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Performance Evaluation of a Hot-Humid Climate Community

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Building Science Corporation

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Performance Evaluation of a Hot-Humid Climate Community

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Unless otherwise noted, all figures were created by BSC.

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Definitions

AHU	Air Handling Unit
BSC	Building Science Corporation
CDD	Cooling Degree Day
CFL	Compact Fluorescent Lamp
CFM	Cubic Feet per Minute
EGUSA	EnergyGauge USA energy modeling software
EUI	Energy Use Intensity
HDD	Heating Degree Day
HDPE	High-Density Polyurethane
HERS	Home Energy Rating System
HSPF	Heating Seasonal Performance Factor
HVAC	Heating, Ventilation, and Air Conditioning
o.c.	On Center
OSB	Oriented Strand Board
PHA	Project Home Again
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
TMY3	Typical Meteorological Year, version 3
UV	Ultraviolet

Executive Summary

Project Home Again is a development in New Orleans, Louisiana, created to provide new homes to victims of Hurricane Katrina. Building Science Corporation (BSC) acted as a consultant for the project, advocating design strategies for durability, flood resistance, occupant comfort, and low energy use while maintaining cost effectiveness. These techniques include the use of high density spray foam insulation, LowE3 glazing, and supplemental dehumidification to maintain comfortable humidity levels without unnecessary cooling. Stringent airtightness goals were achieved by the project, helping to meet the Builder's Challenge targets set by Project Home Again. Floor plans, enclosures, and heating, ventilation, and air conditioning attributes are quite similar among different homes in the project.

While construction is ongoing, several phases of the project are already complete and have been occupied for periods up to two years. BSC arranged to receive the monthly utility bills of all completed projects so that ongoing performance of the homes could be monitored. At least one year of utility data have been collected for 19 of the homes during the same time period, January–December 2010. These yearly energy use data are analyzed and compared to various benchmarks, including country-wide and regional home energy use averages, 2030 Challenge targets, and the modeled B10 Benchmark. Both BEopt and EnergyGauge USA models were created for each of the home designs, assuming B10 Benchmark values for attributes controlled by users, including temperature set points and miscellaneous loads.

Most of the 19 homes utilized less source energy than the U.S. and regional averages. None of the homes' energy use intensities achieved the stringent 2030 Challenge target of 16.6 kBtu/ft^2/yr. All homes achieved Home Energy Rating System ratings below 70 based on their design and post construction blower door test results, achieving the Builder's Challenge goal.

Although all design prototype models achieve the goal of 20% savings below the B10 Benchmark model, only one home's actual utility data achieve the 20% savings below Benchmark. Significantly more heating degree days and cooling degree days were recorded during the monitoring period than are in the B10 Benchmark model's Typical Meteorological Year, version 3 file. When an adjustment calculation is made to account for this weather data discrepancy, four more homes achieve the 20% goal, but most homes show very low or negative energy savings compared to the B10 Benchmark goal.

BEopt was used to optimize costs. Although the actual design fell reasonably close to the lowest cost curve, components such as spray foam insulation over more traditional options increased costs. Independent of energy use or installation cost, the flood resistance of spray foam insulation was an important factor in its selection.

The supplemental dehumidification used by the project could not be modeled with BEopt or EnergyGauge USA software, so an estimation of its contribution to energy use was calculated and added to model results for comparison. Actual home energy use was found to be 95%–208% of model predictions. The various reasons for this discrepancy are discussed. Monthly and yearly energy use tabulations suggest that base miscellaneous loads are underpredicted by models. In homes with high-performance enclosures, heating and cooling loads are greatly reduced, amplifying their relative effects, which were estimated to account for 53%–81% of total energy use in the homes.

One major factor examined as it relates to the high miscellaneous loads is supplemental dehumidification. Cooling-decoupled dehumidification is a strategy promoted by BSC to improve occupant comfort in hot, humid climates without unnecessary cooling during the swing seasons. Higher dry bulb temperatures can feel more comfortable if humidity levels are controlled. However, it was discovered that after installation many of the systems had erroneously been set to maintain relative humidity set points in the mid 30s instead of the 55%–60% relative humidity recommended. This contributed to additional energy use by the systems and increased cooling loads. Although several of the homes' dehumidification set points were corrected, this issue and the comfort conditions achieved by the systems are still being monitored by BSC. However, an initial comparison to available data from Phase III homes (without supplemental dehumidifiers) shows very similar yearly energy performance to the first two home phases that include supplemental dehumidifiers. Because energy use of the first two home phases also includes periods of time when some of the dehumidifiers are known to have been over-dehumidifying, current data suggest that the operation or misoperation of the dehumidifiers is a relatively minor factor in the homes' high energy use. Other miscellaneous uses are likely to be larger contributors.

The significant influence of user-controlled factors (set points, miscellaneous loads) in high-performance home energy use underlines the importance of homeowner education. After durable, high thermal resistance enclosures and efficient heating, ventilation, and air-conditioning systems are installed, a low-energy home is dependent on user behavior. BSC will continue to monitor Project Home Again and to promote low-energy operational strategies as more homes are completed. In addition to continued monitoring of utility data from the project, future work involves more detailed submonitoring of energy end use in a smaller number of homes to glean more insight into the performance of building system components and miscellaneous end uses.

1 Introduction and Background

1.1 Project Home Again

Building Science Corporation (BSC) began working with Project Home Again (PHA) in New Orleans, Louisiana (hot-humid climate zone) in 2008. PHA is constructing new community homes in the Gentilly neighborhood of New Orleans. This community will demonstrate advanced building practices that promote energy efficiency, durability, and sustainability, and that maintain a comfortable living environment. The PHA community is a culmination of BSC and PHA efforts to integrate advanced building technologies into a production environment.

1.1.1 New Home Construction in New Orleans

PHA (www.projecthomeagain.net/) is a not-for-profit development that was started by the Riggio Foundation with the goal of providing homes to those whose homes were destroyed or badly damaged by Hurricane Katrina. From the website: “To qualify for a Project Home Again House, an applicant must have owned a home in Gentilly prior to Hurricane Katrina and be unable to amass the resources needed to repair and reoccupy that home.”

The potential homeowners must be willing to “swap” their current properties for PHA homes and must live in the new PHA homes for at least five years. Potential homeowners are responsible for paying property taxes, insurance, fuel, and general maintenance and be employed in the New Orleans area. PHA is selecting potential homeowners who meet these criteria. Approximately 70 homes have already been completed as part of different construction phases. Phases I, II, III, and IV are complete; construction is in progress on Phases V and VI. Funding is expected to continue into later phases of this successful development.

1.1.2 Home Specifications

A variety of home floor plans are used in each phase. In Phase I, the home designs are known as B4, H2, L2, L4, and F3. These single-family homes are a mix of one and two stories ranging from 1,016 ft^2 to 1,544 ft^2 (see Figure 1).

Figure 1. Phase I house – L3 floor plan

In Phase II, the home designs are known as Gertrude, Templeton, and Camille. These single-family homes are all one story with three bedrooms, ranging in size from 1,213 to 1,316 ft^2 (see Figure 2).

Figure 2. Phase II house – Gertrude floor plan

Table 1 summarizes the building enclosure assemblies used for Phase I of this project.

