Can Increasing Energy Performance Be a Key to Unlocking Rural Home Affordability?

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Though home energy use should be considered in every residential project, it is particularly critical for low-wealth individuals and families. While higher-budget projects can rely on a return on investment for energy-saving features, "affordable" housing projects built by not-for-profit organizations frequently rely on reductions in construction costs to keep purchasing prices low for homeowners. However, this can result in higher maintenance and operations costs over the useful life of the home. Could linking home performance to the mortgage carry of an individual homeowner provide opportunities to create a housing stock of homes that consider the total cost of homeownership? This paper describes a research initiative designed to seek the balance point between up-front investments in improved energy performance and home affordability in support of a pilot, systems-based approach to more affordable homeownership.

In a design-build studio format, the authors and their students have revised and constructed multiple versions of the same small, two bedroom prototype home developed for the context of a mixed-humid climate: one built to the Passive House Institute U.S. (PHIUS) standard and the other to the Department of Energy's Zero Energy Ready Home (ZERH) standard. By constructing two prototype homes on the same street and with similar orientation, but with differing energy-related details, the authors are able to evaluate the initial cost of construction associated with achieving these two performance standards while simultaneously comparing the monthly energy savings afforded by each approach.

Each home underwent a rigorous process of modeling, testing, and monitoring. Computational energy modeling during the design phase were used to to test various envelope assemblies. At key points in construction, blower door tests and thermal imaging were utilized to assess the specific efficacy of alternative approaches construction detailing and to verify systems and envelope airtightness. Long-term monitoring is used to evaluate actual post-occupancy energy use against that which was predicted in the initial design phase. Furthermore, post-occupancy engagement with the homeowner allows for a deeper understanding of the design of end-user education programs that empower families to leverage the high-performance potential of their homes.

Ultimately, these findings provide an invaluable contribution to the authors' broader research and development where, in partnership with federal agencies as well as mortgage and insurance providers, the team continues to explore mechanisms to better integrate both the policies and products necessary to support a new paradigm of truly affordable homeownership to families in the rural South.

INTRODUCTION

While the cost of operating homes is a concern for everyone, it is a particularly compounded burden for low-wealth families living in areas of rural persistent poverty. Rural residents have a higher energy burden when compared to the national average, and rural low-income households face a higher burden than their more affluent neighbors. Furthermore, the South has some of the nation's lowest energy rates yet has some of the highest energy bills and associated energy burdens.[1] This is further exacerbated by an aging, and increasingly substandard, housing stock.[2]

Rural areas have higher rates of homeownership.[3] While home valuation in urban areas is most often based on land ownership, in rural areas home value is largely based on the leverageable asset of the house itself, which can be passed from generation to generation. Therefore, providing homes that are both durable and energy efficient is critical for maintaining housing affordability in rural areas, and developing an integrated approach that links financing mechanisms to housing performance is a key strategy to unlocking affordability.

This paper focuses on one research project designed to seek the balance point between up-front investments in improved energy performance and home affordability in support of a pilot, systems-based approach to more affordable rural homeownership. By constructing two homes built to different third-party operating standards and then comparing the construction and operation costs of the home, we seek to find affordable methods for building high-performance homes in rural markets.

RURAL STUDIO AND THE FRONT PORCH INITIATIVE

The homes presented in this paper are built on an iterative research project that began at Auburn University Rural Studio in 2004. The 20K House is a research project to develop small, well-designed, affordable home prototypes. Each year, student teams design a build a small house prototype based on a conceptual proforma. To date, Rural Studio has designed and constructed over twenty-four prototype homes.

Expanding on the 20K House work, the Front Porch Initiative is a faculty-led endeavor developed to extend the impact of the research by working with housing providers outside of Rural Studio's service area. The Front Porch Initiative harnesses the student prototype designs and develops them into a "product line" of homes. There, the prototype designs are paired with a library of building assemblies to create climate- and client-appropriate houses. Front Porch Initiative provides both home designs and technical assistance to housing provider partners who, in turn, build the homes in their local communities. In return, partners share information on the opportunities and challenges of developing, building, occupying, and maintaining the homes. Currently, Front Porch Initiative is working with housing providers in climate zones 2, 3 and 4 to further the research, with the goal of offering the prototypes to a wider audience in the future.

