Lessons Learned: A New Norris House

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Abstract

In 1933, the Tennessee Valley Authority created a model community as part of the Norris Dam construction project. Built entirely anew, the town of Norris was envisioned as a self-sustaining utopian community. A key feature of this New Deal village was the Norris House, a series of home designs built for modern, efficient, and sustainable living. New technologies and prefabricated elements were quietly integrated into aesthetically pleasing, vernacularly-inspired homes. In light of the 75th anniversary of the Norris Project, a multidisciplinary, university-led design/build team reinterpreted the Norris paradigm and created a New Norris House – a LEED for Homes Platinum home designed to address the constraints and imperatives of the 21st century. Partnering with a large modular home builder, the academic project team completed the home in a design/build setting over the course of 2.5 years.

Currently, the project is in a demonstration and evaluation phase. Qualitative and quantitative assessments are collected, reflecting the residency of two live-in subjects. Their occupancy patterns are monitored digitally through sensors in the home and landscape. This paper presents selected analysis and results of the design and environmental strategies employed. Data collected over the past 12 months is used to assess residential building design, systems and performance. Strategies for integrating passive and active systems and their benefits, risks and rewards based on the design intentions and data collected are shared.

Keywords – Design/build; Evaluate; Case study; Solar Thermal; TVA; Modular; Passive

1. Introduction

In 1933, by the passing of the TVA Act, the United States Congress created the Tennessee Valley Authority—the nation's first federally operated utility. Tasked with the goal of bringing the impoverished region out of the depression, the agency would address "a wide range of environmental, economic, and technological issues, including the delivery of low-cost electricity and the management of natural resources".[1] Shortly after its formation, the TVA began the Norris Waterworks Project. As part of the dam construction effort, the TVA also created a small model community to serve as worker housing. Built entirely anew, the town of Norris was designed around the principles of the Garden City movement and was envisioned as a self-sustaining utopian community.

A key feature of this New Deal Village was the Norris House, a series of homes built for modern, efficient, and sustainable living. Employing a large team of designers, engineers, and both skilled and unskilled laborers, the TVA experimented with new types of materials and delivery methods.[2] New technologies and prefabricated elements were quietly integrated into aesthetically pleasing, vernacularly-inspired homes, allowing residents to immediately identify with the new structures. However, despite their familiar aesthetic, the introduction of electricity and indoor plumbing revolutionized the way residents of the Tennessee Valley would dwell. The TVA's interest in exploring new building technologies, including prefabricated housing, would continue for many years, though the town of Norris and its iconic Norris Houses would stand as their most complete effort.[3]

In 2008, a University of Tennessee – Knoxville team, led by the School of Architecture and Department of Planning set out to reinterpret the Norris paradigm and to reconsider the shape of landscapes, communities and homes today. The design consists of an infill lot and a single-family dwelling that is modular, prototypical, and resource efficient. A LEED for Homes Platinum project, the New Norris House (NNH) pursues high performance building through both traditional and innovative means. Inspired by the TVA's organization, the project was delivered by a multidisciplinary team integrated across professional, academic, and industry lines. The home conforms to the local, vernacular form yet sharpens it with crisp contemporary details. Complimentary performance and design intentions extend to the landscape, and a monitoring, residency and demonstration program is extending lessons learned from the old and the new Norris houses. This paper focuses on this the first year of evaluation efforts and presents selected analysis and results of the design and environmental strategies employed in the New Norris House project.

2. Overview and Methodology

Qualitative and quantitative data was generated by the activities of two live-in residents who resided in the New Norris House from August 2011 – July 2012. Separate electronic and digital systems monitor residents' occupancy patterns and the performance of various building systems. The first system, a Powerhouse Dynamics 24-channel Residential eMonitor, tracks electrical consumption. The eMonitor is an affordable, user-friendly suite of off-the-shelf hardware and software that logs channelized electrical loads at a maximum 1-minute resolution. The second installed system is a Campbell Scientific CR23X Datalogger programmed to collect weather data, interior air temperatures and relative humidities, energy recovery ventilation temperatures and relative humidities, water flow volumes and temperatures, cistern water level, as well as a redundant value of total electrical consumption. The third installed system is a Campbell Scientific CR10, used to collect data associated with the greywater system including soil saturation. (The greywater system is a subject of another paper and will not be discussed.) The team also uses Onset HOBOS devices to monitor various conditions as they arise (glycol temperatures, daylighting values, comparison home temperature studies, etc). All data is logged at 15-minute intervals and remotely downloaded hourly.