Table 1. PHA Phase I Enclosure Specifications

Enclosure	Specifications
Ceiling	
Description	Light color asphalt shingles on rafter roof – unvented roof
Insulation	R-30 high density spray foam (4.5 in.) on underside of roof FlameSeal intumescent coating installed on foam for ignition barrier
Walls	
Description	Pressure-treated borate 2 × 6 wood studs 24 in. o.c,* nonadvanced framed
Insulation	R-20 high-density spray foam (3 in.) in stud bay
Foundation	
Description	Block pier foundation – vented crawlspace with borate-treated 2 × 10 floor joists
Insulation	R-13 high-density spray foam (2 in.) in floor joist bay
Windows	
Description	Double-pane vinyl-framed with $LowE^2$ spectrally selective glazing
Manufacturer	Alenco windows

U-value	0.36
SHGC*	0.30
Infiltration	
Specification	2.5 in.^{2} leakage area per 100 ft^2 enclosure area

*On center
** Solar heat gain coefficient

Each PHA Phase I house is elevated at least 3 ft off grade with blocks on a grade beam foundation. The crawlspace is vented and the perimeter fenced off with low-cost wood latticework. This will allow floodwater to pass through and is inexpensive to fix should the latticework break. The two story plans have cantilever sections of the second floor elevated 11 ft. with a carport below. A metal flashing piece is installed over each pier as a capillary break, with a borate-treated sill plate.

Floor framing is pressure-treated borate 2 × 10s at the traditional 19.2 in. o.c. spacing and the subfloor is ¾ in. CDX plywood. The architect did not upgrade to 24 in. o.c. because of the increased cost and low availability of 7/8-in. subflooring that would be needed to ensure floor stiffness at that joist spacing. The joist bays were insulated with 2 in. of high-density spray foam (R-13) to the underside of the tongue-and-groove CDX subfloor.

Exterior walls are 2 × 6 pressure-treated borate studs at 24 in. o.c. This "advanced framing" design reduces the amount of wood used in the wall and reduces thermal bridging caused by the wider stud spacing (Lstiburek 2010). The stud cavity was insulated with 3 in. of high-density closed-cell spray foam sprayed up against the ½-in. oriented strand board (OSB) wall sheathing. Additional advanced framing elements such as single top plate and two stud energy corners were not utilized in this project because of structural requirements. The architect chose to design the floor plans to conform to the Wood Frame Construction Manual (AF&PA 2006) for a 130 mph wind zone. The Wood Frame Construction Manual design document addresses few upgrades that full optimum value engineering framing, or advanced framing, call for, such as single top plate or two stud corners, but will allow for 2 × 6 @ 24-in. o.c. wall construction. It is possible to structurally design a house to comply 100% with all the advanced framing recommendations. However, the architect would have had to hire a licensed structural engineer to analyze the floor plans and calculate a design that includes the full optimum value engineering package. The extra money and time involved in doing so were not cost effective for PHA.

The ½-in. OSB served as a structural sheathing on the entire exterior wall. A woven high-density polyurethane (HDPE) house wrap was installed over the OSB in place of the recommended spun HDPE house wrap. This was due to cost concerns; the spun house wrap was priced three times higher than the woven house wrap. Furring strips made of cut strips of 3/8-in. XPS were recommended to provide a drainage space, but the architect deemed it unnecessary. Pre-primed fiber cement board was installed directly onto the woven house wrap.

Closed-cell spray foam was utilized as the air and thermal barrier for the entire enclosure. BSC highly recommends a "flood recoverable" enclosure design for homes in high risk flood areas. A spray foam enclosure has the ability to dry out after a wetting event; therefore, the insulation is not required to be removed (Lstiburek 2006).

The roof has R-30 high-density spray foam (4.5 in.) installed under the roof deck to create an unvented attic. Light color hurricane rated asphalt shingles were installed over #30 felt roofing underlayment over 5/8-in. CDX roof sheathing. The roof sheathing has the joints taped with butyl-based, adhesive-backed flashing strips. The building code requires that intermittently occupied spaces with exposed spray foam must have an ignition barrier. Therefore, PHA sprayed an intumescent coating called FlameSeal over the entire closed-cell high-density installation in the unvented cathedralized attic.

The windows installed at PHA Phase I are vinyl frames with $LowE^2$ spectrally selective glazing. The low SHGC of 0.30 reduces the solar gain, resulting in a smaller rightsized heat pump and lowered annual space conditioning energy consumption. This glazing technology has some secondary benefits as well, such as reducing ultraviolet (UV) damage on interior floors or fading on furniture.

The air infiltration rate was very low, commensurate with the Building America infiltration goal of 2.5 $in.^2$ of free area per 100 ft^2 of enclosure. The high density spray foam on the entire enclosure contributes much to this. The low-expanding spray foam that is installed between the window frame and the rough opening also helps. The high-density spray foam is an excellent air and thermal barrier system for this application. It is critical in the floor assembly because the low permeability rate of the foam will resist any upward vapor drive. The spray foam will also keep the subfloor warm and will minimize any condensation potential. PHA was careful to avoid impermeable floor coverings in the homes to prevent any moisture from being trapped and potentially condensing. This will have a positive effect on the durability and the indoor air quality of the house (Lstiburek 2008).

Please refer to Figure 3 for the building section.

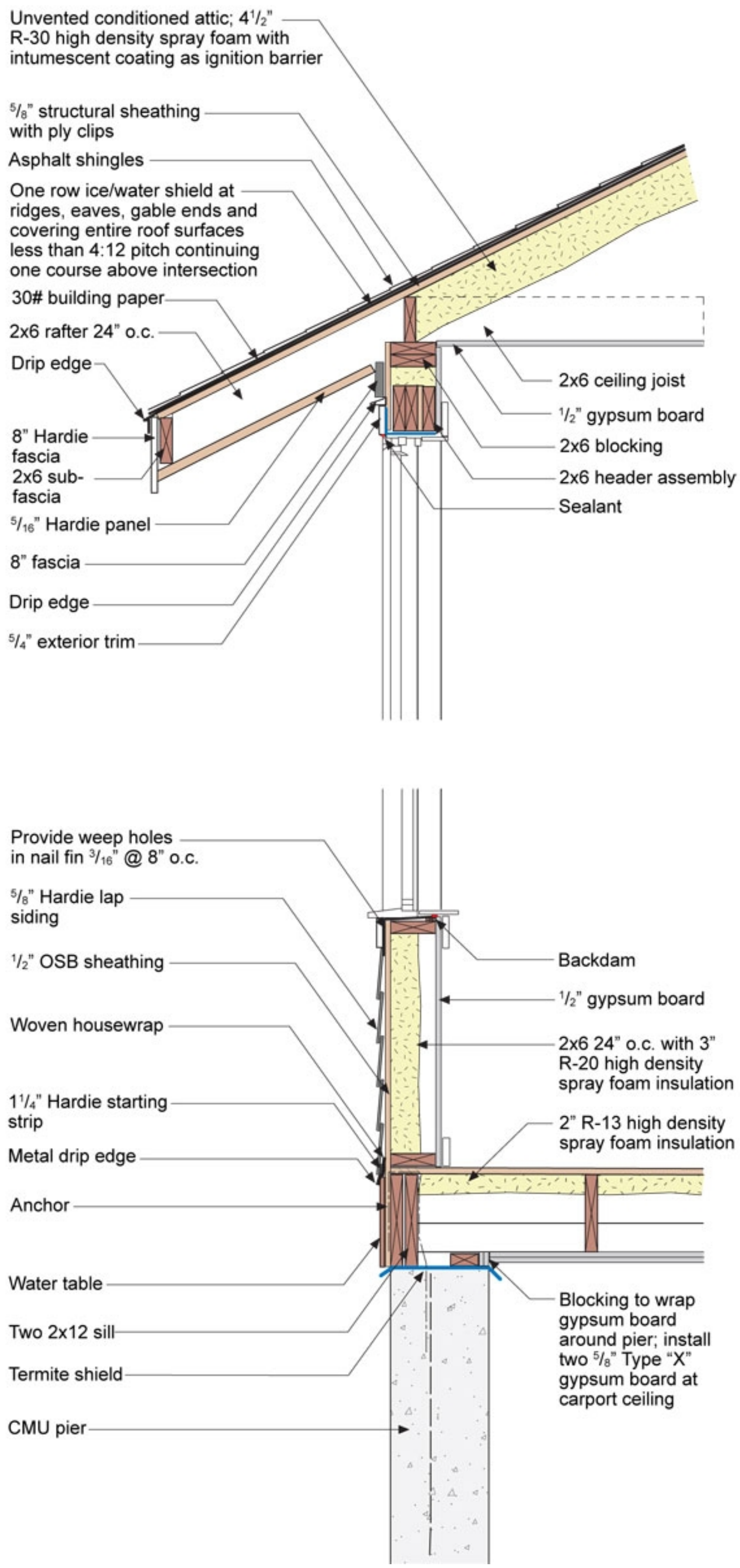

Figure 3. Phase I PHA community building enclosure section

Table 2 summarizes the mechanical systems used by this project.