THE PROJECT

A partnership with Auburn Opelika Habitat for Humanity (AOHFH) afforded a unique opportunity for a focused research project on energy performance. With a close proximity to Auburn University's main campus, the partnership with AOHFH allowed Front Porch Initiative to harness additional student and faculty assets. The project consists of two homes constructed on the same street in Opelika, Alabama, approximately twenty minutes from campus.

The home design chosen for these sites was based on Buster's House,[4] one of the models in the Front Porch Initiative product line. Auburn Opelika Habitat for Humanity felt that this two-bedroom, 900-square-foot prototype filled a gap in their offerings to eligible families. Furthermore, the home met the 800-square-foot minimum area required by local zoning regulations while also fitting within the setbacks of irregularly-shaped parcels in AOHFH's portfolio. This allowed AOHFH to leverage non-conforming lots that they had previously found challenging to build on while simultaneously providing more opportunities for homeownership to their clients.

Each home was the focus of a design-build studio taught in the architecture program at Auburn University. The first house, referred to as House 66 by Auburn Opelika Habitat for Humanity, was designed and constructed in the spring and summer semesters of 2018. The second house, House 68, in the spring and summer of 2019. Each house was then constructed by the student and faculty teams working alongside local volunteers.

In each instance, the students, faculty, and energy consultants began with energy modelling, working through different iterations of key details to optimize assemblies and ensure each design met the respective standard.[5] The final chosen design was modeled in WUFI to ensure compliance with each performance standard. Blower door tests were conducted at critical milestones during construction, allowing for corrections to air sealing.

RESEARCH DESIGN

The primary objective behind this research project is to develop an understanding of how the energy performance of small, single-family detached homes could be optimized within an affordable cost-to-construct and cost-to-operate framework.

To pursue this question, the faculty-led team elected to build the first home to the most rigorous certification standard: Passive House Institute U.S. (PHIUS). Construction costs were tracked and documented, and energy consumption monitoring began once the home was occupied. This initial choice to build to the highest performance standard first is a key element of the research design. This set optimized energy performance as the benchmark for the project and focused the assembly design, engineering, and construction efforts on finding the most affordable way to reach that goal.

Using the insights gained from the construction of House 66, the following year House 68 was built with an eye toward reducing the cost-to-construct while holding as closely to the performance standards of the PHIUS home. House 68 was constructed to the Zero Energy Ready Home (ZERH) standard developed by the U.S. Department of Energy. The desired outcomes of the ZERH standards are similar to the more prescriptive PHIUS requirements but allow more flexibility in the approach to detailing construction systems due to its more descriptive nature. This is a key factor when considering construction approaches across markets and procurement strategies.

Upon completion, each home was occupied by a homeowner family. With the permission of the homeowners, the research team installed monitoring equipment in each home that provides detailed, circuit-by-circuit information on energy use as well as indoor temperature and humidity conditions. Side-by-side monitoring of the two homes began in February of 2020 and will continue into 2021.

Most often housing "affordability" is addressed by investigating processes of simply reducing up-front construction costs. As such, one of the primary barriers to delivering

Figure 1. Completed houses. House 66, left. House 68, right. Image cre att Hall.

high-performance homes in the affordable markets is most often the up-front additional cost that these performance "upgrades" require. This research theorizes that targeted increases in construction costs can actually enhance affordability when they are considered as but a single variable in the total cost of homeownership. However, in order to eliminate any risk to Auburn Opelika Habitat for Humanity created by the need to increase the initial construction costs to meet the desired beyond-code performance outcomes, all "extra" costs to build the homes to beyond-code standards were covered through University grants and contracts.

KEY ASSEMBLIES

Based on the experience of building House 66 to the PHIUS standard, three key construction assemblies were identified as critical opportunities in simplifying constructability and reducing construction cost to House 68 without creating a significant negative impact on building performance. These assemblies are illustrated comparatively in Figure 2.

APPROACH TO UNDER-SLAB AND SLAB EDGE INSULATION / THERMAL BREAKS

PHIUS standards place significant emphasis on limiting energy transfer through the foundation. The amount of under-slab insulation (4" of extruded polystyrene) and the insulation required to isolate the slab edge from the foundation wall (2" of extruded polystyrene) on House 66 made for a time- and labor-intensive detail at the top of the foundation wall. The necessity of a physical termite barrier associated with the use of under-slab foam products in the "very heavy" termite infestation zone further complicated the assembly. Given the relative mildness of climate zone 3 winters, it was determined that under-slab insulation at House 68 could be eliminated, and the thickness of the slab edge insulation was reduced (to ¾"of polyisocyanurate) while still maintaining a thermal break.