3. Overall Energy Use

The project team sought to minimize the footprint of the home, resulting in a final area of 93.6 m^2. This was done for several reason—first, the historic context of Norris is primarily populated with homes within the 55 – 130 m^2 range. Secondly, the team sought to benefit from inherit benefits of downsizing the amount of conditioned space— further incentivized by the LEED for Homes program which offers credit adjustments for reduced floor footprints (the project received the maximum reduction of 10 points). Rightsizing of the home, the specification of efficient building systems, and the integration of passive heating/ cooling strategies played a central role in reducing the overall energy consumption of the New Norris House. Modeled results predicted a consumption of 25,744 MJ per year, a HERS value of 49, and a 55.4% reduction compared to average homes in the US East South Central region (57,535 MJ).[4] Observed values fall close to this prediction, consuming 27,932 MJ (298 MJ/ m^2 / year) during the study period, a 51.4% reduction compared to averages homes in the US East South Central region.

Using the eMonitor, it was determined that the majority of consumption within the NNH originated from the heat and air system. Though quantitative consumption values varied more widely, distribution fluctuated only 9-15% within respective major energy use categories.[5]

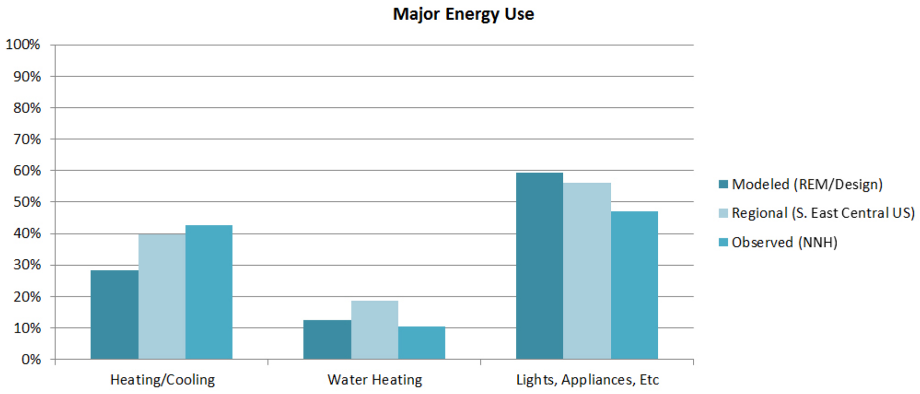


Fig. 1 Distribution of major energy use within modeled, regional, and observed datasets

4. Envelope and Passive Design

In designing the envelope of the New Norris House, the project team sought to optimize useful solar gain, reduce the total framing loss factor of the home, reduce air infiltration, and maximize assembly R-values. This process began with the design of an efficient structural system. Advanced wood framing techniques were employed in the floor, walls, and roof, including 70.0 cm (24”) on center spacing. This was digitally modeled and compared to a similar model of traditional framed construction at 40.6 cm spacing (16”). These results indicate a 17.4% savings of lumber volume (1.71m^3, or 724BF). This inversely implies a 17.4% increase in insulation values and a significantly reduced framing factor as a consequence of the larger stud bays. The project team considered the use of structurally insulated panels (SIPs) to further optimize these values, but limitations of the modular builder eliminated this alternative. The home was built on a sealed, unconditioned, and insulated crawlspace. A variety of insulating products are used and selections based on application criteria and installation restrictions as related to on-site versus off-site construction and fabrication, as seen in Table 1.

Table 1. NNH Assembly R-Values

	Foundation	Wall	Roof
R-Value	R-4.23	R-5.12	R-8.63

The combination of on-site and off-site construction also complicated efforts to air seal the home. As various components came together to complete assemblies, often times the responsibility of air sealing was not clearly defined. The academic team functioned as the designer, client, and general contractor, and consequently took direct responsibility to ensure this task was completed in an appropriate manner. Upon completion of the envelope, a blower door test was conducted. The home tested at 1.75ACH at a pressure of 50Pa. Though this figure exceeds standards set by the 2012 IECC (3.0ACH @50Pa) and Energy Star v3 (5.0ACH @50Pa) for the project's climate zone (4- Mixed Humid), it is nearly triple that of the Passivhaus standard (0.6ACH @50Pa). Less than exemplary sealing during factory production, and use of custom doors and windows fabricated by the project team likely influenced blower door test results. A smoke test was performed on-site after the blower door test and confirmed these assumptions to a degree.

