1' - 9 3/8"	21 SF	16' - 8 29/32"	Wood Stud Layer	3.46 CF	Int. Partition 2" stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	11' - 1 3/4"	10' - 5 5/16"	82 SF	61' - 5 1/4"	Metal Stud Layer	15.56 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: Int. Partition - 4" Stud + GWB- one side	4"	7' - 8 1/4"	1' - 5 3/8"	23 SF	17' - 1 9/32"	Wood Stud Layer	7.46 CF	Int. Partition - 4" Stud + GWB- one side	CORE
Basic Wall: Int. Partition - 4" Stud + GWB- one side	4"	3' - 3 1/4"	1' - 5 3/8"	10 SF	7' - 4 15/16"	Wood Stud Layer	3.29 CF	Int. Partition - 4" Stud + GWB- one side	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	4 5/8"	8' - 0"	1 SF	6 5/8"	Wood Stud Layer	0.31 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	3' - 1 5/8"	8' - 0"	18 SF	13' - 9 1/8"	Wood Stud Layer	7.56 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	7' - 7 3/4"	6' - 10 1/4"	32 SF	24' - 3 1/2"	Wood Stud Layer	10.61 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	5' - 4 1/4"	8' - 0"	27 SF	19' - 11 9/16"	Wood Stud Layer	11.06 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	7' - 7 3/4"	6' - 10 1/4"	32 SF	24' - 3 1/2"	Wood Stud Layer	10.61 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	14' - 7"	10' - 3 25/32"	122 SF	51' - 6 5/16"		79.64 CF	Generic Standard Type_ Wood Framed EW	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	11' - 1 3/4"	13' - 0"	96 SF	71' - 5 3/4"		64.66 CF	Generic Standard Type_ Wood Framed EW	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	11' - 1 3/4"	13' - 0"	116 SF	88' - 6 3/32"		80.05 CF	Generic Standard Type_ Wood Framed EW	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	14' - 7"	8' - 0"	130 SF	57' - 11 3/8"		88.68 CF	Generic Standard Type_ Wood Framed EW	CORE
Tabulated Totals				856 SF	649' - 2"				

Quantity Takeoff - CORE - Floor

Family and Type	Area	Structural Material	Level
Floor: CLT - 8"	161 SF	<By Category>	01-Floor Plan - CORE
Floor: Generic Floor - 8"	76 SF		Loft

Quantity Takeoff - CORE - Doors

Mark	Family and Type	Count	Function	Door Size		Typical Remarks	Additional Comments
				Width	Height		
40	Doors_Sliding_Folisse_Unico-Versione-Interach-SP-601-1-600xH-2000 2	2		3'-0"	6'-7"		
51	Door-Exterior-Single: 36" x 80"	2	Exterior	3'-0"	6'-8"		

Quantity Takeoff - CORE - Cabinetry

Family and Type	Count	Depth	Width	Height	Comments
Base Cabinet Double Door Sink Unit: 27"	2	2' - 0"	2' - 3"	2' - 10 1/2"	
Base Cabinet-Filler: Base Cabinet Filler	1	2' - 0"	1 7/32"	2' - 10 1/2"	
Base Cabinet-Filler: Base Cabinet-Filler 2	1	1' - 0"	4 3/4"	2' - 10 1/2"	
Base Cabinet-Single Door & Drawer: 15"	1	2' - 0"	1' - 0"	2' - 10 1/2"	
Counter Top No Backsplash: 22" Depth	1	1' - 10"		2' - 8"	
Counter Top w Sink Hole: 24" Depth	1	2' - 1"		3' - 0"	
Upper Cabinet-Double Door-Wall: 27" over Sink 2	2	1' - 0"	2' - 3"	1' - 6"	
Upper Cabinet-Double Door-Wall: 27" Refrigerator 2	1	1' - 0"	2' - 3"	1' - 6"	
Upper Cabinet-Double Door-Wall: 30"	1	1' - 0"	2' - 6"	2' - 6"	
Upper Cabinet Single Door Wall: 15"	1	1' - 0"	1' - 3"	2' - 6"	

Quantity Takeoff - CORE - Lighting Fixtures

Mark	Manufacturer	Model	Count	Description	Family and Type	Elevation from Level	Type Mark	Additional Comments
177	Cooper Industries, Inc	Model	1	Description	Interior_Cooper_Shaper_Wall_600: Interior_Cooper_Shaper_Wall_600	0"		
178	TBD	TBD	1	ROUND SURFACE LED	Ceiling Light - Flat Round: 60W - 120V	0"	CA	
179	TBD	TBD	1	ROUND SURFACE LED	Ceiling Light - Flat Round: 60W - 120V	0"	CA	
180	TBD	TBD	1	ROUND SURFACE LED	Ceiling Light - Flat Round: 60W - 120V	0"	CA	

Quantity Takeoff - CORE - Mechanical Equipment

Refer to Energy Forms and HVAC Short Form for Units requirements and Specs

Mark	Manufacturer	Family and Type	Model	Count	Description	Typical Remarks	Additional Comments	Back-up Battery Power	Capacity_Rated_Cooling (kW)	Capacity_Rated_Heating (kW)
	LG Electronics	REV_SingleZone_Low_Static_Ducted_LDU097HV_08_19: REV_SingleZone_Low_Static_Ducted_LDU097HV_08_19		1						
	LG Electronics	REV_SingleZone_High_Efficiency_LSN120HSV5_08_19: REV_SingleZone_High_Efficiency_LSN120HSV5_08_19		1						
ERV-1	Broan	BROAN ERVS100S-DV1: 120 V Single Phase 2	ERVS100S	1	Energy Recovery Ventilator	Energy Recovery Ventilator				
		Exhaust Vent: 4" Diameter		1						

Quantity Takeoff - CORE - Specialty Equipment

Mark	Family and Type	Count	Typical Remarks	Comments
RE-5	Washer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFW450SSMWW stackable washer
RE-6	Dryer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFD45ESSMWW stackable dryer

Quantity Takeoff - CORE - Windows

Mark	Family and Type	Count	Width	Height	Typical Remarks	Additional Comments
16	Window-Siding-Double: 48" x 24"	1	4' - 0"	2' - 0"		
20	Window-Siding-Double: 36" x 24"	1	3' - 0"	2' - 0"		
27	Window-Siding-Double: 84" x 24"	1	7' - 0"	2' - 0"		

Quantity Takeoff - CORE - Electrical Fixture

Family and Type	Count	Description	Electrical Data	Level	Type	Elevation from Level	Phase Created	Phase Demolished
Duplex Receptacle: GFCI	13		120 V/1-180 VA		GFCI	0"	CORE	Core_Demoliti

Quantity Takeoff - CORE - Lighting Device

Family and Type	Count	Description	Electrical Data	Type	Model	Switch ID	Comments
Lighting Switches: Three Way	2		120 V/1-0 VA	Three Way			

Quantity Takeoff - CORE - Plumbing Fixture

Product Name	Family	Count	Depth	Height	Length	Capacity	Manufacturer	Type	Description	Model	Comments
	Shower-46in_Base-Sterling_Plumbing-Ensemble-72120100	1		6' - 5"	2' - 11 1/4"		Sterling Plumbing	Vikrell-White	46in Shower Base and Wall Surround	72120100	
	Toilet Domestic Niagara Stealth - The Original-N7755_Bowl-N7714_Tank	1					Niagara Conservation	7755 Bowl with 7714-HH Tank	Quiet, powerful flush delivered with a patented Stealth flush chamber and air transfer system	N7755 Bowl N7714-HH Tank	
	Washing Machine Inlet-Outlet	1		8 5/8"			IPS Corporation	1/2" Sweat Connection	1/4 Turn Valves Installed, 1/2" Sweat Connection, 2" Slipout Drain Kit	MWB16	
	Washing Machine Inlet-Outlet	1		8 5/8"			IPS Corporation	1/2" Sweat Connection	1/4 Turn Valves Installed, 1/2" Sweat Connection, 2" Slipout Drain Kit	MWB16	
	Sink Kitchen-Island	1						25" x 22"			

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

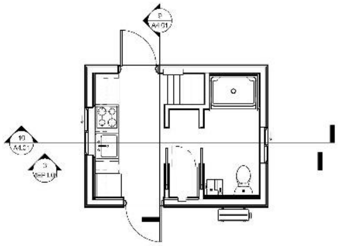
Schedules &
Quanitities - CORE

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

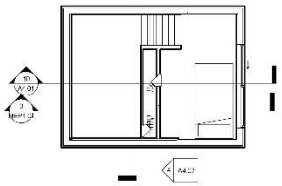
A4.00

Scale

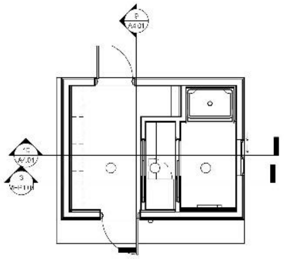
9/29/2021 10:34:03 AM



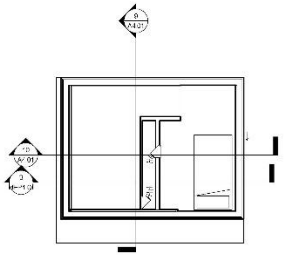
① 01-Floor Plan - CORE
1/4" = 1'-0"