Table 2. PHA Phase I Mechanical System Specifications

Mechanical Systems	Specifications
Heating	
Description	8.25 HSPF* air source heat pump
Manufacturer and model	Carrier
Cooling (outdoor unit)	
Description	14 SEER**
Manufacturer and model	Carrier
Cooling (indoor unit)	
Description	AHU*** with heat pump coil
Manufacturer and model	Carrier AHU
Domestic Hot Water	
Description	0.93 Electric water heater
Manufacturer and model	Rheem Fury 50 gal
Distribution	
Description	R-6 flex ducts in conditioned unvented attic
Leakage	5% duct leakage to outside
Ventilation	
Description	Supply-only system integrated with AHU, controlled by Aprilaire 1750 50 CFM 33% duty cycle: 10 minutes on; 20 minutes off
Manufacturer and model	Carrier Performance programmable thermostat
Return Pathways	
Description	Central return on first floor and second floor, jump ducts in bedrooms
Dehumidification	
Description	Whole-house dehumidifier controlled by separate humidistat
Manufacturer and model	Aprilaire Model 1750 whole-house dehumidifier
Solar Hot Water	
Description	Potential solar domestic hot water option to be offered to homeowners
Manufacturer and model	n/a

* Heating seasonal performance factor
** Seasonal energy efficiency ratio
*** Air handling unit

Full room-by-room Manual J8 (Rutkowski 2006) system sizing and duct layout calculations were performed by BSC on each of the five plans. The very efficient enclosure and heating, ventilation, and air conditioning (HVAC) system resulted in smaller heat pumps when rightsized. PHA installed a 14 SEER/8.25 HSPF air source heat pump in all the community homes. This was the most efficient unit that could be afforded given the strict budget.

Supplemental dehumidification is one of the key improvements to the community, and is necessary because of the very efficient enclosure. The sensible load has been reduced such that the ratio of sensible to latent load is very different than in a standard home. Supplemental dehumidification enables the occupant to control indoor humidity levels year round. This has a beneficial impact on the comfort and durability of the structure by preventing high humidity levels and potential mold risks (Rudd et al 2005).

BSC recommended that PHA utilize a central fan integrated supply ventilation system (Rudd 2008). This system draws outside air via a 6-in. flex duct to the return plenum of the HVAC system (see Figure 4). This allows the introduction of outside air to the living space whenever space conditioning is already operating. The Aprilaire Model 1750 dehumidifier has fan cycling capability included in its circuitry. Fan cycling will turn on the fan at a 33% duty cycle (10 minutes on, 20 minutes off) to provide outside air during periods of no space conditioning. A 6-in. mechanical damper is also installed on the 6-in. outside air duct. This is controlled by the fan cycler and will close off the outside air duct during periods of consistent space conditioning to prevent overventilation of the living space.

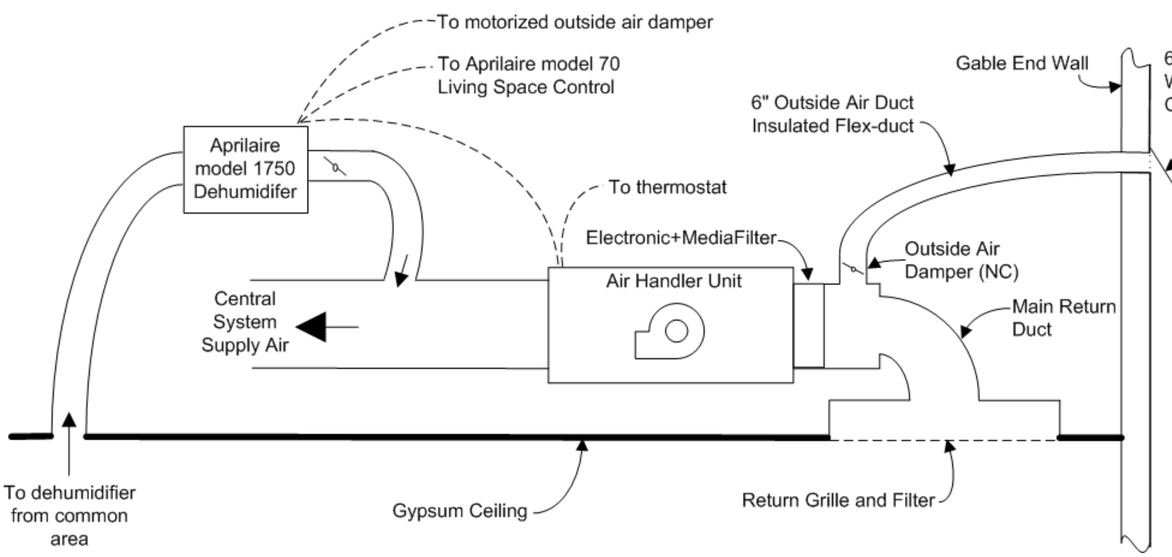

Figure 4. Central fan integrated supply ventilation schematic

The recommended ventilation system was not entirely implemented. The mechanical damper was not installed and the fan cycling controller on the dehumidifier's circuit board was never wired to the AHU. These homes do not have fan cycling enabled, but are drawing in outside air whenever the AHU is operating. Also, a 4-in. duct was installed in lieu of the specified 6-in. outside air duct. This system cannot draw in outside air during periods with no call for heating or cooling. Conversely, it cannot prevent overventilation during periods of excessive heating or cooling, but the 4-in. duct is drawing in less outside air so overventilation is a lesser concern. Despite the recommendation by BSC that the ventilation system be remediated, the builder chose not to correct the installation and no comfort complaints have been received from the homeowners.

Bathroom exhaust fans and a kitchen hood are installed to provide spot ventilation when necessary. These are all routed to the outside and are not recirculating fans. One of the bathroom fans is rated to provide American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.2-compliant levels of ventilation so that the house can be operated at that rate when needed.

Phase II enclosure design is summarized in Table 3. Overall, the enclosure design was similar to Phase I, except for the amount of roof insulation and the foundation design. The Alenco windows were upgraded to LowE^3 glazing.

Table 3. Phase II Enclosure Specifications

Enclosure	Specifications
Ceiling	
Description	Light color asphalt shingles on rafter roof – unvented cathedralized attic
Insulation	R-21 closed-cell high-density spray foam (3.5 in.) on underside of roof FlameSeal intumescent coating installed on foam for ignition barrier
Walls	
Description	Pressure-treated borate 2 × 6 wood studs 24 in. o.c, nonadvanced framed
Insulation	R-20 closed-cell high-density spray foam (3.5 in.) in stud bay
Foundation	
Description	Block pier foundation – vented crawlspace with borate-treated 2 × 10 floor joists
Insulation	R-13 closed-cell high-density spray foam (2 in.) in floor joist bay
Windows	
Description	Double-pane vinyl-framed with LowE^3 spectrally selective glazing
Manufacturer	Alenco windows
U-value	U = 0.35
SHGC	SHGC = 0.23
Infiltration	
Specification	2.5-in.^{2} leakage area per 100 ft^2 enclosure @ 50 Pa
Performance test	Average test result = 1.5-in.^{2} leakage area per 100 ft^2 enclosure @ 50 Pa

PHA decided to change the foundation design from filled concrete masonry units to piles for Phase II, because of cost concerns and different soil conditions. Each PHA house is elevated at least 3 ft off grade with wooden piles. This reduced height is due to a lower base flood elevation as specified by the Federal Emergency Management Agency for the Phase II neighborhood. Each pile is a pressure-treated Class 5 wood pile with 8 tons of capacity. They are spaced 6 ft, 10 in. apart and are embedded 30 ft below grade. The Phase II neighborhood has poor soil conditions; therefore, the 30 ft was necessary from a structural perspective. The base flood elevation as designated by the National Flood Insurance Program Elevation Certificate was 2 ft above grade. PHA decided to elevate the building 1 ft above the base flood elevation (see Figure 5).