Monitored results of the envelope's ability to resist exterior temperature fluctuations (while space conditioning elements were disabled) confirm a high degree of resistance To evaluate this, we specifically analyzed data on days when mechanical heating or cooling equipment was not used. Results from June's passive performance study (Figure 2) indicate the envelope successfully resists temperature fluctuations. However, the lack of user modifications (i.e., user opens windows at night to flush the warm interior with cooler night air) resulted in temperatures that were just above the comfort zone 100% percent of the time during the three day period. Compared with a traditional, similar sized home as a function of interior temperature fluctuations and Δ Interior-Exterior temperatures, the NNH showed a 35% higher resistance, as seen in Figure 3.

Table 2. Passive Performance Data

	AVG. Interior Temp	AVG Exterior Temp	AVG ΔTemp Int-Ext	AVG Interior RH	% of Time in Comfort Zone
March	25.32 °C	21.01 °C	4.31 °C	51.8 %	83.6 %
June	27.47 °C	23.95 °C	3.52 °C	60.9 %	0.0 %
October	21.64 °C	10.27 °C	11.37 °C	61.3 %	97.9 %

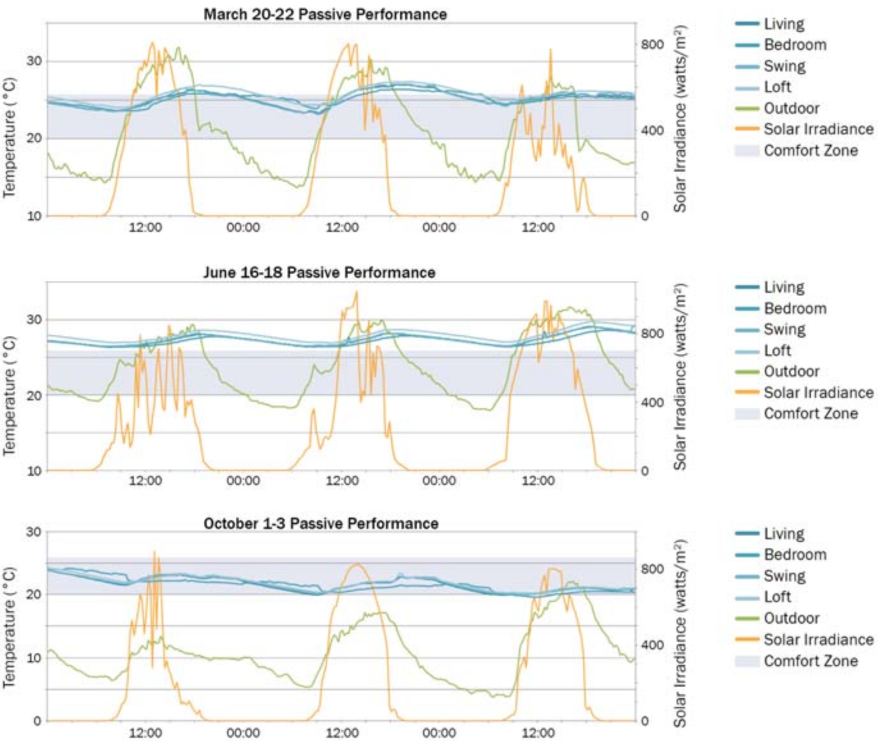


Fig. 2 Seasonal diagrams of the homes passive resistance to exterior temperature fluctuations.