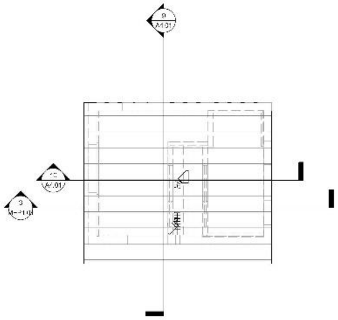
② 02-Floor Plan - CORE Loft
1/4" = 1'-0"



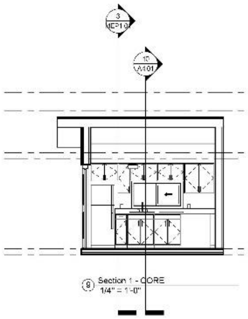
⑪ 01-RCP- CORE
1/4" = 1'-0"



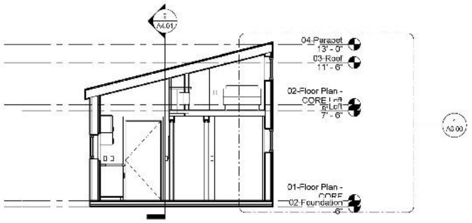
⑫ 02-RCP- CORE Loft
1/4" = 1'-0"



⑬ 01-Roof Plan - CORE
1/4" = 1'-0"



⑨ Section 1 - CORE
1/4" = 1'-0"



⑩ Section 2 - CORE
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

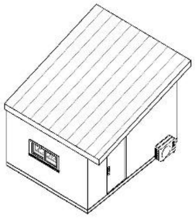
Project Address

CORE - Plans and Sections

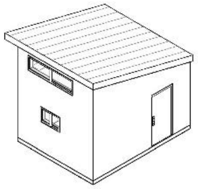
Project number 99999
Date 2020-02-19
Drawn by UF
Checked by UF

A4.01

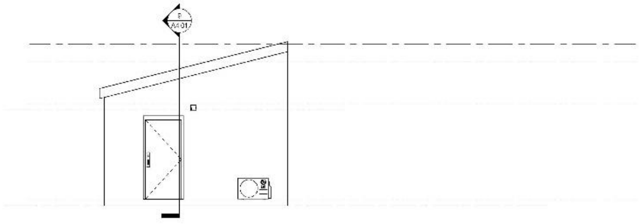
Scale 1/4" = 1'-0"



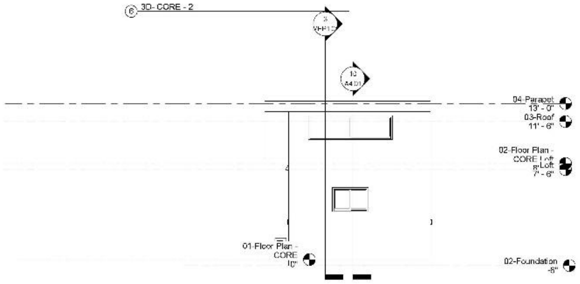
⑤ 3D- CORE - 1



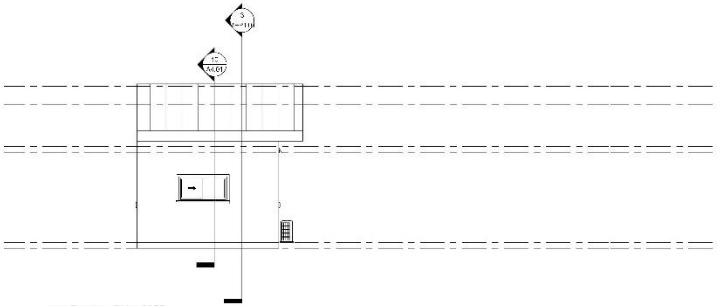
⑥ 3D- CORE - 2



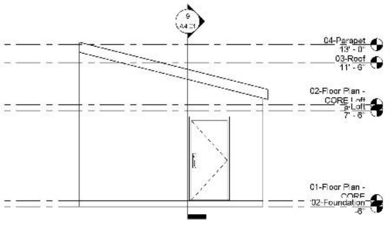
③ Elevation - Rear - CORE
1/4" = 1'-0"



④ Elevation - Left - CORE
1/4" = 1'-0"



① Elevation - Right - CORE
1/4" = 1'-0"



② Elevation - Front - CORE
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

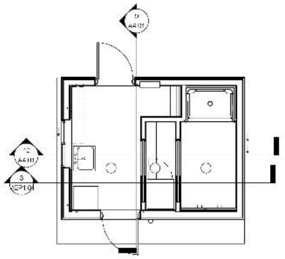
Project Address

CORE - Elevations and Axonometrics

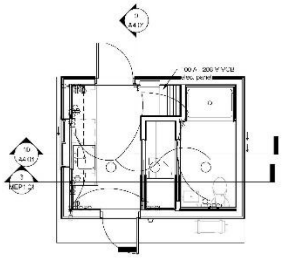
Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A4.02

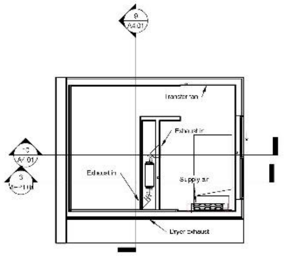
Scale	1/4" = 1'-0"



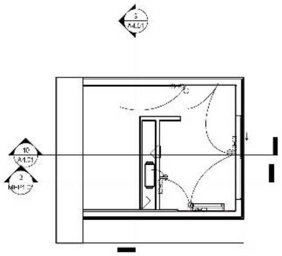
④ 01-Mechanical Reflected Ceiling Plan - CORE
1/4" = 1'-0"



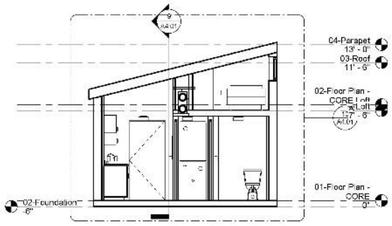
② 01-Lighting/Switching Plan - CORE
1/4" = 1'-0"



① 02- Mechanical Reflected Ceiling Plan - CORE Loft
1/4" = 1'-0"



⑤ 02- Lighting/Switching Plan - CORE Loft
1/4" = 1'-0"



③ Section 1
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Mechanical, Electrical, Plumbing - CORE

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

MEP1.01

Scale	1/4" = 1'-0"

Quantity Takeoff - SPACE - Exterior Envelope & Partitions

Family and Type	Width	Length	Finish Height	Area: GWB, Insulation, Paint	Footage - LGMF	Structural Material	Volume	Type	Phase Created
Exterior Walls									
Basic Wall: Generic Standard Type_ Wood Framed EW	6 1/4"	12' - 3 3/8"	13' - 0"	124 SF	96' - 2 23/32"		84.50 CF	Generic Standard Type_ Wood Framed EW	SPACE
Basic Wall: Generic Standard Type_ Wood Framed EW	6 1/4"	14' - 7"	9' - 2"	92 SF	69' - 0 15/32"		63.14 CF	Generic Standard Type_ Wood Framed EW	SPACE
Basic Wall: Generic Standard Type_ Wood Framed EW	6 1/4"	12' - 3 3/8"	7' - 7 7/16"	80 SF	60' - 1 15/32"		54.23 CF	Generic Standard Type_ Wood Framed EW	SPACE
Tabulated Totals				296 SF	222' - 4 25/32"				

Quantity Takeoff - SPACE - Floor

Family and Type	Area	Structural Material	Level
Floor: Generic Floor - 8"	794 SF		01-Floor Plan - CORE

Quantity Takeoff - SPACE - Doors

Mark	Family and Type	Count	Function	Door Size		Typical Remarks	Additional Comments
				Width	Height		
51	Door-Exterior-Single: 36" x 80"	1	Exterior	3'-0"	6'-8"		

Quantity Takeoff - SPACE - Windows

Mark	Family and Type	Count	Width	Height	Typical Remarks	Additional Comments
20	Window-Sliding-Double: 36" x 24"	2	3' - 0"	2' - 0"		
21	Window-Single-Hung: 36" x 60"	2	3' - 0"	5' - 0"		
28	Window-Sliding-Double: 120" x 24"	1	10' - 0"	2' - 0"		
26	Window-Single-Hung-Double: 72" x 60"	1	6' - 0"	5' - 0"		

Grand total: 6

Quantity Takeoff - SPACE - Electrical Fixture

Family and Type	Count	Description	Electrical Data	Level	Type	Elevation from Level	Phase Created	Phase Demolished
Duplex Receptacle: GFCI	5		120 V/1-180 VA	01-Floor Plan - CORE	GFC		SPACE	Space_Demolish

Quantity Takeoff - SPACE - Lighting Fixtures

Mark	Manufacturer	Model	Count	Description	Family and Type	Elevation from Level	Type Mark	Additional Comments
101			1	CEILING FAN WITH LIGHT	pndr_Ceiling Fan: Ceiling_Fan	10' - 4 27/32"		

Quantity Takeoff - SPACE - Mechanical Equipment

Refer to Energy Forms and HVAC Short Form for Units requirements and Specs

Mark	Manufacturer	Family and Type	Model	Count	Description	Typical Remarks	Additional Comments	Back-up Battery Power	Capacity_Rated_Cooling (kW)	Capacity_Rated_Heating (kW)

Quantity Takeoff - SPACE - Lighting Device

Family and Type	Count	Description	Electrical Data	Type	Mode	Switch ID	Comments
Lighting Switches: Three Way	1		120 V/1-0 VA	Three Way			