Figure 5. Wood pile foundation system

The ½-in. OSB wood sheathing from Phase I was changed to 15/32 in. Windstorm OSB. A woven HDPE house wrap was installed over the OSB in place of the recommended spun HDPE house wrap. Furring strips made of cut strips of 3/8-in. XPS were recommended to provide a drainage space, but the architect deemed it unnecessary. Pre-primed 5/16-in. fiber cement board was installed directly onto the woven house wrap (see Figure 6 and Figure 7).

Figure 6. Windstorm OSB installed over the entire wall system as the exterior sheathing

Figure 7. Woven house wrap installed over the exterior sheathing

The vinyl windows installed at PHA Phase II were upgraded to units with state-of-the-art LowE[3] spectrally selective glazing. This next-generation coating excels at blocking infrared and UV light while maintaining a high visual transmission. The low SHGC of 0.23 greatly reduces the solar gain, resulting in a smaller rightsized heat pump and lowered annual space conditioning energy consumption. This glazing technology has some secondary benefits as well, such as reducing UV damage on interior floors and fading of furniture (see Figure 8 and Figure 9).

Figure 8. Single-hung windows

Figure 9. Fixed window

The roof has R-21 closed-cell high-density spray foam (3.5-in.) installed under the roof deck to create an unvented cathedralized attic. This is a reduction of roof insulation compared to Phase I, which had R-30. Phase II had a slightly lower budget than Phase I and the builder decided to insulate to R-21 as a cost-saving measure. However, it was first confirmed with BSC to make sure the energy savings are still meeting the 40% savings versus the benchmark. Light color hurricane-rated asphalt shingles were installed over 30# felt roofing underlayment over 5/8-in. CDX roof sheathing. The roof sheathing has the joints taped with butyl-based adhesive-backed flashing strips. A fully adhered roofing membrane, WR Grace Ice and Water Shield, was installed at the eaves and gable ends.

The air infiltration rate tested very well, about 40% better than the Building America infiltration goal of 2.5 in^2 of free area per 100 ft^2 of enclosure. This improvement versus the Phase I houses is most likely due to the builder being more experienced with the Building America design and the simpler geometries of the single story “shotgun” style Phase II floor plans (see Figure 10).

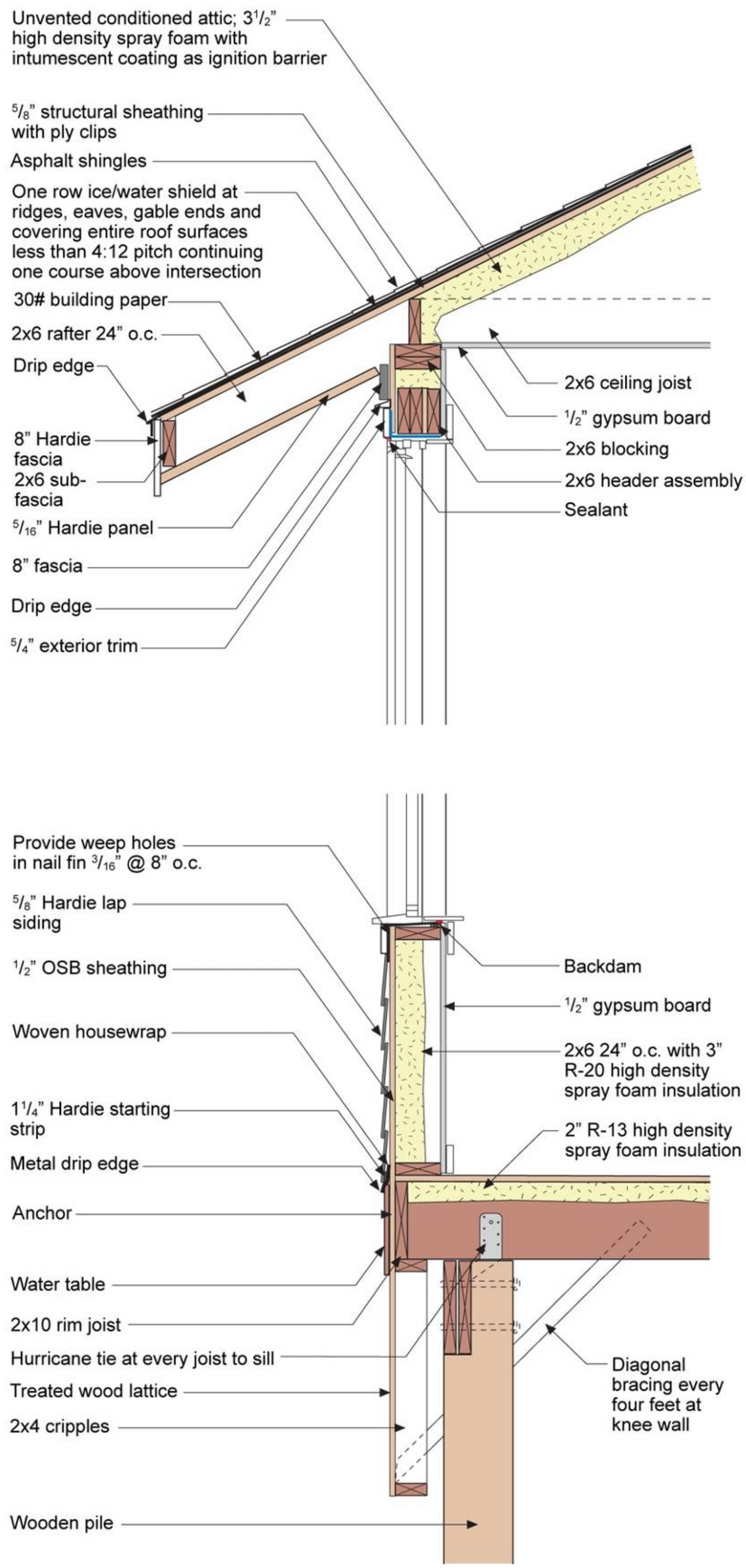

Figure 10. Phase II PHA community building enclosure section

Table 4 summarizes the mechanical systems used in Phase II. Phase II has identical mechanical specifications as Phase I.

Table 4. PHA Phase II Mechanical System Specifications

Mechanical Systems	Specifications
Heating	
Description	8.25 HSPF air source heat pump
Manufacturer and model	Carrier 25HBB
Cooling (outdoor unit)	
Description	14 SEER, all homes have 2-ton systems
Manufacturer and model	Carrier 25HBB
Cooling (indoor unit)	
Description	AHU* with heat pump coil
Manufacturer and model	Carrier FV4 AHU
Domestic Hot Water	
Description	50-gal 0.92 energy factor tank water heater in unvented cathedralized attic
Manufacturer and model	Rheem 82MV52
Distribution	
Description	R-6 flex ducts in conditioned unvented cathedralized attic
Leakage	5%–8% duct leakage to outside
Ventilation	
Description	Supply-only system integrated with AHU, controlled by Aprilaire 1750 50 CFM 33% duty cycle: 10 minutes on; 20 minutes off
Manufacturer and model	Aprilaire 1750 motherboard contains fan cycler
Return Pathways	
Description	Central return on first floor and second floor, jump ducts in bedrooms
Dehumidification	
Description	Whole-house dehumidifier controlled by separate humidistat
Manufacturer and model	Aprilaire Model 1750 whole-house dehumidifier

Full room-by-room Manual J8 system sizing and duct layout calculations were performed by BSC on each of the three plans. The very efficient enclosure and HVAC system resulted in smaller heat pumps when rightsized. PHA installed a 14 SEER/8.25 HSPF air source heat pump in all the community homes. This was the most efficient unit that could be afforded given the strict budget.