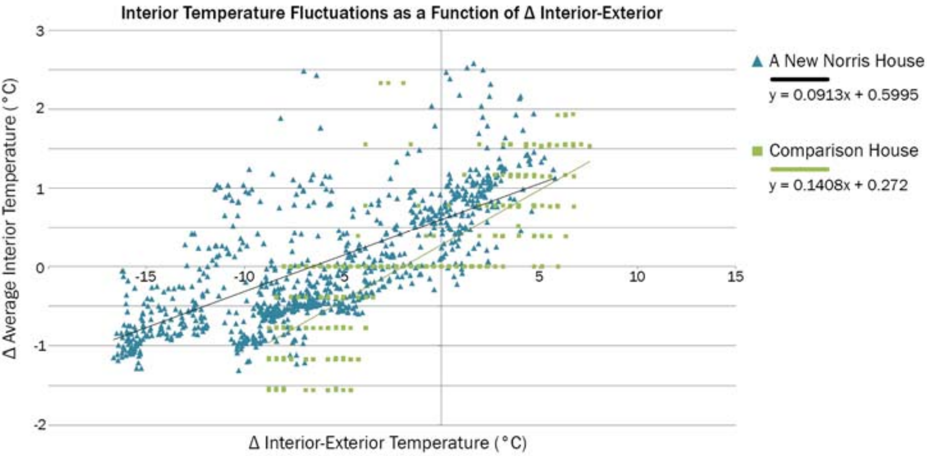


Fig. 3 Scatter plot of the NNH and a comparison home's resistance to exterior temperature fluctuations.

5. Energy Recovery Ventilator

The NNH heat and air system is comprised of a ductless Mitsubishi multi-split system driven by an air source heat pump. A Fantech SE704N Energy Recovery Ventilator (ERV) compliments this system and achieves ASHRAE 62.2 required rates for both whole house and local ventilation. The ERV runs in continuous operation providing 1.27 m^3/min of fresh air to the home. Electrical consumption from the heat pump is used to calculate joules delivered to the home by the heat pump (1). Data from temperature sensors within ERV ductwork are used to establish a similar figure in order to compare joules delivered to the home by the ERV (2 & 3) to joules delivered to the home by the heat pump. These figures reveal that during the study period, 16% of delivered joules to the home originated from the energy recovery ventilator. This translates to \$56 in annual savings, but only yields a \$27 savings after the cost of operating the ERV is deducted. Based on price of the installed Fantech equipment, this savings compounds to a 16 year payback period.

$$(2.931)\, C_{hp} = D_{hp,} \tag{1}$$

$$60\, \rho\, c_p\, \Delta T(erv)\, CFM_{erv} = D_{ervh} \tag{2}$$

$$D_{ervh}\, H(month) = D_{ervm} \tag{3}$$

Where, *2.931* is the Coefficient of Performance (COP) of the heat pump; C_{hp} is total energy consumption of the heat pump in one month; D_{hp} is delivered joules to the home by the heat pump; *60* is a unit conversion factor (min/h); ρ is density (1.201 kg/m^3); c_p is specific heat (1.005 kJ/kg-°C); $\Delta T(erv)$ is ΔT is the average temperature difference (°C); CFM_{erv} is volumetric flow of the ERV unit (m^3/min); D_{ervh} is delivered joules to the home by the ERV system per hour (kJ/h); *H(month)* is hours per month; and D_{ervm} is delivered joules to the home by the ERV per month.