APPROACH TO WALL INSULATION, WINDOWS, AND EXTERIOR DOORS

House 66 utilized open cell spray foam in the 2x6 wall stud cavity. ZIP sheathing was used as the primary air barrier coupled with 2" of extruded polystyrene (XPS) attached outside the sheathing. This provided the necessary thermal break while simultaneously achieving the R-value required to meet the PHIUS target. Vertical furring and fiber cement lap siding followed. While this approach ultimately created a well-sealed and well-insulated wall assembly, it did so at an expense of several complex steps. It required the installation of several additional layers of the assembly and special detailing around the window frames and door openings to accommodate the depth of the XPS. In response to these concerns, House 68 utilized ZIP-R sheathing, which allowed for the installation of the sheathing and thermal break in one step.

PHIUS certification is tied to using PHIUS-listed products, and sourcing PHIUS-listed windows is often one of the most challenging from a supply and budget perspective. House 66 incorporates PHIUS-listed, triple-glazed vinyl window and upgraded exterior doors. When designing House 68, predictive energy modelling indicated that the ZERH goal could be achieved with a locally-supplied, double-glazed window at a much lower cost.

APPROACH TO AIR SEALING AND INSULATION AT THE CEILING PLANE

Concerns over meeting the PHIUS air sealing target led to the framing and sheathing of the ceiling plane on House 66 with ZIP sheathing followed by a site framed roof. This provided an air-tight lid on the house and a ceiling joist cavity to contain ductwork, plumbing lines, and light fixtures below the "lid." The underside of the sheathing was sprayed with closed-cell foam with an additional 14" of blown-in cellulose in the ventilated attic.

This approach involved a significant amount of additional framing material and on-site labor. House 68 shifted to a simpler approach, incorporating prefabricated roof trusses. The gypsum wallboard (GWB) at the ceiling acts as the top-side air barrier. It was determined this approach was more in line with a typical Habitat for Humanity build and provided the opportunity to explore the management of air leakage with this more

