Scaling Up to Zero Energy Ready—and Down to 530 ft²

The 1-bedroom home combines high-performance thermal envelope, construction details, and equipment to reach for Zero Energy Ready Home certification and enhance long-term affordability. *Photo by Jeremy Gary, Building Performance Consultants Inc.*

Manatee County Habitat for Humanity (MC-HFH) is building a 530 ft², 1-bedroom, 1-bathroom high-performance home in central Florida's climate zone 2A (hot humid) in response to market gaps facing the local and national housing industry.

Market Gap and Motivation

National media coverage and recent research both highlight America's accelerating need for affordable housing across all sectors. In particular, a national dialogue around energy equity[1,2] has brought to light the disproportionate energy burden in low- and moderate-income communities in many areas, including west, central Florida. MC-HFH addresses affordable housing availability and home energy costs by building affordable energy-efficient, high-performance homes, typically 3-bedroom designs of approximately 1,100 ft². MC-HFH has developed construction standards over the past decade to ensure a consistent, cost-effective home performance across the neighborhoods and jurisdictions in which they work.

In a new approach, the MC-HFH is now scaling down to a 530 ft², 1-bedroom, 1-bath (1/1) design while also upgrading performance to meet the U.S. Department of Energy's (DOE) Zero Energy Ready Home (ZERH) program standards (version 1). In this approach, first cost savings on the smaller footprint can pay for performance upgrades to reduce long-term costs.

The University of Central Florida's Florida Solar Energy Center (FSEC) has worked with Habitat for Humanity International and local affiliates to reach progressively higher performance levels since 1994[3]. Technical assistance for the 1/1 project included comparing MC-HFH's standards to ZERH requirements, collaborating on a flexible HVAC strategy, and applying research and best practices. This demonstration project can validate solutions for known issues that challenge broad adoption of high-efficiency technologies.

Upgrading to a Zero Energy Ready Home

MC-HFH's goal to reach ZERH certification builds on the organization's history of high-performance construction that addresses occupant health and safety, building durability, thermal comfort, and energy efficiency. ZERH qualifies those measures with a certification that can result in being able to receive incentives that help to make high-performance homes more accessible to all.

[1] American Council for Energy-Efficient Economy https://www.aceee.org/research-report/u2006
[2] Harvard Joint Center for Housing Research Harvard report https://www.jchs.harvard.edu/state-nations-housing-2023
[3] High-Performance Affordable Housing PNNL-SA-90552. https://www.energy.gov/eere/buildings/articles/high-performance-affordable-housing-habitat-humanity-building-america-top

Table 1: Key Characteristics of the Manatee County Habitat for Humanity Climate Zone 2A, Central Florida 1 Bedroom, 1 Bath ZERH

ZERH Target ERI = 61 | Actual ERI = 35
42% improvement over the ZERH Target
Projected annual energy use: 4,016 kWh, $468

Mandatory ENERGY STAR Labeled Products:

Windows, refrigerator, washing machine, range, lighting fixtures (9, all Tier 2), and ceiling fans (2).

Mandatory IECC 2015 Thermal Envelope Levels:

Overall UA = 78.1, meets Option 3, Total UA method.

Thermal Envelope Characteristics:

Walls: R-22 insulated concrete form walls
Exterior wall area = 744 ft² gross, 656 ft² net.

Attic and roof: Unvented attic, R-21 open cell spray foam insulation under roof deck. White metal over self-adhered bituminous membrane, hip roof with raised heel trusses; Gross roof area = 559 ft², 2′ overhangs.

Windows: Solar heat gain coefficient 0.23, 0.33 U-value.

Foundation: Uninsulated slab on grade.

Field verified infiltration: ACH50 = 2.31

Heating and Cooling:

Equipment: Variable capacity, ductless, single head, minisplit heat pump in main living space. 9,000 Btu/H rated cooling capacity; 10,900 Btu/h rated heating capacity. SEER2 24.3, HSPF2 10.9, SHR 0.82. Wall-mounted remote control.

Air circulation: Insulated jump duct with inline transfer fan from living area to bedroom; on/off wall switch in bedroom. Passive return air grille.

Humidity control: Ducted central dehumidifier (65 pints/day, 4.7 pints/kWh, 100–160 cfm) with return and supply ducts in unvented attic, internal humidistat. Dedicated circuit for on/off control if necessary.

Water heating: 0.96 EF standard electric tank water heater with compact piping; 0.39 gallons water storage meets standby loss limits.

Mandatory Mechanical Ventilation:

100 cfm ENERGY STAR kitchen exhaust fan;
50 cfm ENERGY STAR bathroom exhaust fan.