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

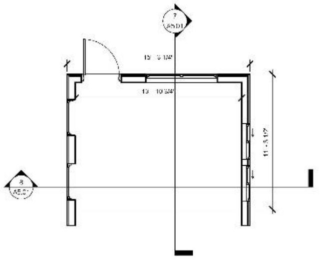
Schedules &
Quanitities - SPACE

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

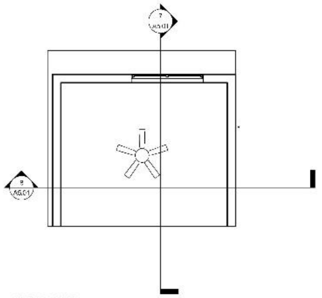
A5.00

Scale

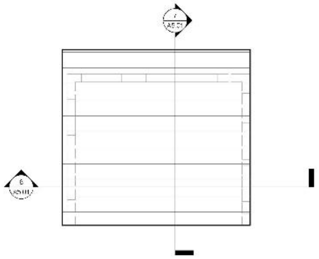
9/28/2021 10:35:04 AM



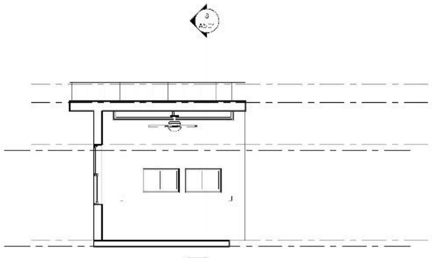
① Floor Plan - SPACE
1/4" = 1'-0"



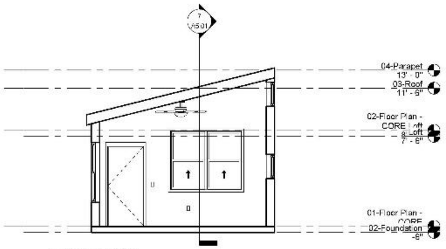
⑨ 01-RCP- SPACE
1/4" = 1'-0"



⑩ Roof Plan - SPACE
1/4" = 1'-0"



⑦ Section 1 - SPACE
1/4" = 1'-0"



⑧ Section 2 - SPACE
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

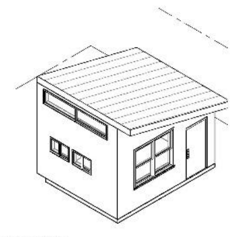
Project Address

SPACE - Plans and Sections

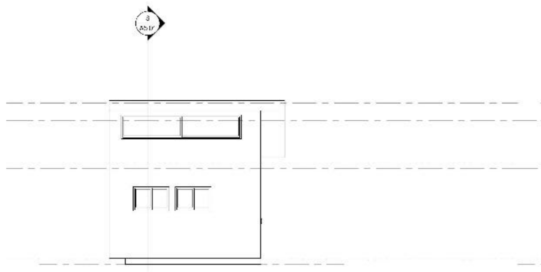
Project number 99999
Date 2020-02-19
Drawn by Author
Checked by Checker

A5.01

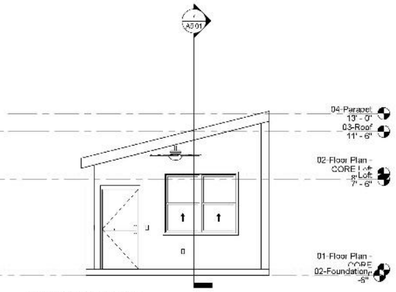
Scale 1/4" = 1'-0"



⑤ 3D- SPACE



③ Elevation - Left - SPACE
1/4" = 1'-0"



④ Elevation - Rear - SPACE
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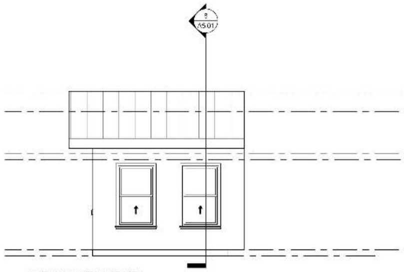

① Elevation - Right -SPACE
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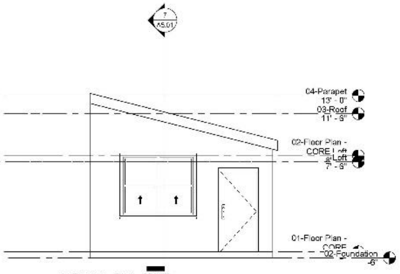


STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

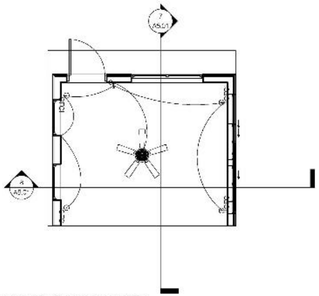
SPACE - Elevations and Axonometrics

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A5.02

Scale 1/4" = 1'-0"

9/28/2021 10:35:13 AM



① 01-Lighting/Switching Plan -SPACE
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Mechanical, Electrical,
Plumbing - SPACE

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

MEP2.01

Scale 1/4" = 1'-0"

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Quantity Takeoff - DWELL - Exterior Envelope & Partitions

Family and Type	Width	Length	Finish Height	Area : GWB, Insulation, Paint	Footage - LGMF	Structural Material	Volume	Type	Phase Created
Exterior Walls									
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	9' - 4 5/8"	10' - 5 5/16"	65 SF	47' - 5 29/32"	Metal Stud Layer	10.55 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	5 3/8"	8' - 0"	1 SF	1' 1 29/32"	Metal Stud Layer	0.22 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	2' - 5 1/2"	8' - 0"	20 SF	14' - 9 3/8"	Metal Stud Layer	3.28 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	4' - 3 1/2"	8' - 0"	26 SF	21' - 2 1/8"	Metal Stud Layer	4.69 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	5' - 2 3/8"	8' - 0"	33 SF	24' - 7 5/32"	Metal Stud Layer	5.45 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	4 3/8"	3' - 6"	0 SF	3 9/32"	Metal Stud Layer	0.08 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: Int. Partition 2" stud + GWB	2"	7' - 8 1/4"	11' - 8 3/8"	21 SF	15' - 8 29/32"	Wood Stud Layer	3.46 CF	Int. Partition 2" stud + GWB	CORE
Basic Wall: sdcp - Ext. Overlay - 1 1/2" Stud + GWB	2"	11' - 1 3/4"	10' - 5 5/16"	82 SF	61' - 5 1/4"	Metal Stud Layer	15.58 CF	sdcp - Ext. Overlay - 1 1/2" Stud + GWB	CORE
Basic Wall: Int. Partition - 4" Stud + GWB one side	4"	7' - 8 1/4"	11' - 5 3/8"	23 SF	17' - 1 9/32"	Wood Stud Layer	7.48 CF	Int. Partition - 4" Stud + GWB one side	CORE
Basic Wall: Int. Partition - 4" Stud + GWB one side	4"	3' - 3 1/4"	11' - 5 3/8"	10 SF	7' - 4 15/16"	Wood Stud Layer	3.26 CF	Int. Partition - 4" Stud + GWB one side	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	4 3/8"	8' - 0"	1 SF	6 5/8"	Wood Stud Layer	0.31 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	3' - 1 5/8"	8' - 0"	19 SF	13' - 9 1/8"	Wood Stud Layer	7.58 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	7' - 7 3/4"	6' - 10 1/4"	32 SF	24' - 3 1/2"	Wood Stud Layer	10.81 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	5' - 4 1/4"	8' - 0"	27 SF	19' - 11 9/16"	Wood Stud Layer	11.06 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"	7' - 7 3/4"	6' - 10 1/4"	32 SF	24' - 3 1/2"	Wood Stud Layer	10.81 CF	Int. Partition - 4" Stud + GWB 2	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	14' - 7"	10' - 5 25/32"	122 SF	91' - 5 5/16"		79.64 CF	Generic Standard Type_ Wood Framed EW	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	11' - 1 3/4"	10' - 0"	96 SF	71' - 5 3/4"		64.66 CF	Generic Standard Type_ Wood Framed EW	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	11' - 1 3/4"	13' - 0"	118 SF	88' - 9 3/32"		80.05 CF	Generic Standard Type_ Wood Framed EW	CORE
Basic Wall: Generic Standard Type_ Wood Framed EW	8 1/4"	14' - 7"	8' - 0"	130 SF	97' - 11 3/8"		88.66 CF	Generic Standard Type_ Wood Framed EW	CORE
Tabulated Totals				656 SF	643' - 0"				

Quantity Takeoff - DWELL - Floor

Family and Type	Area	Structural Materia	Level
Floor: Generic Floor - 6"	794 SF		01-Floor Plan - CORE

Quantity Takeoff - DWELL - Doors

Mark	Family and Type	Count	Function	Door Size		Typical Remarks	Additional Comments
				Width	Height		
7	Single Flush: 34" x 80"	4	Interior	2' 10"	6' 8"		
10	Door Opening: 72" x 80"	1	Interior	0' 0"	0' 0"		
15	Door-Interior-Double-Sliding-2_Panel-Wood: 84" x 80"	1	Interior	7' 0"	6' 8"		
16	Door-Interior-Double-Sliding-2_Panel-Wood: 48" x 80"	2	Interior	4'-0"	6'-8"		
47	Doors_Sliding_UPVC_Porte-Fenetre_Coulissante_2V: 2050 x 2180 mm 2	1	Exterior	7'-0"	7'-2"		