In addition to the building enclosure and mechanical system specifications described, ENERGY STAR® appliances and compact fluorescent lamps (CFLs) were installed in all homes with the goal of further reducing internal loads and electricity use.

1.1.3 Scope of Analysis

This report will analyze collected energy consumption data from a sample of PHA homes, and compare these results with energy models created using both EnergyGauge USA (EGUSA) and BEopt. Anomalies and patterns of interest will be examined in more detail, with energy use compared to various performance benchmarks. The subject dehumidification control for the PHA homes will be addressed as a key energy end use and occupant comfort control issue.

2 Mathematical and Modeling Methods

2.1 Data Collection

Arrangements were made for BSC to be mailed second copies of the monthly utility bills sent to PHA homes from the utility provider. Since mid-2009, these have been collected and tabulated in spreadsheets for analysis.

The analysis in this report focuses on 19 homes in Phases I and II that have utility bill data available and have been occupied for at least one year starting in January 2010. Additional homes with one year of data were available, but were eliminated from the study to remove climate conditions as a variable. Monitoring of other existing and future homes will continue for future analysis.

All PHA homes use electricity as their only energy source. This makes data collection easier, but makes the separation of heating, cooling, and base electrical loads more difficult. Electrical end uses are not submonitored, as this requires more expensive configuration and wiring that were not within the PHA budget.

2.2 Comparison to Energy Models

Monthly utility bill tabulations were compared to the results from both EGUSA and BEopt as built (prototype) models. The models were meant to reflect the home design parameters described in the Home Specifications section of this report. Unknown items such as schedules, temperature set points, and internal loads were based on B10 Benchmark assumptions (Hendron and Engebrecht 2010). As installed in the actual homes, ENERGY STAR appliances and 100% CFLs were assumed.

In addition to modeling of monthly and yearly energy use, EGUSA was used to calculate a Home Energy Rating System (HERS) Index.

BEopt is able to generate a model of the B10 Benchmark (Hendron and Engebrecht 2010) for comparison, as well as perform cost optimization analysis. One advantage of BEopt modeling software over EGUSA is the ability to view the model geometry, even though there are limitations in the geometry variations that can be modeled (Figure 11).

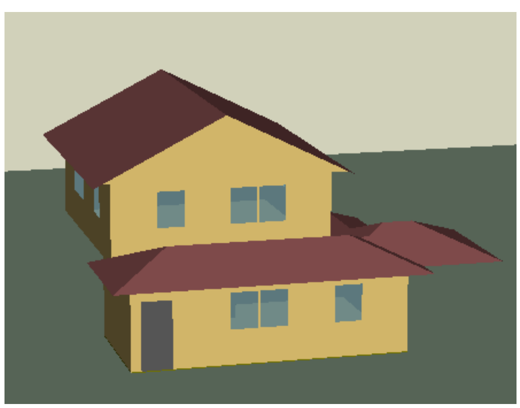

Figure 11. BEopt model geometry for design L2

Both software packages have limitations on the variety of HVAC systems they can model, but both were able to get reasonably close to the home specifications with the exception of the supplemental dehumidification. Neither BEopt nor EGUSA has the capability to model supplemental dehumidification to 55%–60% RH, an important attribute of the Phase I and II PHA Homes. However, an estimate of yearly energy use resulting from a correctly operating supplemental dehumidifier was made to better understand the effect of this component. This estimate was added to energy use calculated by the BEopt and EGUSA prototype models. Hourly energy modeling software such as TRNSYS allows the modeling of this element and it is hoped that detailed modeling of the supplemental dehumidifier can be performed as part of a future BSC project.

A supplemental dehumidifier contributes to two different components of energy use: (1) the dehumidifier draws a certain amount of electrical power to operate; and (2) the heat removed in the process of drying the air is not rejected outside the home but is instead rejected into the central supply airstream. Heat from the compressor and fan is rejected to the indoors as well. The heat pump cooling system must then remove this heat along with the rest of the home's cooling load. The calculation estimating 970 kWh/year is shown in Table 5.

Table 5. Calculation of Additional Energy Used by Supplemental Dehumidifier

Variable	Value	Notes
Estimate of run hours	876	Estimated 10% of 8760 hours per year
Electrical draw of unit (W)	830	from 115V, 8 amps, 0.9 power factor. Energy used by fan compressor, etc., goes to space.
Electrical draw of unit (Btu/h). This is also equal to additional heat going into the space from the fan and compressor.	2,832	Multiply by 3.412
Heat of removed moisture added to the space (Btu/h)	3,000	AHAM (Association of Home Appliance Manufacturers) rated capacity (at 80°F and 60% RH) is 90 lbs/day = 3.75 lbs/hr, derated by 20% because of lower temperature actual conditions = 3 lb/h. Multiply by 1000 Btu/lb of H_20 to get the heat of space moisture removal.
Total heat going into the space when Dehumidifier is running (Btu/h)	5,832	Add the electric draw of the unit to the heat of moisture removed from the space.
Amount of power used by cooling system to remove this heat (W)	278	1.5 ton 12 EER rated heat pump estimated EER = 21 during milder conditions when the dehumidifier is expected to be operating, from product catalog data. Divide Btu/h by EER 21 to get Watts. EER is ratio of output cooling in Btu/h over Watts of electrical use.
Yearly energy used for this cooling (kWh)	243	Multiply by the estimated run hours
Additional energy used by compressor, fans (kW)	727	Multiply electrical draw of dehumidification unit by the estimated run hours
Total annual electrical energy used by the dehumidifier and the cooling system to remove the heat introduced into the space by the dehumidifier (kWh)	970	Add the yearly electrical draw of the dehumidification unit to the extra electricity used by the heat pump for cooling

The B10 Benchmark also specifies "a stand-alone dehumidifier with an energy factor of 1.2l/kWh" set to maintain 60% (Hendron and Engebrecht 2010). The calculated energy factor from the numbers in Table 5 is approximately 1.7 l/kWh; however, this value was used instead of the B10 Benchmark value to make a more conservative estimate of energy that the unit actually installed in the homes would use.

Though mentioned by the B10 Benchmark standard, the stand-alone dehumidifer does not appear to be included in B10 Benchmark models generated by BEopt, and is not mentioned in the help file. Therefore, the estimated additional energy resulting from supplemental dehumidification is added to energy calculated by the BEopt B10 Benchmark model.

Along with energy use reported by utility bills, heating degree days (HDDs) and cooling degree days (CDDs) in New Orleans were also monitored. It is useful to plot these together as particularly high numbers of degree days should be observed to correspond with increased energy use.

Although real degree days were collected to compare to bills, the EGUSA and BEopt models (discussed in the following sections) used Typical Meteorological Year 3 (TMY3) weather files for New Orleans to generate model loads. TMY3 files contain a year of hourly weather data meant to represent typical conditions at a particular geographic location over a long period of time (Wilcox and Marion 2011). It is industry standard to use these weather files for energy models as they are meant to aid in the prediction of long-term building performance.

Table 6 compares the New Orleans degree days collected in the January 2010 to December 2010 period and the degree days represented by the TMY3 files. These numbers were generated by postprocessing the hourly temperature data from the TMY3 file.