Whole-house ventilation: ASHRAE Standard 62.2 2010; 20 cfm of outside air (constant or intermittent equivalent) to dehumidifier return side. Programmable, electronic OA control module. Single circuit breaker manual override.

Ready for Future Solar PV Power:

Structural, electrical, and utility preparations.
Future PV system: 2.6 kW, production: 4,016 kWh.

ZERH certification combines achievement of a dwelling-specific Energy Rating Index (ERI) target, along with ENERGY STAR® and other program certifications, advanced equipment and appliance efficiency, field verifications, renewable energy readiness, and indoor air quality standards[4]. These requirements establish a compliance path for a healthy efficient home that's ready to be primarily powered by solar photovoltaic (PV) energy in the future.

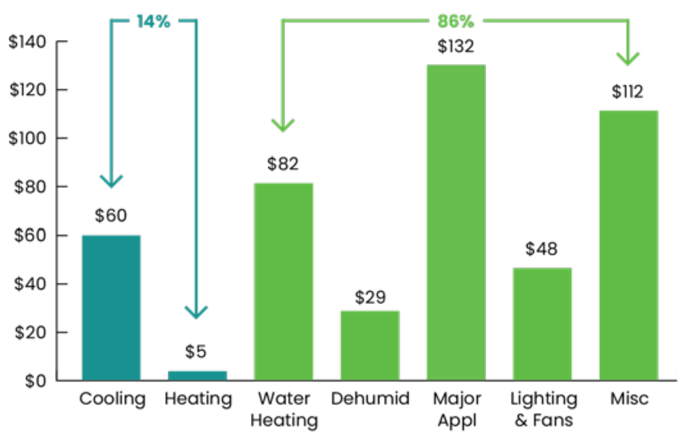
The ERI target is a number on a sliding scale that is generated by accredited rating software. It sets a baseline level of performance needed for ZERH certification. It is based on construction type, design, and climate. A "0" ERI score indicates a home that generates as much energy as it uses, meaning the projected net annual energy use is zero.

MC-HFH's standard specifications plus the ZERH program measures brought the 1/1's ERI target score down to 35, 42% better than the software-prescribed target ERI of 61. With the addition of a 2.6-kW PV array in the future, the 1/1 ERI drops to 1. For key home characteristics, see Table 1.

Thermal Envelope: To meet the IECC 2015 thermal envelope levels that ZERH Version 1 requires, the 1/1 design combines the mandatory ENERGY STAR windows with R-22 insulated concrete form exterior walls, and R-21 open cell foam[5] under the roof deck to satisfy the Total UA requirement.

Space Conditioning and Air Circulation: The high-performance thermal envelope creates very low external heat gain and space conditioning loads, reflected in the low projected annual heating and

Figure 1: Projected Annual Energy Cost by End Use ($)
Annual Total $468



[4] U.S. DOE, Zero Energy Ready Home program (v. 1): https://www.energy.gov/eere/buildings/zero-energy-ready-home-program
[5] Hot humid climate building characteristics and performance improvements may not be appropriate for other climate zones.

cooling cost of $65 (Figure 1, blue bars). ZERH requires ducts and air handlers to be installed in conditioned or unvented spaces. The high-efficiency minisplit heat pump is ductless. The central dehumidifier and its ducts are in the unvented attic.

Appliances, Lighting, and Fans: In low-conditioning-load homes, non-conditioning energy uses make up a larger percentage of projected annual energy use at 86%, compared to 60% in typical homes. The mandatory ENERGY STAR labeled lighting, ceiling fans, exhaust fans, refrigerator, washing machine, and range bring these non-conditioning loads down to projected annual energy cost of approximately $400 (Figure 1, green bars).

Water Efficiency and Indoor Air Quality: ZERH requires that "standby losses" of hot water volume in pipes be limited to 0.6 gallons, or a water heater with energy factor of 2.2 or higher such as a heat pump water heater be used. In the 1/1 home, the plumbing system is compact and aligned so that the furthest point of use (kitchen sink) is only 21 feet from the water heater. The ¾" pipe results in only 0.39 gallons of standby pipe water storage. The standard electric water heater saves hundreds in first cost, which is a significant consideration for the target market. Although this does not improve the ERI score, the long-term operational cost savings and carbon reductions are considered with the other requirements.

The ZERH program allows tradeoffs like this that allow equipment selections that may not offer maximum available efficiency but meet other design goals to accommodate a wide variety of construction combinations.

HVAC and Thermal Comfort Challenges

HVAC goals for the 1/1 include appropriately sized equipment and keeping the temperature even and within a ±3°F range between main body and bedrooms, with relative humidity throughout below 60%. The following elements are involved to achieve these goals, which are also described in the HVAC schematic in Figure 2.