Quantity Takeoff - DWELL - Windows

Mark	Family and Type	Count	Width	Height	Typical Remarks	Additional Comments
21	Window-Single-Hung: 36" x 60"	2	3' - 0"	5' - 0"		
27	Window-Sliding-Double: 84" x 24"	2	7' - 0"	2' - 0"		
29	Window-Single-Hung Double: 72" x 60"	5	6' - 0"	5' - 0"		

Grand total: 9

Quantity Takeoff - DWELL - Cabinetry

Family and Type	Count	Depth	Width	Height	Comments
inch - 4 inch Backsplash: 1/2" Solid Surface	1	1/2"		3' - 0"	
Counter Top No Backsplash: 22" Depth	1	1' - 10"		2' - 8"	
Vanity Cabinet Double Door Sink Unit: 36"	1	1' - 9"	3' - 0"	2' - 6 1/2"	Basis of Design: Glacier Bay 31" W bathroom vanity with integral countertop

Quantity Takeoff - DWELL - Mechanical Equipment

Refer to Energy Forms and HVAC Short Form for Units requirements and Specs

Mark	Manufacturer	Family and Type	Model	Count	Description	Typical Remarks	Additional Comments	Back-up Battery Power	Capacity_Rated_Cooling (kW)	Capacity_Rated_Heating (kW)
	LG Electronics	RFV_MultiV_Standard_Wall_Mounted_ARNU093SJA4: RFV_MultiV_Standard_Wall_Mounted_ARNU093SJA4		1						
	LG Electronics	RFV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: RFV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1						
	LG Electronics	RFV_MultiV_Standard_Wall_Mounted_ARNU053SJA4: RFV_MultiV_Standard_Wall_Mounted_ARNU053SJA4		1						
	LG Electronics	RFV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: RFV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1						

Quantity Takeoff - DWELL- Electrical Fixture

Family and Type	Count	Description	Electrical Data	Level	Type	Elevation from Level	Phase Created	Phase Demolished
Duplex Receptacle: GFCI	15		120 V/1-180 VA		GFCI	0"	DWELL	Dwell_Demolish

Quantity Takeoff - DWELL - Lighting Device

Family and Type	Count	Description	Electrical Data	Type	Mode	Switch ID	Comments
Lighting Switches: Three Way	1		120 V/1-0 VA	Three Way			

Quantity Takeoff - DWELL - Plumbing Fixture

Product Name	Family	Count	Depth	Height	Length	Capacity	Manufacturer	Type	Description	Model	Comments
Clara Undermount Rectangular Vitreous China Lavatory Sink Double Glazed	Sink-Undermount-Waterworks-Rectangular-Clara	1	1' - 2 1/8"	8"	1' - 8 1/16"		Waterworks	Double Glazed	Clara Undermount Rectangular Vitreous China Lavatory Sink Double Glazed	CYLV22	Basis of Design Glacier Bay 31" W bathroom vanity with integral countertop
	Sanitary_Taps&Mixers_Zurn-Industries_Z82200	1					Zurn Industries, LLC	Z82200-XL	Zurn's AquaSpec® faucet and accessories provide the highest level of durability for commercial applications. Its cast brass construction and lifetime warrantied ceramic disc cartridge ensure lasting product life	Z82200-XL	
	Toilet-Domestic-Niagara-Stealth-The_Original-N7755_Bowl-N7714_Tank	1					Niagara Conservation	7755 Bowl with 7714-HH Tank	Quiet, powerful flush delivered with a patented Stealth flush chamber and air transfer system	N7755 Bowl N7714-HH Tank	
Underscore	Bath-Alcove-KOHLER-Underscore-K-1956	1		1' - 10 1/4"	5' - 0"		KOHLER Co	Not a Type - See Type Catalog	60inch x 30inch alcove bath with integral apron, integral flange and left-hand drain	NA	

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Schedules &
Quanitities - DWELL

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A6.00

Scale

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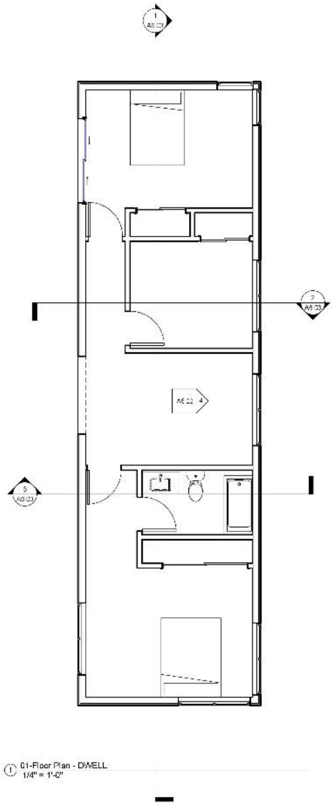
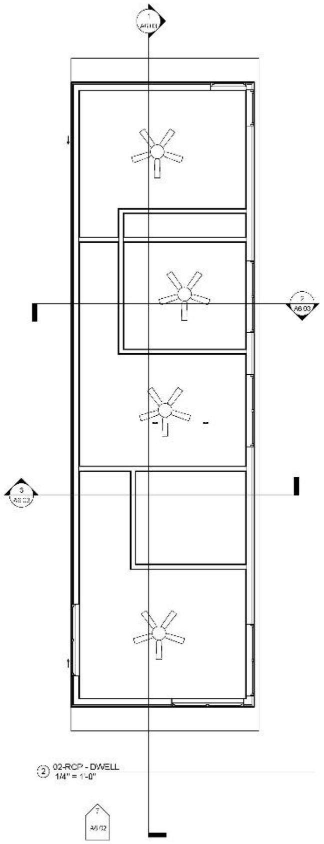
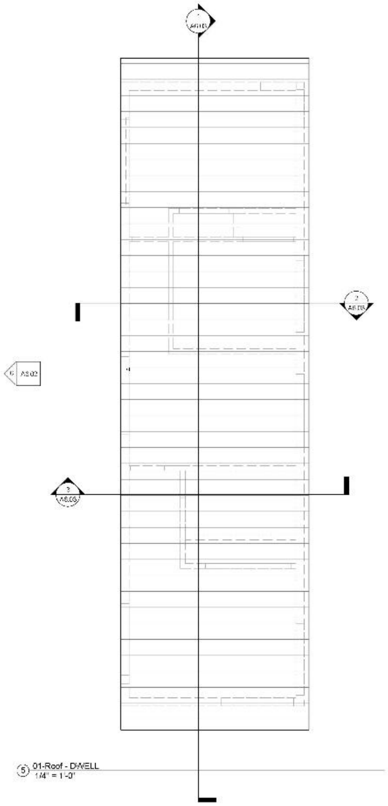


① 01-Floor Plan - DWELL
1/4" = 1'-0"



② 02-RCP - DWELL
1/4" = 1'-0"



⑤ 01-Roof - DWELL
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

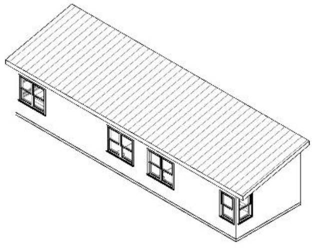
Project Address

DWELL - Plans

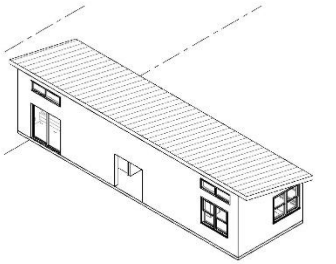
Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A6.01

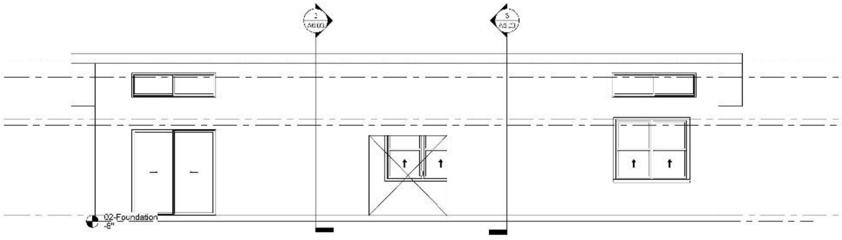
Scale 1/4" = 1'-0"



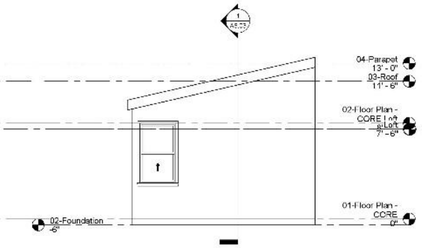
① 3D- DWELL - 1



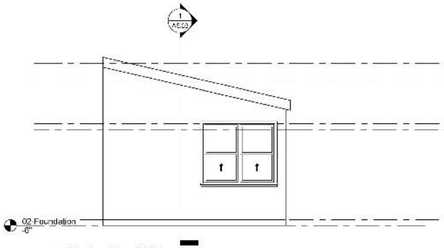
② 3D- DWELL - 2



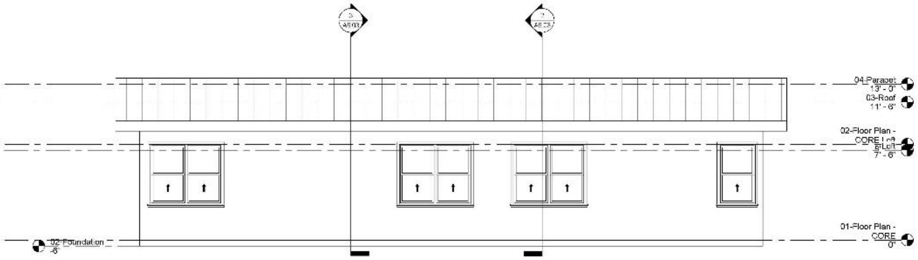
④ Elevation - Right - DWELL
1/4" = 1'-0"