Table 6. HDDs and CDDs, Actual Versus TMY3 for New Orleans

	Actual January to December 2010 Degree Days	TMY3 File Degree Days	% Increase of Actual Over TMY3
HDDs	1,796	1,304	27.4%
CDDs	3,166	2,705	14.6%

Although degree days are a useful and simple indicator of the relative magnitude of heating and cooling that should be needed, they do not take into account the complexity of real building systems, including such factors as temperature set points and theoretical base temperature. HDDs are relatively straightforward; CDDs are based on dry bulb temperature only and do not account for dehumidification requirements, a major energy user in hot humid climates.

As shown in Table 6, measured HDDs and CDDs significantly exceeded those of the TMY3 file, showing increases of 27.4% and 14.6%, respectively. This is likely to account for some of the discrepancy between measured and model-predicted energy use discussed in the results.

3 Results

Utility bills from were collected from all homes and monthly energy use compiled, as shown in the example in Figure 12. This sample of utility bill collection starts in July 2009 and ends in June 2011. Monthly utility data were compared to degree days and energy models. Yearly energy use was compared to various benchmarks to help gauge the success of energy efficiency measures.

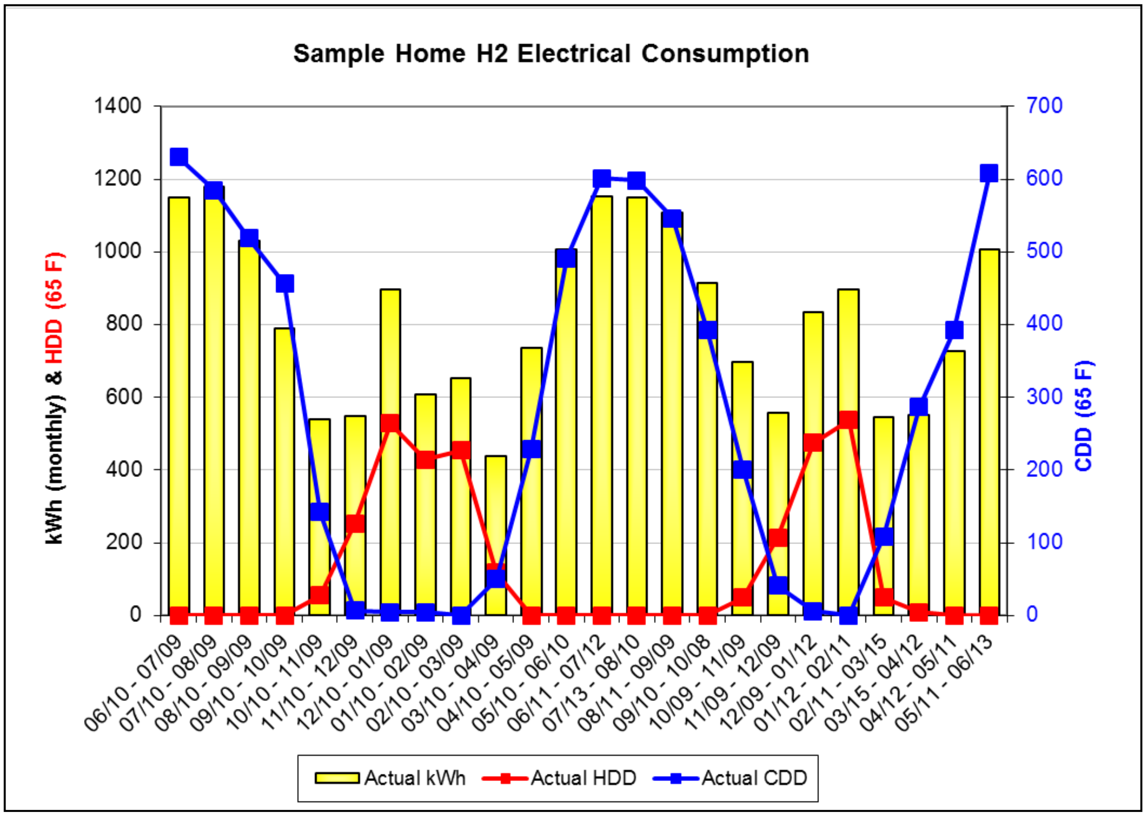

Figure 12. Sample design H2 measured kilowatt-hours per month and degree days, July 2009 to June 2011

Most of the analysis concerns 19 homes for which a whole year of data were available, starting in January 2010 (with the exception of one home with data available starting in February 2010). Although complete years of data were available for several other homes, these were excluded from the analysis for weather data consistency as the available utility bills started several months later than this set. Eight of the different PHA designs are found in the dataset. These designs are B4, F3, H2, L2, and L3 from Phase I and Gertrude, Camille, and Templeton from Phase II.

3.1 Project Benchmarking

Home energy use data collected from utility bills were compared to U.S. and regional averages to better understand the relative performance of the completed homes. Much of this information is typically reported as site energy use, and fuel use breakdowns are required to estimate source energy use.

Figure 13 shows a timeline of the latest household site energy use available from the Energy Information Administration Annual Review; Figure 14 shows a regional breakdown of average site energy for 2005, the most recent year available (EIA 2009).

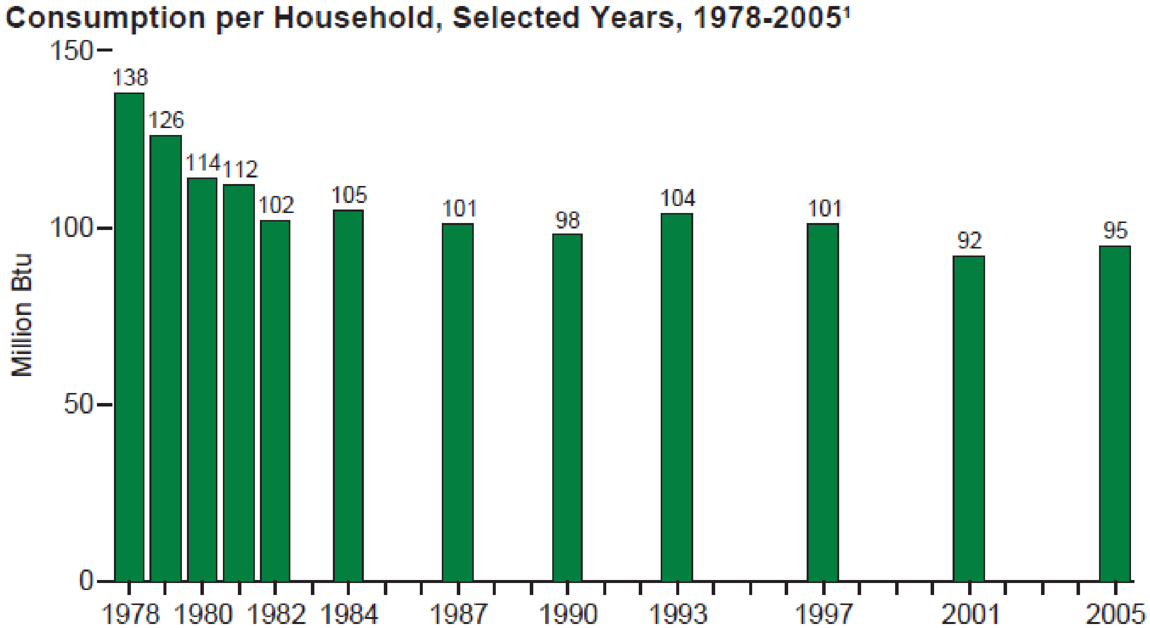

Figure 13. U.S. average site energy consumption per household (EIA 2009)