Heating and Cooling Equipment Sizing: The estimated peak cooling load for this home is 5,450 Btu/h, just under ½ ton, including outside air ventilation. The lowest capacity minisplit made by the builder's chosen manufacturer is rated at 9,000 Btu/h or ¾ ton, about 30% oversized. Oversized high-efficiency air conditioners tend to quickly meet the desired temperature without circulating air long enough to extract moisture.

Through-the-wall heating and cooling units are available in this capacity range, but at much lower efficiencies. Still, comfort should come before efficiency. So, in case the careful planning does not ultimately result in the desired comfort, FSEC and MC-HFH's construction director made accommodations to make a potential equipment swap less expensive. A larger rough opening was framed around the intended location of the wall-mounted minisplit air handler. Then the air handler was framed in and finished as normal. In the event that minisplit needs to be replaced, this larger rough opening will accommodate replacement with a range of unit sizes and greatly reduce the amount of work needed to make the swap in an insulated concrete form wall. This approach is modestly more expensive, but it speaks to the value of contingency plans that can support the adoption of newer technologies.

Modeled Cooling Load Components (ACCA Manual J Calculation): Looking more closely at the modeled cooling load profile, we find that the small volume and high-performance thermal envelope reduced the calculated peak external load to 30% of the total. This is expected since the home contains all the conventional

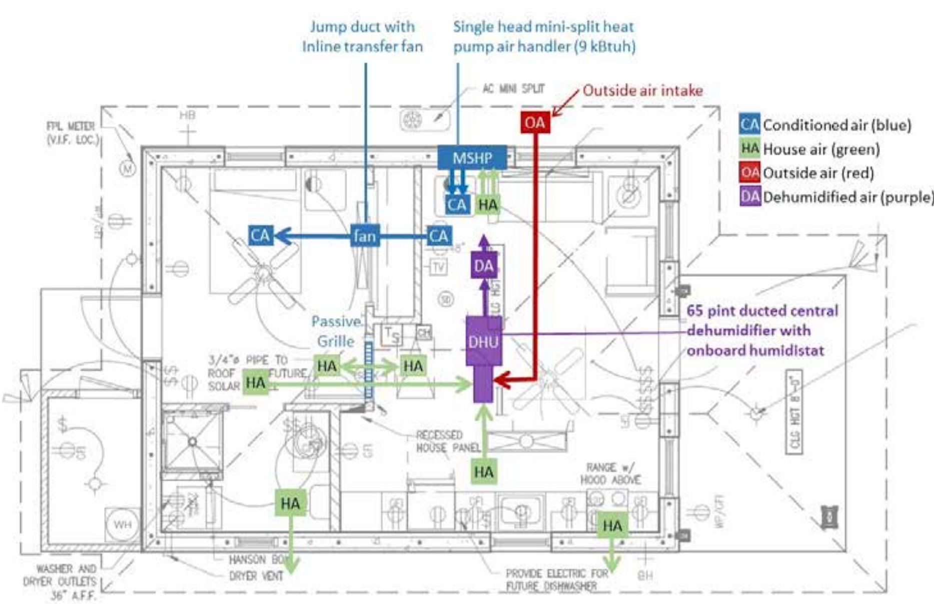
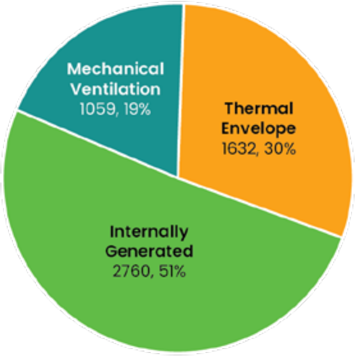


Figure 2: HVAC Schematic for MC-HFH 1 Bedroom, 1 Bathroom (1/1) 530 ft² Home

Figure 3: Calculated Peak Latent and Sensible Cooling Loads by Source (Btuh, %)



appliances generating the normal levels of heat and moisture (e.g., cooking, laundry, breathing, and bathing). These internal loads become the dominate contributor to the peak cooling load at 51% (see Figure 3).

Whole-house mechanical ventilation accounts for 19% of the peak load. The heat in these two load components is likely easily managed by the oversized minisplit. The humidity, however, is another matter. ZERH-required ENERGY STAR exhaust fans for spot ventilation in the kitchen (100 cfm) and bathroom (50 cfm) may be sufficient to remove the internally generated moisture load, with help from the minisplit. But in the overnight hours when sensible cooling loads are lowest, and outside air ventilation flow remains constant, studies in similar homes have documented sustained relative humidity above 60%, particularly in the fall and spring[6]. In an effort to avoid this, the 1/1 design couples mechanical ventilation with dehumidification.