⑤ Elevation - Front - DWELL
1/4" = 1'-0"



⑦ Elevation - Rear - DWELL
1/4" = 1'-0"



⑥ Elevation - Left - DWELL
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

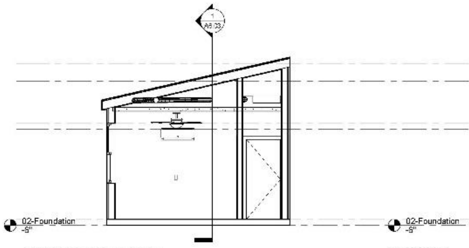
DWELL - Elevations and Axonometrics

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

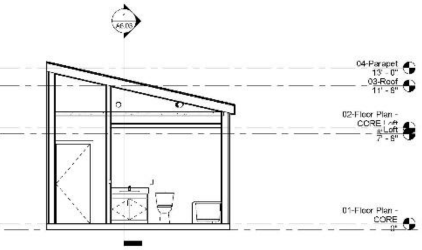
A6.02

Scale	1/4" = 1'-0"

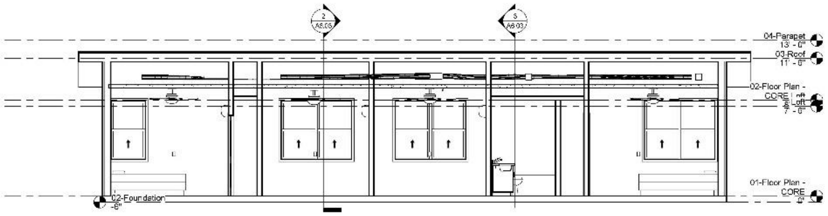
9/28/2021 10:35:22 AM



② Section 2 - DWELL Transversal
1/4" = 1'-0"



③ Section 3 - DWELL Transversal
1/4" = 1'-0"



① Section 1 - Dwell Longitudinal
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

DWELL - Sections

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A6.03

Scale	1/4" = 1'-0"

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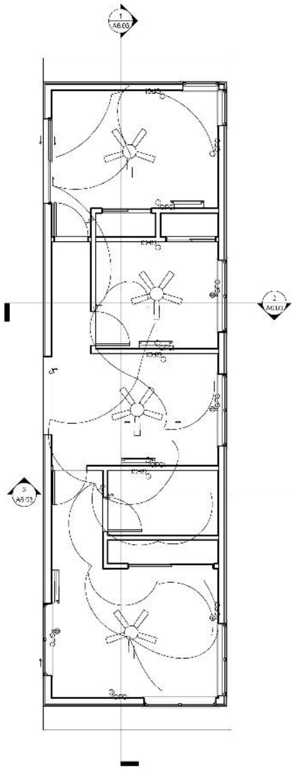

① 02- Lighting/Switching Plan - DWELL
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Mechanical, Electrical. Plumbing - DWELL

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

MEP6.01

Scale	1/4" = 1'-0"

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Quantity Takeoff - Overall - Exterior Envelope & Partitions

Family and Type	Width	Length	Finish Height	Area: GWB, Insulation, Paint	Footage - LGMF	Structural Material	Volume	Type	Phase Created
Exterior Walls									
	2"			744 SF	558' - 5 25/32"				Overall
	4"			585 SF	442' - 8 7/8"				Overall
Basic Wall: Int. Partition - 4" Stud + GWB 2	5"			2524 SF	1897' - 9 1/32"	Wood Stud Layer		Int. Partition - 4" Stud + GWB 2	Overall
Basic Wall: Generic Standard Type - Wood Framed LW	8 1/4"			5499 SF	4133' - 8 1/16"			Generic Standard Type - Wood Framed LW	Overall
Tabulated Totals				9355 SF	7033' - 5 23/32"				

Quantity Takeoff - Overall - Floor

Family and Type	Area	Structural Material	Level
Floor: CLT - 8"	131 SF	<By Category>	01 Floor Plan - CORE
Floor: CLT - 8"	131 SF	<By Category>	01 Floor Plan - CORE
Floor: CLT - 8"	131 SF	<By Category>	01 Floor Plan - CORE
Floor: Generic Floor - 6"	195 SF		01-Floor Plan - CORE
Floor: Generic Floor - 6"	76 SF		Left
Floor: Generic Floor - 6"	794 SF		01-Floor Plan - CORE
Floor: Generic Floor - 6"	195 SF		01-Floor Plan - CORE
Floor: Generic Floor - 6"	76 SF		Left
Floor: Generic Floor - 6"	794 SF		01 Floor Plan - CORE
Floor: Generic Floor - 6"	195 SF		01 Floor Plan - CORE
Floor: Generic Floor - 6"	76 SF		Left
Floor: Generic Floor - 6"	794 SF		01-Floor Plan - CORE

Quantity Takeoff - Overall - Doors

Mark	Family and Type	Count	Function	Door Size		Typical Remarks	Additional Comments
				Width	Height		
7	Single-Flush: 34" x 80"	12	Interior	2'-10"	6'-8"		
10	Door-Opening: 78" x 80"	6	Interior	0'-0"	0'-0"		
15	Door-Interior-Double-Sliding-2_Panel-Wood: 84" x 80"	3	Interior	7'-0"	6'-8"		
16	Door-Interior-Double-Sliding-2_Panel-Wood: 48" x 80"	6	Interior	4'-0"	6'-8"		
20	Doors_Sliding_Polissa_Unico-Versione-Intonaco-SP-001-L=900/H=2000 2	6		3'-0"	6'-7"		
47	Doors_Sliding_UPVC_Porte Fenetre_Coulissante_2V: 2350 x 2180 mm 2	3	Exterior	7'-8"	7'-2"		
51	Door-Exterior-Single: 36" x 80"	6	Exterior	3'-0"	6'-8"		

Quantity Takeoff - Overall - Lighting Fixtures

Mark	Manufacturer	Model	Count	Description	Typical Remarks (Basis of Design)	Additional Comments
CA	TBD	TBD	9	ROUND SURFACE LED	DSTWIN OW-LFMVR-1502530-NK	

Quantity Takeoff - Overall - Cabinetry

Family and Type	Count	Depth	Width	Height	Comments
Base Cabinet-Double Door Sink Unit: 27"	6	2' - 0"	2' - 3"	2' - 10 1/2"	
Base Cabinet-Filler: Base Cabinet Filler	3	2' - 0"	1 7/32"	2' - 10 1/2"	
Base Cabinet-Filler: Base Cabinet-Filler 2	3	1' - 3"	4 3/4"	2' - 10 1/2"	
Base Cabinet-Single Door & Drawer: 15"	3	2' - 0"	1' - 0"	2' - 10 1/2"	
[illegible] - 4 inch Backsplash: 1/2" Solid Surface	3	1/2"		3' - 0"	
Counter Top No Backsplash: 22" Depth	5	1' - 10"		2' - 8"	
Counter Top w Sink Hole: 24" Depth	3	2' - 1"		3' - 0"	
Upper Cabinet-Double Door-Wall: 27" over Sink 2	6	1' - 0"	2' - 3"	1' - 6"	
Upper Cabinet-Double Door-Wall: 27" Refrigerator 2	3	1' - 0"	2' - 3"	1' - 6"	
Upper Cabinet-Double Door-Wall: 30"	3	1' - 0"	2' - 6"	2' - 6"	
Upper Cabinet-Single Door-Wall: 15"	3	1' - 0"	1' - 0"	2' - 6"	
Vanity Cabinet-Double Door Sink Unit: 36"	3	1' - 9"	3' - 0"	2' - 8 1/2"	Basis of Design: Glacier Bay 31" W bathroom vanity with integral countertop

Quantity Takeoff - Overall - Windows

Mark	Family and Type	Count	Width	Height	Typical Remarks	Additional Comments
16	Window-Sliding-Double: 48" x 24"	3	4' - 0"	2' - 0"		
20	Window-Sliding-Double: 36" x 24"	5	3' - 0"	2' - 0"		
21	Window-Single-Hung: 36" x 60"	12	3' - 0"	5' - 0"		
27	Window-Sliding-Double: 84" x 24"	9	7' - 0"	2' - 0"		
28	Window-Sliding-Double: 120" x 24"	3	10' - 0"	2' - 0"		
29	Window-Single-Hung-Double: 72" x 60"	18	6' - 0"	5' - 0"		

Grand total: 49

Quantity Takeoff - Overall - Specialty Equipment

Mark	Family and Type	Count	Typical Remarks	Comments
RE-5	Washer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFW450SSMWW stackable washer
RE-5	Washer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFW450SSMWW stackable washer
RE-5	Washer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFW450SSMWW stackable washer
RE-6	Dryer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFD45ESSMWW stackable dryer
RE-6	Dryer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFD45ESSMWW stackable dryer
RE-6	Dryer-Front_Load: 27"	1		Basis of Design: General Electric Model # GFD45ESSMWW stackable dryer

Quantity Takeoff - Overall - Electrical Fixture

Family and Type	Count	Description	Electrical Data	Level	Type	Elevation from Level	Phase Created	Phase Demolished
Duplex Receptacle: GFCI	96		120 V/1-180 VA		GFCI	0"	Overall	None