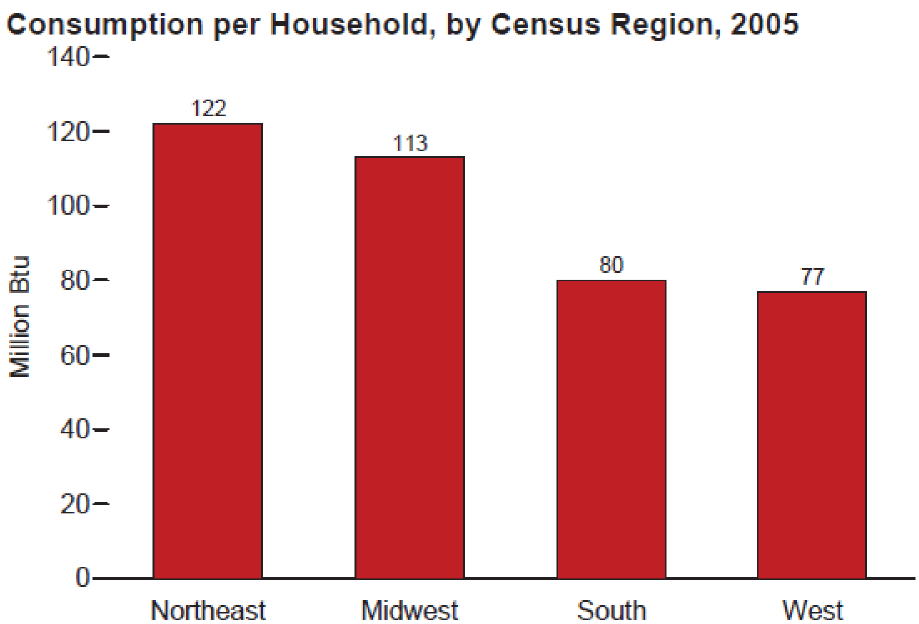

Figure 14. U.S. regional average site energy consumption per household (EIA 2009)

Source energy use is the most useful metric for understanding the success of greenhouse gas reduction efforts, so an estimation of source energy use by region is included in Figure 15 (BSC 2008). The average fuel use breakdown by U.S. region is also shown. Fuel breakdown is important to consider in source and site energy use comparisons because oil and gas burned on site for heating in colder climates make site energy use higher than in other regions while source energy is in fact lower, as can be determined from comparison of Figure 14 and Figure 15. In contrast, cooling-dominated climates where more air conditioning and little heating is needed use a much higher proportion of electricity, resulting in lower site energy use and higher source energy use. In the case of PHA, all homes use only electricity and no other fuels.

It is important to note that these U.S.-wide and regional averages represent existing homes of varying age, airtightness, and size, achieving different degrees of indoor comfort. In addition, occupants use a variety of temperature set points and may or may not use air conditioning, dehumidification, mechanical ventilation, and other elements included in the PHA designs.

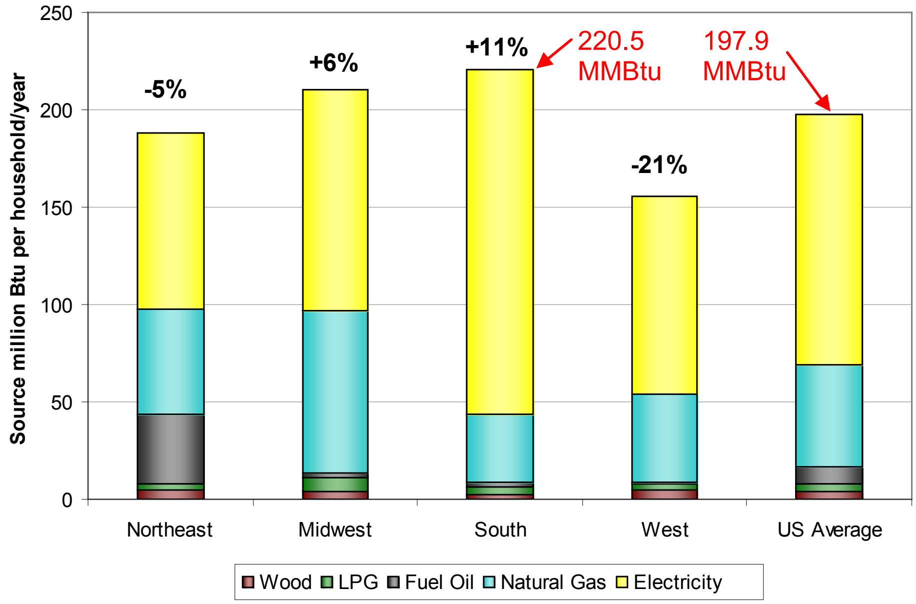

Figure 15. Calculated source energy use per household by U.S. region (BSC 2008)

The national average site-to-source electricity multiplier used for Figure 15 is 3.365 (Deru and Torcellini 2007). This value was used with the PHA utility data for consistency.

PHA, located in New Orleans, Louisiana, falls within the southern region of the United States. The southern and U.S. average household source energy uses are plotted in Figure 16, which ranks the 19 homes in order from least to greatest source energy use per year. The design of each home in the sample set is listed under each so that energy use of identical home designs can be compared.

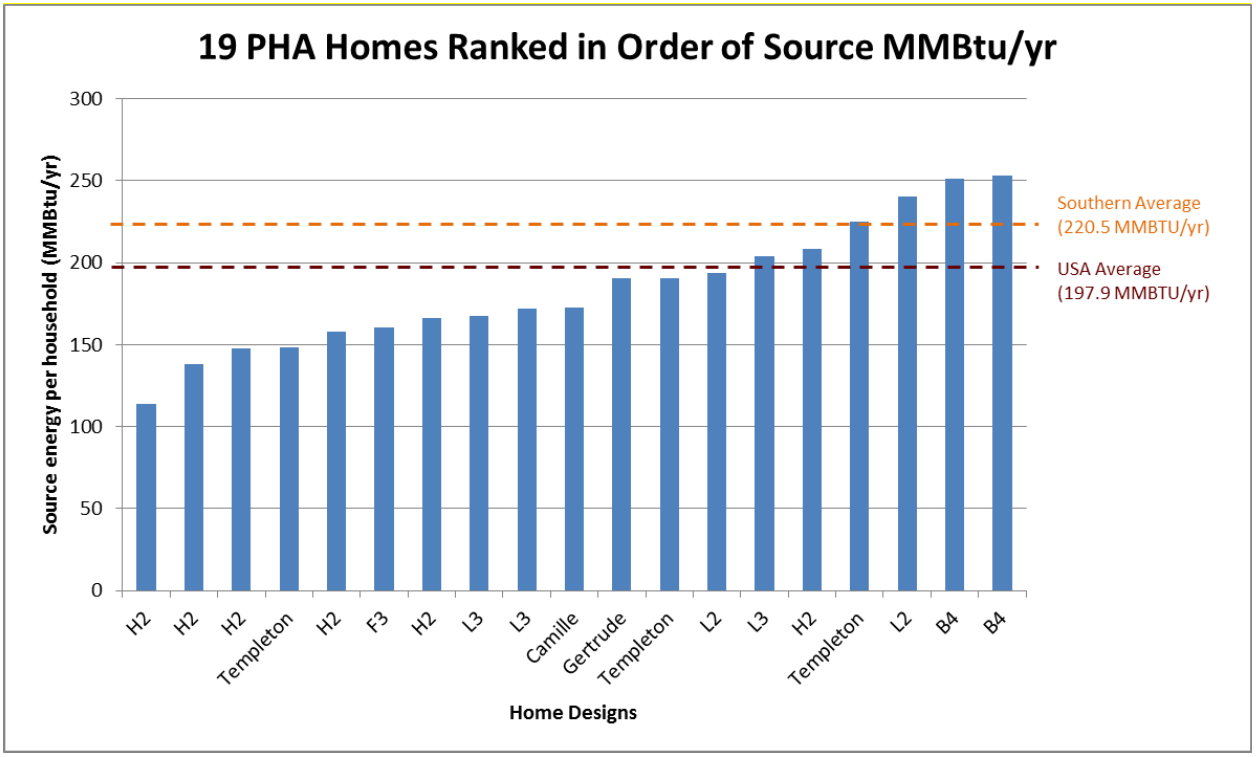

Figure 16. PHA home source energy use compared to U.S. and southern averages

As shown, most of the 19 homes fall below both the U.S. and southern source energy use averages. Compared to the southern average, 15 homes achieve savings of 5%–48%, with four homes using 2%–15% more energy. The homes use an average source energy of 184 MMBtu/yr with a standard deviation of 38 MMBtu/yr.