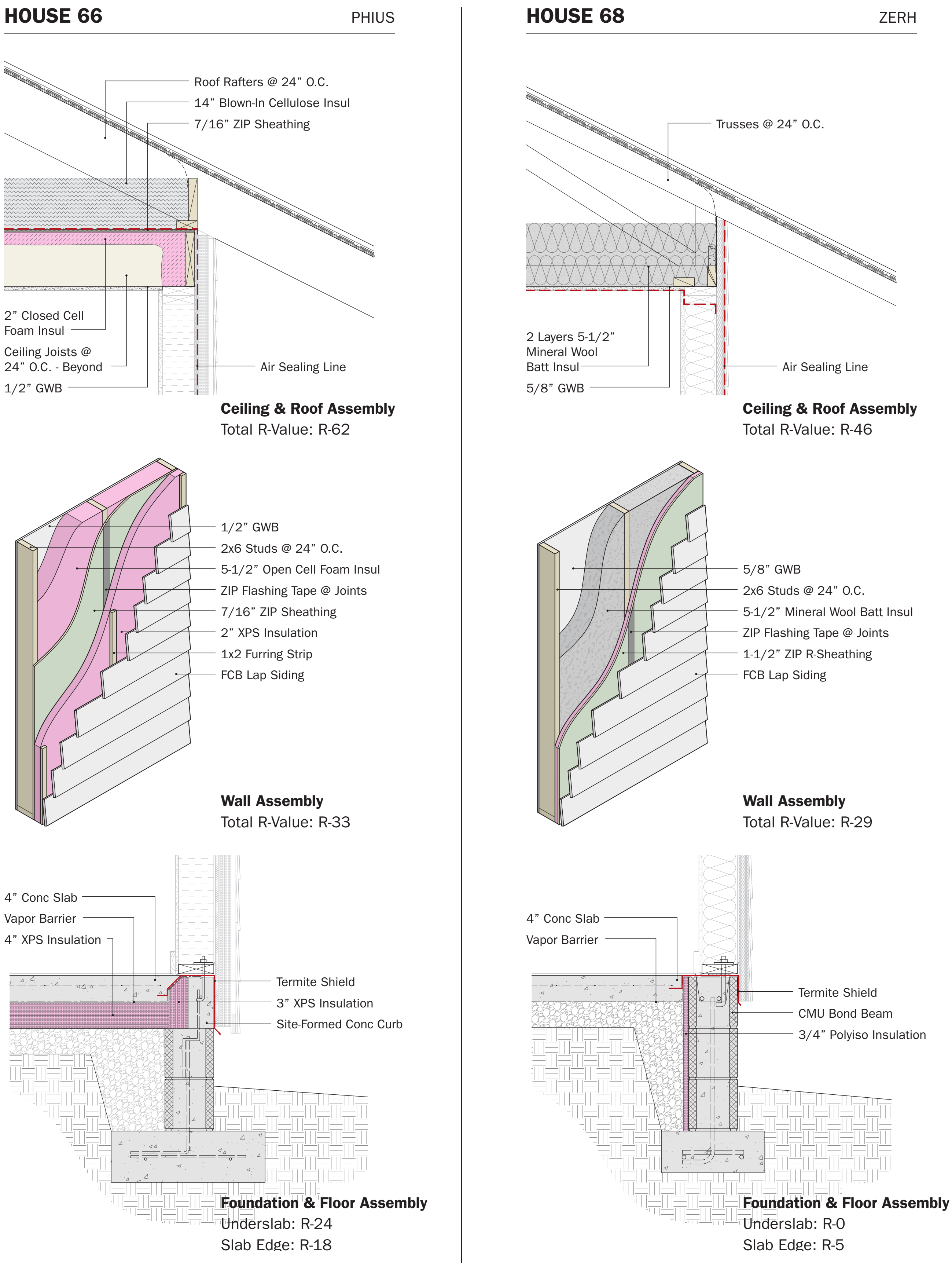

Figure 2. Comparison of Key Assemblies.

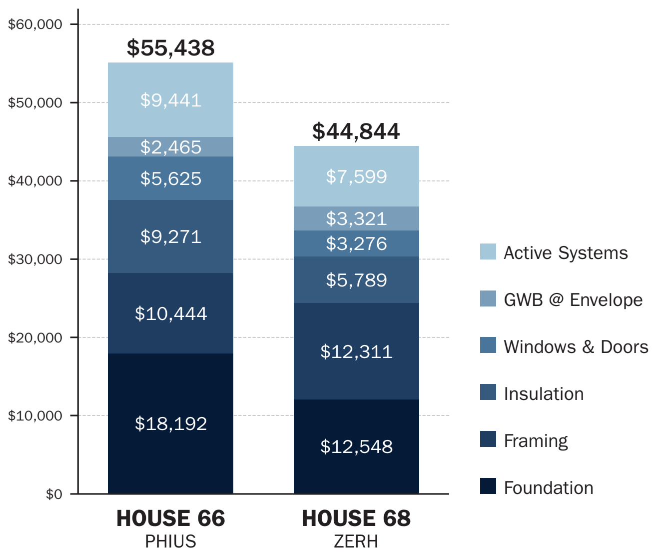

Figure 3. Comparative Construction Cost of Key Elements

straightforward approach.

In House 68, the GWB ceiling was installed first, followed by air sealing the joint between the GWB and the top plate to ensure a good perimeter seal. This break in the GWB installation sequence meant the installer had to make two trips, increasing cost on that part of the project.

ACTIVE SYSTEMS

The approach to active systems on the two houses is almost identical. Both homes utilize mini-splits as the heating and cooling source, a small, in-wall dehumidifier to supplement the mini-split in the humid seasons, an ERV, and a heat pump water heater. The main difference in the two houses is that House 66 has a PHIUS-listed high-efficiency ERV, and the mini split on house 68 is a bit more efficient than the unit used in House 66.

RESULTS (TO DATE)

Given the differences in construction approach and performance standards, the research team measured the cumulative effect of the interventions by comparing air tightness and HERS scores. Upon completion of construction, a final blower door test confirmed air tightness results of 0.37 ACH50 at House 66 and 1.76 ACH50 at House 68.[6] A more comprehensive measure of performance, the HERS score takes into account assemblies, air tightness, and equipment efficiencies. House 66 achieved a final HERS rating of 38. The team is still in the process of finalizing certification for House 68, but the predicted score is 38 despite different envelope approaches.