Quantity Takeoff - Overall - Lighting Device

Family and Type	Count	Description	Electrical Data	Type	Model	Switch ID	Comments
Lighting Switches: Three Way	24		120 V/1-0 VA	Three Way			

Quantity Takeoff - Overall - Mechanical Equipment

Refer to Energy Forms and HVAC Short Form for Units requirements and Specs

Mark	Manufacturer	Family and Type	Model	Count	Description	Typical Remarks	Additional Comments
	LG Electronics	REV_SingleZone_High_Efficiency_LSN120HSV5_06_19: REV_SingleZone_High_Efficiency_LSN120HSV5_06_19		1			
	LG Electronics	REV_SingleZone_Low_Static_Ducted_LDU097HV_06_19: REV_SingleZone_Low_Static_Ducted_LDU097HV_06_19		1			
	LG Electronics	REV_SingleZone_High_Efficiency_LSN120HSV5_06_19: REV_SingleZone_High_Efficiency_LSN120HSV5_06_19		1			
ERV-1	Broan	BROAN ERVS100S-EV1: 120 V Single Phase 2	ERVS100S	1	Energy Recovery Ventilator	Energy Recovery Ventilator	
		Exhaust Vent: 4" Diameter		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU093SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU093SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU053SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU053SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1			
	LG Electronics	REV_MultiV_S_HP_ARUN024GSS4_06_19: ARUN024GSS4		1			
	LG Electronics	REV_SingleZone_High_Efficiency_LSN120HSV5_06_19: REV_SingleZone_High_Efficiency_LSN120HSV5_06_19		1			
	LG Electronics	REV_SingleZone_Low_Static_Ducted_LDU097HV_06_19: REV_SingleZone_Low_Static_Ducted_LDU097HV_06_19		1			
	LG Electronics	REV_SingleZone_High_Efficiency_LSN120HSV5_06_19: REV_SingleZone_High_Efficiency_LSN120HSV5_06_19		1			
ERV-1	Broan	BROAN ERVS100S-EV1: 120 V Single Phase 2	ERVS100S	1	Energy Recovery Ventilator	Energy Recovery Ventilator	
		Exhaust Vent: 4" Diameter		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU093SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU093SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU053SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU053SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1			
	LG Electronics	REV_MultiV_S_HP_ARUN024GSS4_06_19: ARUN024GSS4		1			
	LG Electronics	REV_SingleZone_High_Efficiency_LSN120HSV5_06_19: REV_SingleZone_High_Efficiency_LSN120HSV5_06_19		1			
	LG Electronics	REV_SingleZone_Low_Static_Ducted_LDU097HV_06_19: REV_SingleZone_Low_Static_Ducted_LDU097HV_06_19		1			
	LG Electronics	REV_SingleZone_High_Efficiency_LSN120HSV5_06_19: REV_SingleZone_High_Efficiency_LSN120HSV5_06_19		1			
ERV 1	Broan	BROAN ERVS100S-EV1: 120 V Single Phase 2	ERVS100S	1	Energy Recovery Ventilator	Energy Recovery Ventilator	
		Exhaust Vent: 4" Diameter		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU093SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU093SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU053SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU053SJA4		1			
	LG Electronics	REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4: REV_MultiV_Standard_Wall_Mounted_ARNU073SJA4		1			
	LG Electronics	REV_MultiV_S_HP_ARUN024GSS4_06_19: ARUN024GSS4		1			

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

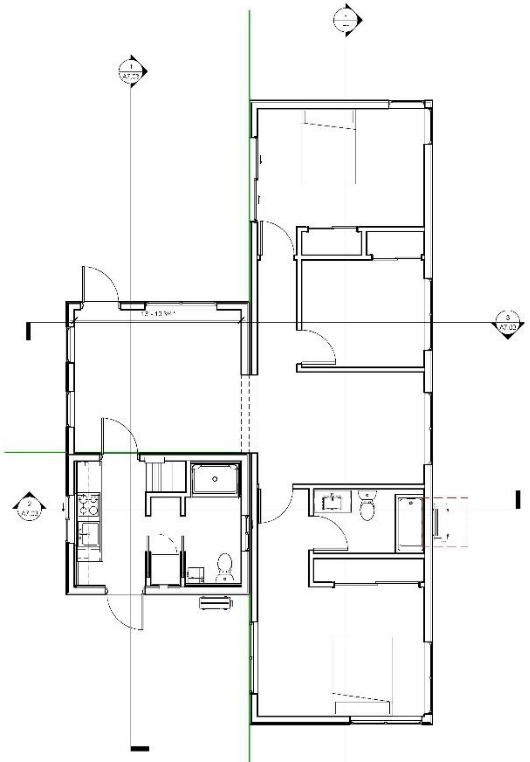
Schedules &
Quanitities - Overall

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

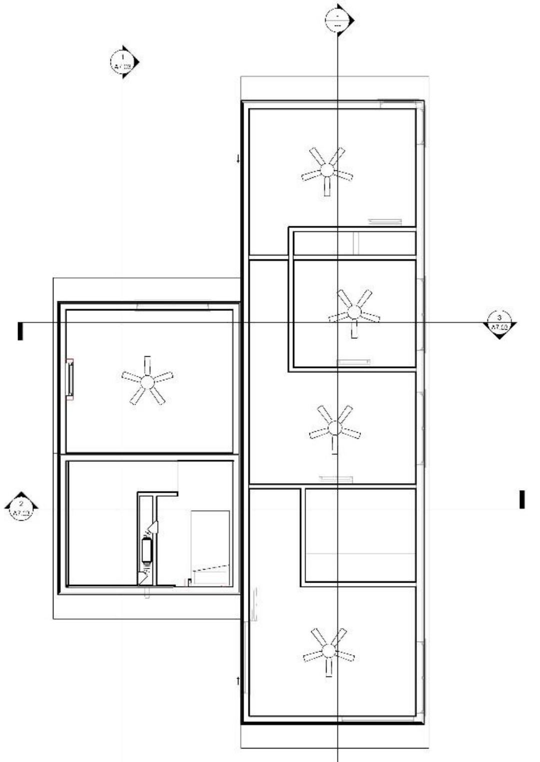
A7.00

Scale

9/29/2021 10:53:19 AM



① 01-Floor Plan - Overall - 3 Units
1/4" = 1'-0"



③ 02-RCP - Overall
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Overall Plan

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A7.01

Scale	1/4" = 1'-0"

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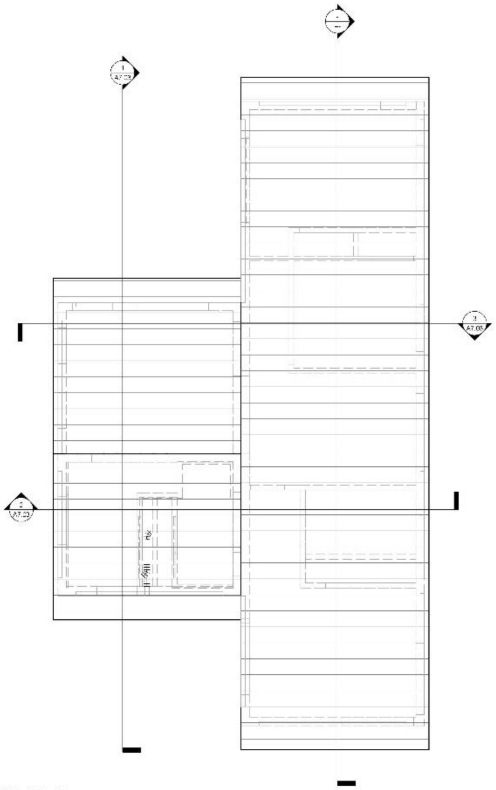


① 01-Roof - Overall
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

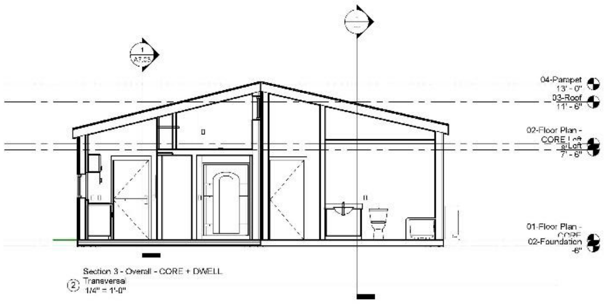
Project Address

Overall - Roof Plan

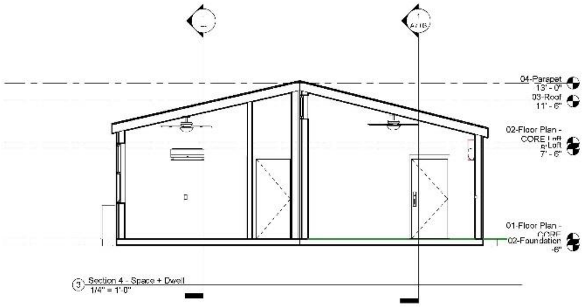
Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A7.02

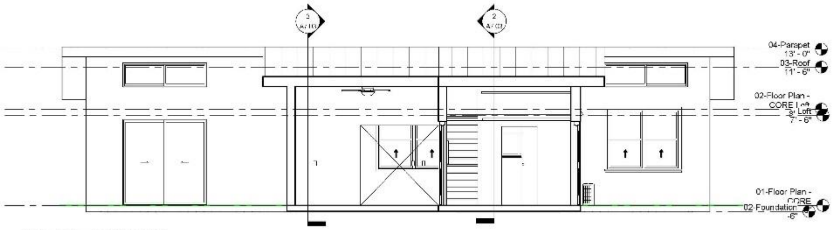
Scale 1/4" = 1'-0"