Whole-House Ventilation and Dehumidification: The ENERGY STAR for Homes certification is a pre-requisite for ZERH certification, and it includes meeting ASHRAE Standard 62.2 2010 guidelines for whole-house mechanical ventilation. For the 1/1 home, 20 cfm of outside air at constant flow is required. Intermittent flow is permitted if equivalent hourly ventilation is provided. In this house, a dedicated duct draws in outside air and delivers it to the return side of a stand-alone, 65 pints/day central dehumidifier in the unvented attic with an internal humidistat. A programmable control module electronically opens and closes a damper for a set time period every hour and triggers the dehumidifier to run at the same time. Regardless of outside air flow, the dehumidifier draws in house air based on an internal humidistat.

If the central supply of outside air creates a comfort problem, the outside air duct can be permanently closed. In that case, the kitchen and bath exhaust fans can be connected to a similar control module without major reconstruction for exhaust-only ventilation.

This is another example of a contingency plan for this demonstration project that allows validation of technology to support scaled deployment.

Air Distribution: Single head minisplits do not distribute air directly to private adjacent spaces such as bedrooms, potentially creating comfort issues, particularly when doors are closed. A Florida field study (see footnote 7) found that transfer fans used in tandem with large passive return air pathways maintained temperature differences of ±3°F during approximately 90% of hours. The 1/1 home has an inline fan with a wall switch connected to an insulated jump duct in the unvented attic. This essentially functions as an independent forced air supply duct to ensure the conditioned air reaches the main occupancy area of the bedroom. A large, passive return grille over the bedroom door allows free flow of air out of the bedroom, similar to the door being open.

Depending on occupant preferences, it's possible that neither the dehumidifier nor the transfer fan will be needed. It is also possible that even with these devices, temperature and relative humidity levels may not meet comfort standards for some occupants. Providing occupant control over individual components, as MC-HFH has done, may provide the best test platform for performance for most occupants rather than trying to identify a single solution.

Provisions for Future Solar PV Installation

The 1/1 has projected annual energy use of 4,016 kWh. To reach zero energy status, a grid-tied solar PV array (or other renewable energy) needs to produce 4,016 kWh annually. The house is oriented such that the largest roof area faces southwest, with a smaller area facing southeast. Both can be used for PV installation. There is no due-south facing roof area.

The ZERH program's PV-ready checklist makes provisions for a future solar PV installation. PV-ready design elements are only required where average daily solar radiation is at least 5 kWh/m^2/day, no site features shade the roof, and roof area facing ±45 degrees of due south has 110 ft^2 of free roof area (for homes up to 2000 ft^2 house). The 1/1 meets the first two criteria. It falls slightly under the free roof area criteria. Regardless, MC-HFH installed an electrical conduit and other the

[6] UCF FSEC Energy Research Center: https://publications.energyresearch.ucf.edu/wp-content/uploads/2019/08/FSEC-CR-2099-19.pdf

components in the PV-ready checklist to facilitate a future solar PV installation.

A PV array of approximately 2.6 kW, depending on system design and attachment methods, could fit on the 1/1 using both the southwest and southeast sides of the roof. The installation is somewhat challenging in that multiple ridges from the hip roof construction may diminish the available attachment area, and HVAC system components in the attic may restrict the work area. A slightly larger capacity PV system would be needed to offset the full projected annual energy use of 4,016 kWh. With the 2.6-kW PV system, the ERI would drop to 1.

Moving Forward

The interactions among the HVAC components and user operating schedules are complex, and energy use simulations using software-generated models are affected by unpredictable factors such as occupant comfort preferences. Field implementation provides valuable lessons on actual energy use and comfort conditions that can be carried forward into MC-HFH's next 1/1 and a broad spectrum of other small, very low-load homes in climates zones 1–3. This demonstration may validate solutions to low-load conditions that currently challenge the adoption of high-efficiency technologies for homes of this type. Lessons learned will be added to the growing body of research on viable approaches for a broad spectrum of small, very low-load homes in climates zones 1–3.

Further Research

Minisplits are variable capacity machines with great potential for dehumidification, but the internal control strategies favor varying the percent of cooling coil in use over varying the airflow over the whole coil, which would remove more moisture. Research to evaluate the technical potential of alternative control strategies for reducing indoor relative humidity levels is needed to achieve comfort goals for low-load homes in the hot-humid climate.

Characteristic wall and ceiling layout for 1/1 design. *Photo by Jeremy Gary, Building Performance Consultants Inc.*

Learn More:

DOE Zero Energy Ready Home Program

bit.ly/3v1fFb7

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Building America | FSEC A Research Institute at the University of Central Florida | Manatee County Habitat for Humanity

For more information, visit:
energy.gov/eere/buildings/building-america

DOE/GO-102024-6119 • April 2024