As noted above, construction costs were carefully documented for each home, and the research team is now performing ongoing energy monitoring on both homes to see how the differences in approach to the key assemblies translate into energy use. Side-by-side monitoring began in February 2020, yielding nine months of comparative data as of the publication date for this paper.[7]

Figure 3 illustrates how the changes to key assemblies translated to construction costs. As with all Habitat for Humanity projects, while some key work is subcontracted to licensed and/or skilled tradespersons, the majority of the on-site work is performed by volunteers (in this case, students, faculty, and community volunteers). Consequently, the project cost histories do not provide a complete picture of the labor costs. However, cost data presented here reflect the same approach regarding volunteer versus subcontracted labor on both homes.

The costs tallied here are isolated to the elements of the building design that relate most directly to performance:[8]

- Active systems (ductless mini-split, ERV, water heating, etc.)
- Insulation
- Windows and exterior doors
- Framing
- Foundation
- GWB at perimeter envelope

The total difference comes to about $10,600, with the largest differences coming in the costs of the foundation system, insulation, windows, and exterior doors.

To more closely compare the energy use of two homes with different families as occupants, the collected data is grouped into three sets:

- *Category One* – This category of energy use relates most directly to how a house is designed and built. It includes the costs to heat and cool the home, the active ventilation system, and the dehumidifier. Additionally, interior temperature and humidity are monitored to understand differences in the interior conditions that tie to the associated energy use in this category.

- *Category Two* – This category of energy use include lighting, large appliances, and water heating. These costs are impacted by the efficiency of the equipment specified but are also impacted by variable occupancy patterns and appliance use.

- *Category Three* – This includes all the user-connected appliances and fixtures. These “plug loads” are entirely occupant-driven. While they can have a significant impact on the total percentage of overall energy consumed (particularly in a high-efficiency house), they have little relation to the way the home was constructed.

Figure 4 illustrates how these three categories of energy use add up for each home, and Figure 5 shows how the Category

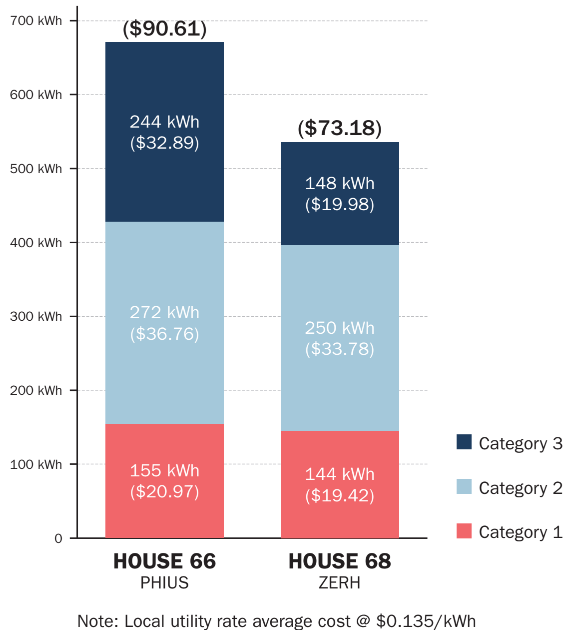

Figure 4. Total Average Monthly Energy Use in kWh.

One energy use tracks over the nine months of use data collected so far. A few unexpected variables have impacted the energy use, such as the stay-at-home order associated with the COVID-19 pandemic and a faulty humidistat at one of the homes.[9]

It is important to note that these results reflect energy data from only three-quarters of a year. It is expected that the added insulation in House 66 will translate to a performance advantage during the three coldest months of the year (November –January). However, the data collected so far suggests that the cost-saving measures associated with House 68 are not translating to significant penalties to the performance thus far.

Returning to the question of how the cost-reduction strategies impact operating costs, and how this relates to affordability, the data collected thus far is beginning to provide some emerging answers.

The costs to heat and cool both homes (Category One energy use) is under $21 per month ($250/year), compared to just over $67 per month ($800/year) for an average home in Alabama.[10] Establishing such an ambitious goal for operating cost savings is critical to our goal of redefining "affordability" as inclusive of the cost-to-operate. Energy cost savings of $46/month can offset over $9,000 in up-front investments in performance.[11]

The $10,600 cost premium on key systems for House 66 translates to about $53 per month more in market-rate mortgage costs. As illustrated in Figure 4, based on data collected to-date, the envelope and systems upgrades on House 66 do not result in a net savings per month on costs to heat and cool the home. Even if House 66 returns a savings in the colder months, the alterations to the key details on House 68 appear to translate to an effective approach to balancing ambitious performance and affordable construction costs.