Section 3 - Overall - CORE + DWELL
② Transversal
1/4" = 1'-0"



③ Section 4 - Space + Dwell
1/4" = 1'-0"



Section 2 - Overall - CORE + SPACE
① Longitudinal
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

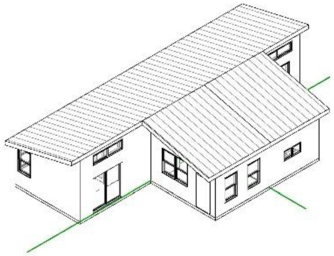
Project Address

Overall - Sections

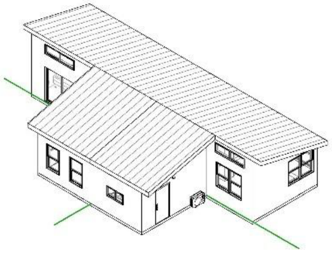
Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A7.03

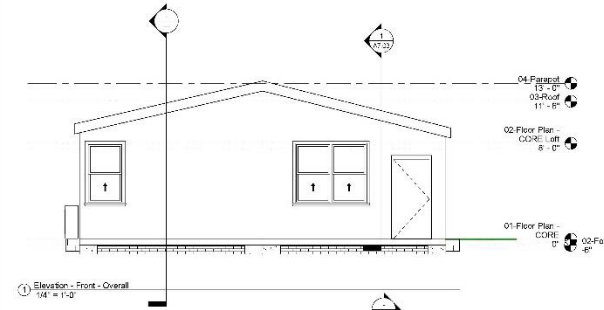
Scale	1/4" = 1'-0"



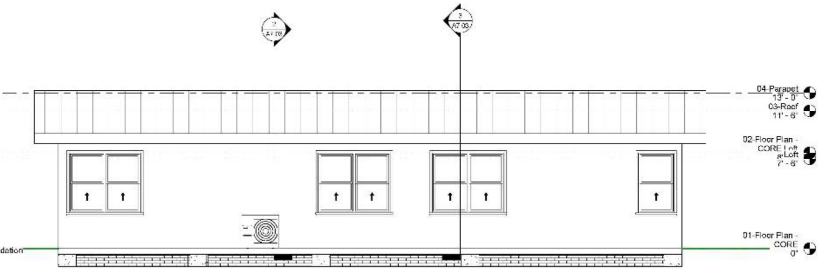
5 Axonometric - Front - Overall - 1



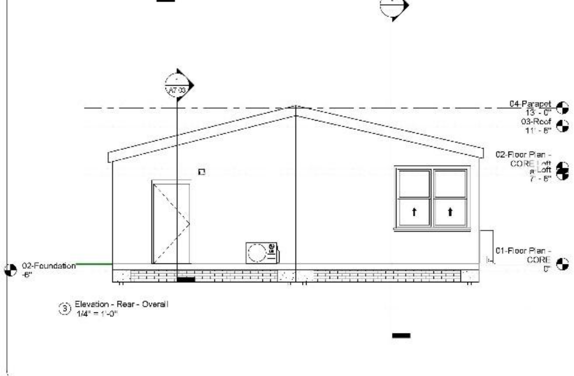
6 Axonometrix - Rear - Overall - 2



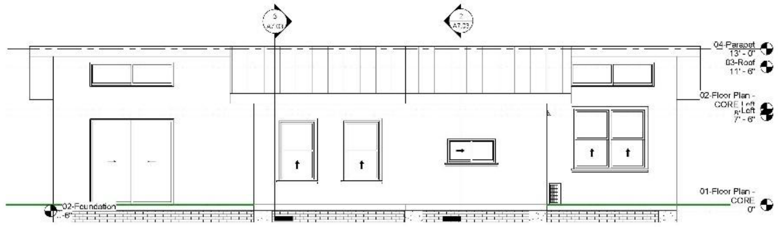
1 Elevation - Front - Overall
1/4" = 1'-0"



2 Elevation - Left - Overall
1/4" = 1'-0"



3 Elevation - Rear - Overall
1/4" = 1'-0"



4 Elevation - Right - Overall
1/4" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

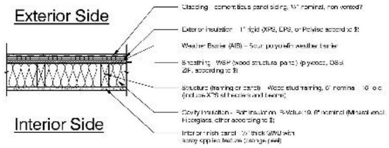
Project Address

Overall - Elevations and Axonometrics

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A7.04

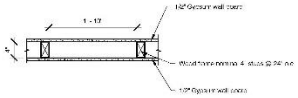
Scale 1/4" = 1'-0"



01 **Typical Exterior Wall - Batt Insul.**

Non-bearing, No Rating

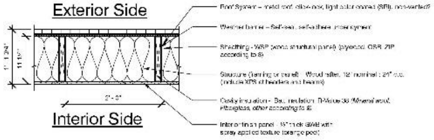
② Types - Exterior - Batt
1" = 1'-0"



02 **Typical Interior Partition**

Non-bearing, No Rating

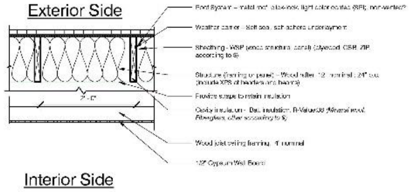
⑤ Types - Int Partition
1" = 1'-0"



01 **Typical Roof - Batt Insul.**

Non-bearing, No Rating

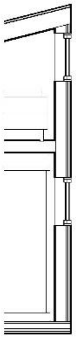
③ Types - Roof
1" = 1'-0"



01 **Typical Roof - with ceiling**

Non-bearing, No Rating

④ Types - Roof with ceiling
1" = 1'-0"



① Section 2 - CORE - Callout 1
1/2" = 1'-0"

STEPHEN BENDER

No.	Description	Date

Client

Client Address

HUD Prototype

Project Address

Details - Wood Framed Details (Common to All)

Project number	99999
Date	2020-02-19
Drawn by	Author
Checked by	Checker

A8.00

Scale	As indicated

9/28/2021 10:35:11 AM

APPENDIX G. NATIONAL GREEN BUILDING STANDARD (NGBS)

The National Association of Home Builders (NAHB) is an industry trade group that represents the interests of home builders, developers, contractors, and associated businesses. Home Innovation Research Labs (formerly the NAHB Research Center) provides a range of standards, guidelines, and analyses regarding housing construction to benefit the community. These studies include energy-saving measurements; calculation; performance assessment; construction details; assembly, cost, and economic analysis; industry supply chains; etc. NAHB provides training and education for the community to educate experts and professionals on improving the housing industry. Following NAHB guidelines to meet the baselines can benefit any designer or builder.

In 2012, NAHB established a green building rating system called National Green Building Standard (NGBS) for residential buildings, including single-family, multifamily, remodeling, and land development projects. NGBS is a residential building standard approved by the American National Standards Institute (ANSI). NGBS includes six categories: (1) energy efficiency, (2) water efficiency, (3) resource efficiency, (4) lot development, (5) operation and maintenance, and (6) indoor air quality (NAHB[20]). Energy requirements of NGBS are adopted from the International Energy Conservation Code (IECC), providing builders with a mechanism to meet code and earn points for green buildings. NGBS also includes lifecycle assessment at the products, assembly, and whole building level (NAHB).

Leadership in Energy and Environment Design for Homes

Leadership in Energy and Environment Design (LEED) is a well-known rating system in the United States and worldwide that offers a wide number of rating tools that can be used to evaluate different types of projects. LEED contains seven major categories: (1) sustainable site, (2) water efficiency, (3) energy and atmosphere, (4) materials and resources, (5) indoor air quality, (6) innovation and design, and (7) regional priority. LEED is organized around six major groupings or rating systems: (1) Building Design and Construction (BD+C), (2) Interior Design and Construction (ID+C), (3) Building Operations and Maintenance (O+M), (4) Neighborhood Development (ND), (5) Homes (H), and (6) Cities and Communities. Each rating system has one or more rating tools designed for specific building types (Kibert, 2016).

LEED for Homes (LEED H) focuses on single-family, low-rise homes (fewer than four stories), affordable housing, and manufactured and modular homes. LEED homes have less exposure to airborne pollutants and toxins and fresher indoor air than conventional homes. Overall, LEED homes provide a healthier indoor environment for occupants. LEED-certified homes use 20 to 30 percent less energy than a conventional home, with some homes even saving up to 60 percent (USGBC, 2019). LEED is also an economic development tool to guide affordable housing development and has been used by policymakers. In 2019, LEED certified more than 78,000 residential units that qualified as affordable housing (USGBC, 2019). This report will assess the proposed design with LEED H criteria to show what has been provided based on LEED H and the final point of the design.