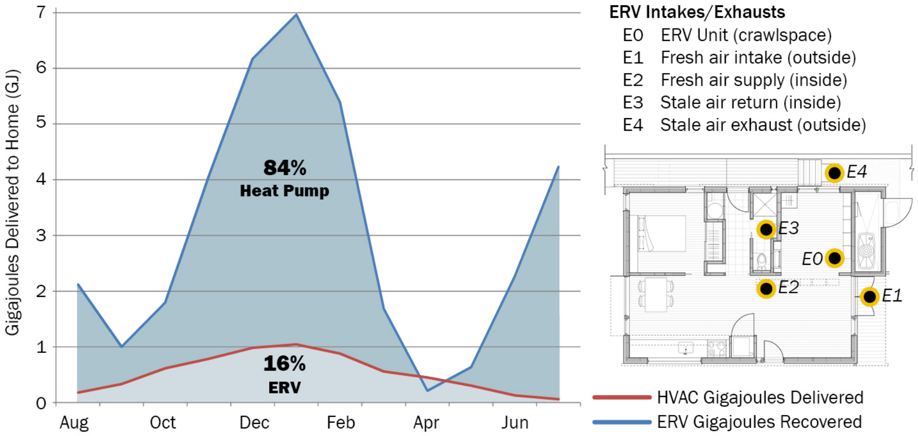
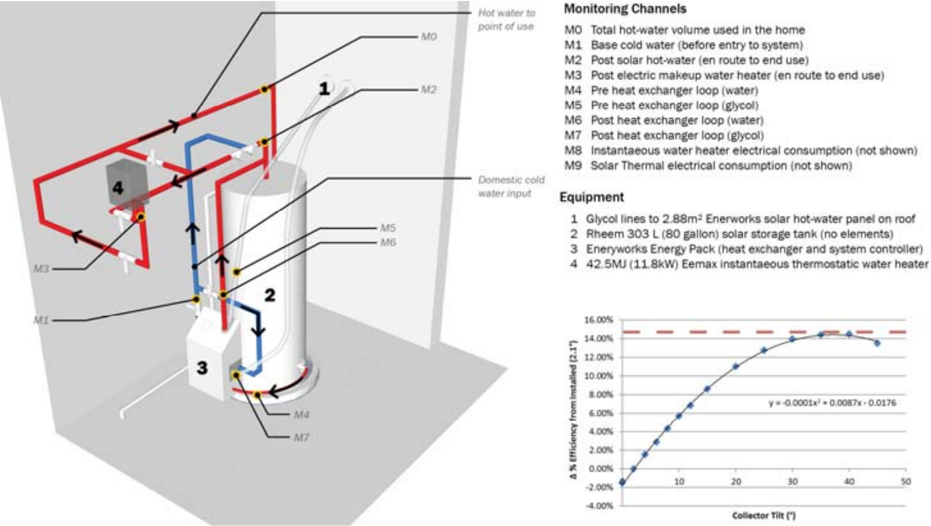


Fig. 4 Joules delivered to the home as a product of ERV and heat pump systems

6. Hot Water

The tight, infill site restricted solar access. A 15.2m lot frontage (yielding a 1:3 ratio of lot width to depth) and voluntary conformance with the historic house form and siting dictated a North-South longitudinal axis (effectively eliminating all south-facing roof area) . Furthermore, community meetings revealed strong sentiment against overtly modern structures that deviate from the historic fabric. Residents expressed opposition to contemporary architectural expressions as well as visible "green" technologies such as solar panels. The design of the dormer is one example of how the team resolved these issues.

The traditional dormer is transformed so that an asymmetric and shallow-sloped roof can accommodates a south-facing solar hot water panel that is invisible from the street. Additionally, the dormer creates more usable space in the loft; provides stack ventilation through a narrow wood shutter; and admits indirect north light. The NNH utilizes an indirect circulation solar hot-water system made by Enerworks. The panel is mounted on the dormer of the home at a 2.1° collector tilt, 22.0° west of south. Make-up and back-up hot water is supplied with an Eemax EX012240T 42.5 MJ (11.8 kW) Instantaneous Electric Tankless Hot Water Heater. A 303 L (80 gallon) Rheem 81VR80TC-T Solar Storage Tank completes the system. Studies conducted by the project team modeled panel performance based on collector tilt, revealing an optimal angle of 40°, and increasing total system efficiency by up to 14.5%. (Figure 5) Despite performance implications, a decision was made to respect community concern for preserving the historic fabric and the collector was installed with minimal tilt.[3]



Monitoring Channels

M0	Total hot-water volume used in the home
M1	Base cold water (before entry to system)
M2	Post solar hot-water (en route to end use)
M3	Post electric makeup water heater (en route to end use)
M4	Pre heat exchanger loop (water)
M5	Pre heat exchanger loop (glycol)
M6	Post heat exchanger loop (water)
M7	Post heat exchanger loop (glycol)
M8	Instantaeous water heater electrical consumption (not shown)
M9	Solar Thermal electrical consumption (not shown)

Equipment

1	Glycol lines to 2.88m² Enerworks solar hot-water panel on roof
2	Rheem 303 L (80 gallon) solar storage tank (no elements)
3	Eneryworks Energy Pack (heat exchanger and system controller)
4	42.5MJ (11.8kW) Eemax instantaeous thermostatic water heater

Fig. 5 Installed solar-thermal equipment; monitoring channels; and collector tilt study.