NEXT STEPS

The research team will continue to monitor energy use on the two homes through the 12-month mark (January 2021) and will update the findings accordingly.[12] Additionally, the research team will conduct focused investigations into the performance of specific elements of the key assemblies identified above. The first of these investigations will include an analysis of the heat transfer characteristics of the different under-slab and slab-edge insulation approaches in House 66 and House 68.

The team will also seek to better understand the differences between actual energy use and the model-predicted energy use, with the goal of helping Front Porch Initiative partners understand how to use modelling as a resource when evaluating alternative construction approaches. The team will also be investigating the labor costs that would be incurred if the scope of volunteer-constructed components of these homes was reduced.

All of the findings from this study will be folded back into ongoing research into the most effective and affordable ways to integrate high performance construction approaches into the homes in the Front Porch Initiative portfolio. The Front Porch Initiative is working to re-center the definition of "affordable" as inclusive of the total cost of homeownership. Concrete, field-validated evidence of the operating cost benefits associated with up-front investments in energy performance—and the costs of implementing them—is critical to helping not-for-profit housing providers and advocates embrace this approach.

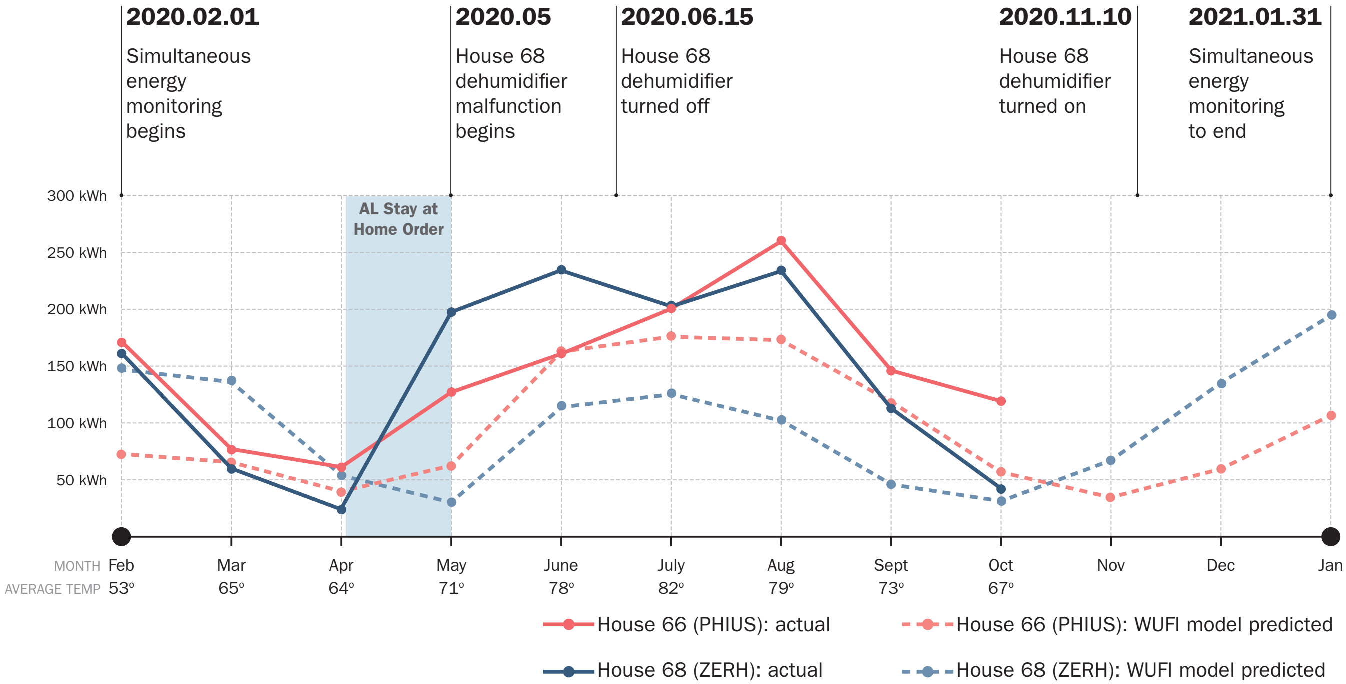

Figure 5. Category 1 Energy Use: Actual and Predicted

ENDNOTES

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2. Pendell, Rolf, et al. The Future of Rural Housing. Urban Institute, October 2016. https://www.urban.org/research/publication/future-rural-housing/view/full_report. Accessed March 30, 2020.