Florida Green Building Coalition

Florida Green Building Coalition (FGBC) has developed a sustainability rating system for homes in Florida. This system aims to improve the built environment and lower the environmental

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[20] National Association of Home Builders.

impact of homes. FGBC created a resource to train builders and certifying agents for rebuilding homes with disaster recovery funds approved by the Florida Department of Economic Opportunity. Florida green buildings include three types of construction: new homes, existing homes (remodeled), and multifamily projects. Each has specific prerequisites and criteria. This rating system has seven sections to rate a building: (1) energy, (2) water, (3) lot choice, (4) site, (5) health, (6) material, and (7) disaster mitigation. FGBC is very similar to LEED; however, because of specific climate conditions in Florida, FGBC considers disaster mitigation as one of the most important sections. This section provides hurricane-resistant guidelines considering winds, rain, and storm surges. Specifically, the disaster mitigation section includes requirements for a safe room, attic, window, skylight, roof, garage, insulation, etc. It also contains specifications for flood- and surge-resistant foundation design. The next important section is energy, which includes electricity usage by equipment; fixture standards; heating, ventilation, and air-conditioning (HVAC) system inspection; and energy measurement.

APPENDIX H. HISTORICAL FACTS

Pre-1900: The two deadliest hurricanes before 1900 occurred in 1893; each caused more than 1,000 fatalities (Blake et al., 2007). Before 1900, just in Florida, 159 hurricanes are known to have occurred. The first recorded tropical cyclone to affect the area that is now called Florida struck in 1523, when two ships and their crews were lost along the western coastline. A strong hurricane hit northwest Florida in 1863 and was the earliest landfall known to have affected the United States (Chenoweth & Mock, 2013). Information is sparse for earlier years owing to limitations in tropical cyclone observation (Rappaport and Fernández-Partagás, 1995)

1900–1949: The 1900 Galveston Hurricane was the deadliest storm in U.S. history, killing between 6,000 and 12,000 people (Blake et al., 2007). The Okeechobee Hurricane caused at least 2,500 fatalities in 1928. Its pressure was recorded at more than 900 millibars (mbar) (Berg, n.d.; Blake et al., 2007). The so-called Labor Day Hurricane in 1935 was the most intense storm that had been recorded to that point, striking the Florida Keys. The cyclone had an internal pressure of 892 mbar.

1950–1974: Between 1950 and 1974, 85 tropical or subtropical cyclones struck in Florida. The most noteworthy were Hurricanes Donna and Dora. The strongest storm in the state during this period was Hurricane Donna, which was the 10th most powerful on record to strike the contiguous United States (Blake et al., 2007). In addition, Hurricanes Easy, King, Cleo, Isbell, and Betsy were all considered major storms. Hurricane Camille, in 1969, was the second most intense tropical cyclone on record to strike the United States. After punishing Cuba, it affected Alabama, Louisiana, Mississippi, and the East Coast (Blake et al., 2007; National Hurricane Center, 2017).

1975–1999: Between 1975 and 1999, 83 tropical or subtropical cyclones affected Florida. The strongest hurricane to hit the state during that period was Hurricane Andrew, which caused 54 direct casualties and was one of only four Category 5 storms to strike the United States. Hurricanes Eloise, David, and Opal also hit the state (Blake et al., 2007).

2000–present: The period from 2000 to the present has been marked by several devastating North Atlantic hurricanes. As of 2017, 79 tropical or subtropical cyclones had occurred in the United States. The most damaging of these was Hurricane Irma in Florida (Weather Underground, n.d.). The strongest hurricane in the state during this period was Michael, in 2018, which made landfall as a Category 5 hurricane. Hurricane Michael was the fourth most intense hurricane to strike the United States. Hurricanes Katrina (2005) and Maria (2017) are tied as the fifth strongest U.S. hurricanes (Blake et al., 2007). Hurricane Maria resulted in at least 2,982 fatalities, and Hurricane Katrina killed approximately 1,800 people (Blake et al., 2007). In addition, Hurricanes Charley, Ivan, Jeanne, Dennis, and Wilma are considered major Florida hurricanes.

APPENDIX I. RENEWABLE ENERGY AND STORAGE SYSTEMS

As shown in exhibit 114, the air-conditioning energy in September is 95 kWh/kW, which means it is approximately 3 kW/kW/day. The September daily estimate (kWh/24 h) is shown in exhibit 112. The battery should be able to store at least 9 kWh to cover the 2-day energy use for Core (see exhibit 113). Typical layout of PV system is shown in exhibit 115.

Exhibit 112. Photovoltaic System Yield Estimate

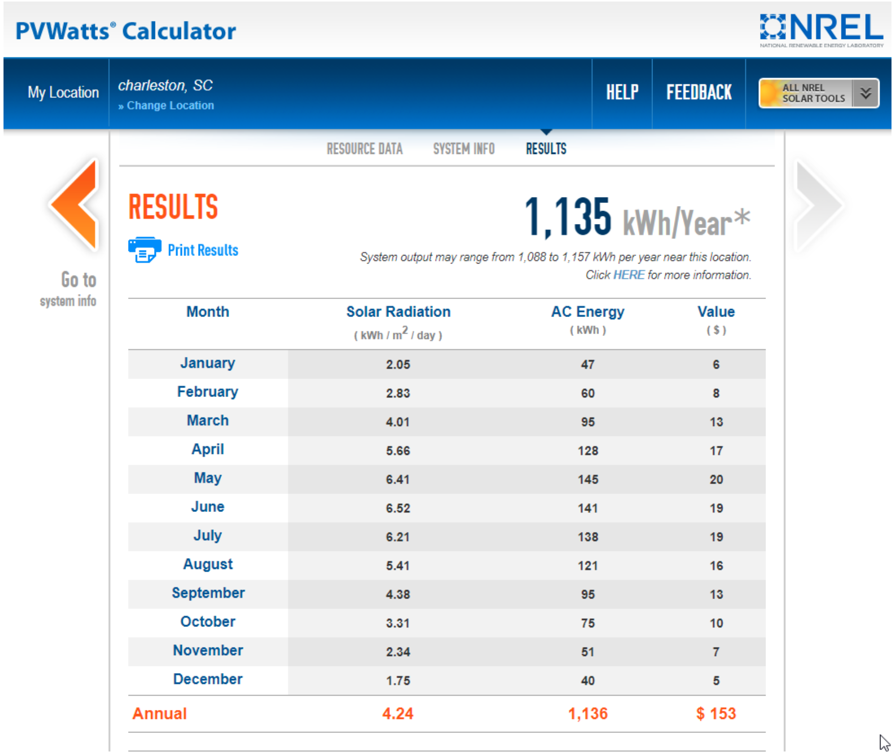
Core Module: 380 W
Location: Charleston, SC

Building	Roof Space	kWh/kW/year	Demand	kW	Modules	Modules	kW
Core	14	1,135	4,707	4.15	12.37	13	4,940

Exhibit 113. ESS Considerations for Core

September Daily Estimate (kWh/24 h)	kWh	W	h
Lg. Appl.	1.19	120	10
Lights	0.98	200	5
Heating	1.53	2,250	0.68
Microwave	0.2	1,000	0.2
Fans	0.6	50	12
Total	4.5	3,620	

Exhibit 114. North Used Estimations for Energy Storage Estimation



charleston, SC
» Change Location

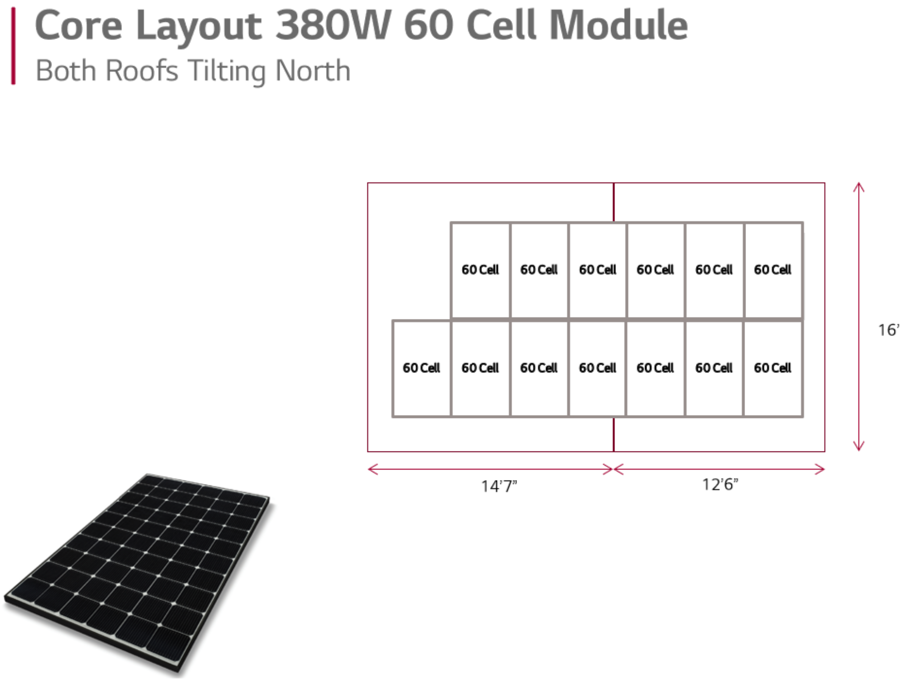
RESULTS

1,135 kWh/Year*

System output may range from 1,088 to 1,157 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Value ($)
January	2.05	47	6
February	2.83	60	8
March	4.01	95	13
April	5.66	128	17
May	6.41	145	20
June	6.52	141	19
July	6.21	138	19
August	5.41	121	16
September	4.38	95	13
October	3.31	75	10
November	2.34	51	7
December	1.75	40	5
Annual	4.24	1,136	$ 153

Exhibit 115. Core Layout 380-W 60-Cell Module



Core Layout 380W 60 Cell Module

Both Roofs Tilting North

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