Modeled energy use using REM/DESIGN software predicted annual consumption of 3165 MJ for hot water heating. Proprietary modeling software provided by Enerworks, the manufacturer of the solar hotwater system, predicted a higher annual consumption value of 4145 MJ, assuming a Solar Thermal/Electrical system. Both of these values are significant reductions from regional baseline averages for domestic electric water heating, which The US Energy Information Administration (EIA) observed in 2005 as 10670 MJ/ year for the South East Central Region.[5]

Electrical data from the eMonitor system shows that the total hot water system (solar hotwater and backup electric water heater) consumed a lower than expected amount of energy, drawing only 2895 MJ during the study period—a reduction of 8.5% and 30% from REM/Design and Enerworks models, respectively, and a 72.9% reduction from observed regional consumptions by the EIA. Though the large reduction from regional values is to be expected given the higher efficiency of the Solar Thermal/Tankless Electric system installed in the home, modeled values were harder to predict. Software to derive these figures is relatively rudimentary and relies primarily on solar orientation and collector tilt.

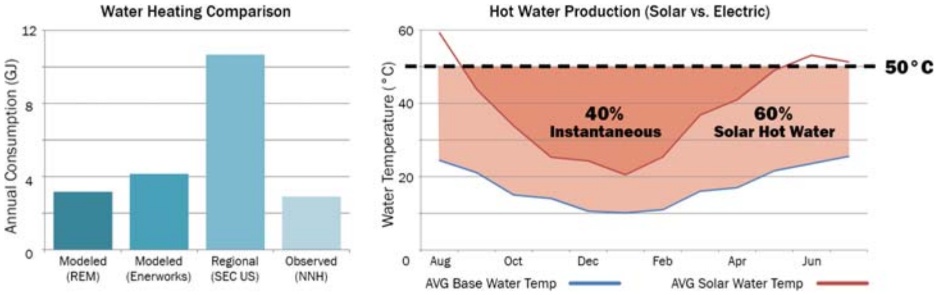


Fig. 6 Comparison of various water heating models with observed results

Investigation of average monthly water temperatures revealed that 60% of the desired heat in final end-use water originated from the Solar Thermal System, with the remaining temperature being made up by the instantaneous heater. Average solar temperatures exceeded desired end use temperature (50 °C) during three out of twelve months during the study year, as seen in Figure 6. It was hypothesised that values for solar thermal water temperatures were likely undervalued, as they represent average temperatures across the entire month, which includes night hours when temperatures are lowest, in addition to the lowest hot-water demand by the occupants. The dataset was filtered to only include intervals during periods of hot-water usage, but found the exact opposite of the project team's assumptions. Average monthly temperatures showed a decrease in temperature of 0.40°C from their unfiltered state.

7. Conclusions

At the conclusion of the first year of study, the project team has garnered many insights into performance of the New Norris House project—some expected and some surprising. Energy use in the home was observed closely to that of modeled values, and performance compared to homes in the region was also within an anticipated range, reducing consumption by over 50%.

As mentioned previously regarding solar-thermal collector tilt, community input and a desire by the project team to address concerns in regards to "fit" within the historic context played a large role in several decisions. Orientation of the home (longitudinally North-South, conforming to the street pattern) was never seriously considered otherwise, which had direct implications on passive solar input and southern exposures. Furthermore, opportunities to integrate a solar-electric system were severely hindered by these same circumstances (as well as budgetary concerns). These efforts would have been of research interest to the project team, and could have potentially been a catalyst for more aggressive measures to reach a net-zero energy home (given the offset potential of solar production).

Fig. 8 The dormer on the west side of the home and a view of the interior towards the street. Winter light is allowed to penetrate deep into the space. (photo by Ken McCown).

During the second year of study, observed passive performance of the envelope will be evaluated further, with additional comparison homes being temporarily monitored, as well as instituting several periods of prescriptive system/ window operation for performance assessment. Additional monitoring efforts will also be put in place to better understand conditions of the two mechanical rooms and the effect of ambient conditions on system performance. A change in the number of residents at the home (reduced to only 1 resident) will require interpretation of datasets between years, but will also produce an additional understanding of the manner in which the integrated systems are able to serve the occupants. These topics, in addition to extended analysis of the overview presented here will be the subject of future research.

Fig. 9 A New Norris House (photo by Ken McCown).

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