3. Mazur, Christopher. "Homes on the Range: Homeownership Rates Are Higher in Rural America." United States Census Bureau, 08 December 2016. https://www.census.gov/newsroom/blogs/random-samplings/2016/12/homes_on_the_range.html

4. Buster's House was designed and built by a team of Auburn University Fifth-Year architecture students at Rural Studio in 2017. The student design team for Buster's House included Olivia Backer, Carley Chastain, Ben Malaier, and Janine Mwenja. The Buster's House Prototype is based on this design.

5. The student team for House 66 included: Spring Studio- Lauren Ballard, Meghan Bernhardt, Fox Carlson, Emma Clark, Katherine Ferguson, Jed Grant, Haley Hendrick, Jeff Jeong, Mary Ma, Kate Mazade, Ashley Mims, Walker Reeves, Rowland Sauls, Jordan Staples, and Matthew Wigard. Summer Seminar- Heath Barton, Emma Clark, Noah Dobosh, Melissa Ensley, John Going, Mason Handey, Dee Katoch, Mack Mahoney, Ashley Wiley, Joshua Williams, and Valencia Wilson.

   The student team for House 68 included: Spring Studio – Claire Bruce, Justin David, Ozzy Delatorre, Adam Fehr, Jonathan Grace, Emily Hiester, Dongting Huan, Reed Klimoski, Mingtao Liu, and Emma Porter. Summer Seminar – Erik Aguilar, Carol Allison, Craig Barker, Elizabeth Bowman, Caty Bowman, Zack Burrogh, McClean Gonzalez, Davis Johnson, Emme Mora, Kamron Sullivan, and Nieman Ugbesia.

   The faculty team for House 66 & 68 included Professors David Hinson and Mackenzie Stagg (Architecture) and Professor Mike Hosey (Building Science.) The consultant team included David Bitter, CPHC; Bruce Kitchell, PHIUS+ Rater; and Alexander Bell, energy modeler. The team also received generous assistance from Mark Grantham, Executive Director of the AOHFH affiliate; Jacqueline Dixon, Contractor of Record; Rob Howard of Mitsubishi Electric Heating & Cooling; Alex Cary and Warner Chang from the Institute For Business and Home Safety; and Eric Oas of Oasis Heating and Air.

6. By comparison, the maximum air leakage allowed by PHUS is 0.6 ACH50.

7. A Site Sage system installed in each home provides energy consumption data on each circuit within the home. Circuits were organized to align with the major categories of the WUFI model: heating & cooling, auxiliary fans, the ERV system, major appliances, lighting, and miscellaneous loads.

   Side-by-side monitoring began in February of 2020 and will continue into 2021. The data reported here reflects results from February through October 2020.

8. The cost of project components that do not translate to differences in performance, such as those associated with sitework, landscaping, interior millwork, etc. are excluded from this analysis.

9. The COVID shutdown meant that both homes were occupied nearly 24 hours/day April-July, impacting all categories of energy use. The humidistat on the dehumidifier in House 68 malfunctioned in May and June, and it was turned off until a repair could be implemented in November.

10. Source for this figure is the U.S. Energy Information Administration report on "2018 Average Monthly Bill – Residential" https://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf?kbid=118190 . This report identifies the average monthly energy use for a home in Alabama as 1,201 kWh. At $0.135/kWh, this equates to $162/month and $1,945/year. The USEIA estimates that 41.5% of energy use in U.S. homes is associated with heating and cooling.

11. Savings due to energy efficiency are most often calculated as an annual cost reduction. However, as most homeowners develop and manage their household budget on a monthly basis it can be more useful to consider monthly energy savings instead. By transferring monthly energy savings from an expense category to the investment category represented by the month mortgage payment in the homeowner's monthly budget, a straightforward cost/benefit analysis can now be considered. For example, in a traditional 30-year fixed-rate mortgage, every dollar of monthly mortgage payment finances roughly $200 of construction. Therefore, if a homeowner reduces their energy expenses by $25.00 per month, they can then invest that same $25.00 in their mortgage payment, affording an additional $5000.00 in energy efficient construction with no increase in their total monthly outlay. Additionally, such upgrades also increase the appraised value of the home thus better protecting the investment of both lender and homeowner.

12. Data collection is facilitated by Elizabeth Farrell Garcia, Assistant Research Professor, and Anthony Spafford, a student worker.