3.2 Square Foot Normalized Use

The energy performance of the 19 homes was also compared to 2030 Challenge goals. The 2030 Challenge, advocated by the nonprofit organization Architecture 2030, seeks to combat climate change by putting forth specific building energy reduction targets for those adopting the Challenge. Using fossil fuel-generated site energy from 2001 surveys as a baseline, the current reduction goal is 60%, with the goals of 70%, 80%, 90% and carbon neutral to be achieved by 2015, 2020, 2025, and 2030, respectively. Buildings are expected to achieve these goals by using a combination of low-energy design strategies, generating on-site renewable energy, and purchasing off-site renewable energy.

2030 Challenge targets are set by building type and U.S. region. For single-family detached homes located in the South, the average site energy EUI used for the baseline is 41.5 kBtu/ ft^2/yr; the 60% reduction target is 16.6 kBtu/ ft^2/yr. The site EUI of each of the 19 homes is plotted in Figure 17, with the 2030 Challenge average and 60% reduction goals included for reference.

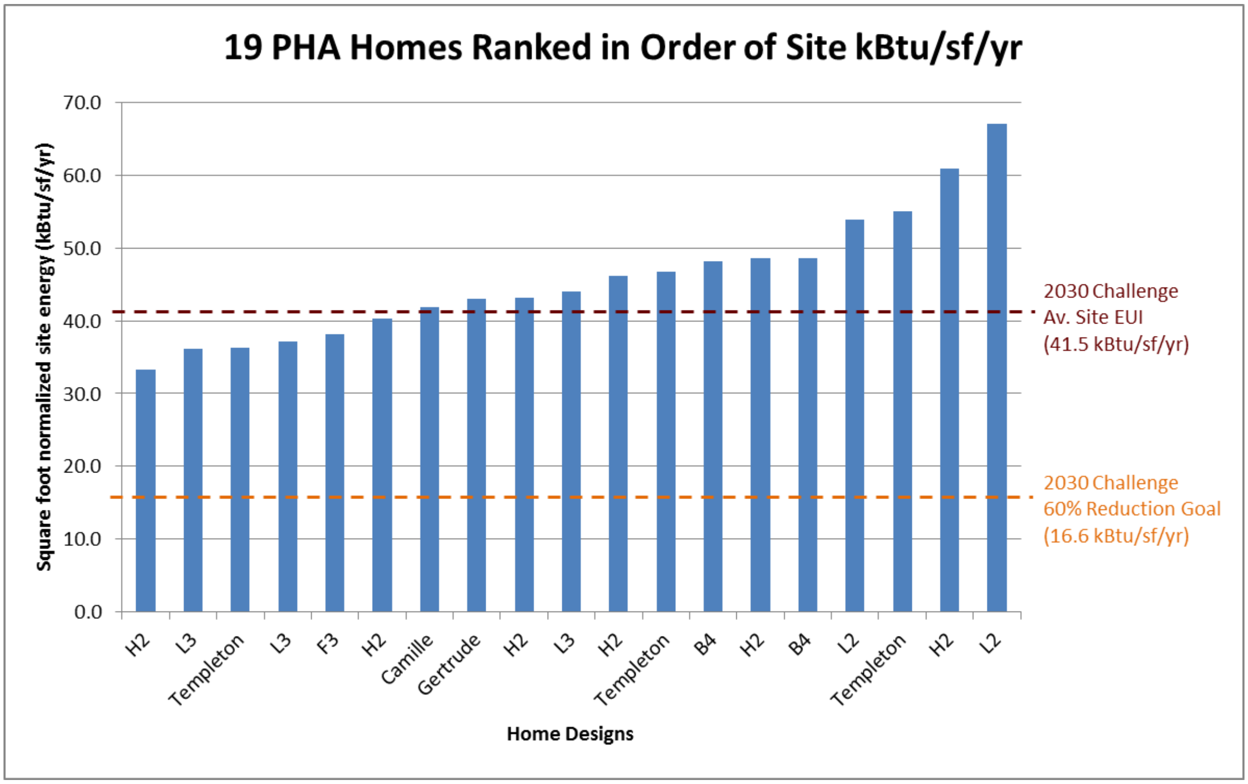

Figure 17. PHA home square foot normalized site energy compared to 2030 challenge goals for single-family detached homes in the South

As shown, none of the homes come close to meeting the 60% reduction target, and only six of the homes fall below the reference average EUI for southern single-family detached homes. The homes have an average site EUI of 46 kBtu/ft^2/yr with a standard deviation of 9 kBtu/ft^2/yr.

It is important to note a few issues with square foot normalized metrics. Smaller homes tend to have proportionally higher EUIs because of their increased surface area to volume ratio and because essentially the same appliances and miscellaneous loads are contained within a smaller space. Additionally, the inclusion or exclusion of basements in reported home square footage used to calculate the original average further affects the baseline, as basements can add significant square footage to a home while using relatively little energy due to ground coupling effects, especially in warmer climates such as those in the South. Because basements are in fact much less common in southern states, this factor probably has a greater effect on the U.S. average. None of the PHA designs include basements (standard practice in the New Orleans area), so their relatively smaller conditioned area makes their EUIs higher than those of larger buildings or of similarly sized buildings that include basements.

Apart from these issues, it is unfortunate that the homes did not get closer to the 2030 Challenge reduction targets. Renewable systems were not considered in PHA Phases I and II due to budget constraints, but are being installed in later phases. However, it is hoped that lower energy use will be achieved in the future as the homes continue to operate. One major issue to be discussed in Section 3.5 is that many homes' dehumidification systems were set at too high a set point, resulting in very high energy use before the issue was corrected. Monthly graphs showing energy use before and after this change occurred will underline the improvements that were made. The issues of miscellaneous loads will also be discussed, as some site observation noted fairly high use and home occupancy during standard working hours, though no formal survey or end use submonitoring has yet been implemented.

3.3 Energy Simulations

Several energy simulations were performed to help predict and understand the energy performance of the home designs. First, PHA's stated energy goal of exceeding the Builder's Challenge standard was evaluated using EGUSA.

Under the U.S. Department of Energy's Builder's Challenge program, new homes must achieve an index of 70 or below using HERS, which the Builder's Challenge program certifies as the EnergySmart Home Scale. Using this scale, an index of 100 represents a typical new home, while an index of zero means that a net zero home has been achieved. The index is based on an energy model of the design and is not adjusted based on performance metrics of the completed home (with the exception of the blower door test results).

Phase I project designs (B4, H2, F3, L2, and L3) all achieved the BSC and Building America goal of 2.5 $in.^2$ of free area per 100 ft^2 of building enclosure. Phase II project designs (Camille, Gertrude, and Templeton) achieved an even better leak ratio of 1.5 $in.^2$ of free area per 100 ft^2 of building enclosure. These tested values were used in the final EGUSA models to calculate the HERS index for each home type. Among homes of the same design, leak ratios were nearly identical, so multiple models per home design were not needed. The lower leak ratio achieved by the Phase II projects is likely due to the increased experience of the building team at that project phase as well as the less complicated floor plans compared to those of Phase I.

As shown in Figure 18, all eight home designs evaluated achieved scores below the Builder's Challenge target of 70. The increase in HERS Index values for Phase II is mainly due to a reduction in roof insulation from R-30 to R-21, which was a decision made by the builder due to cost concerns.

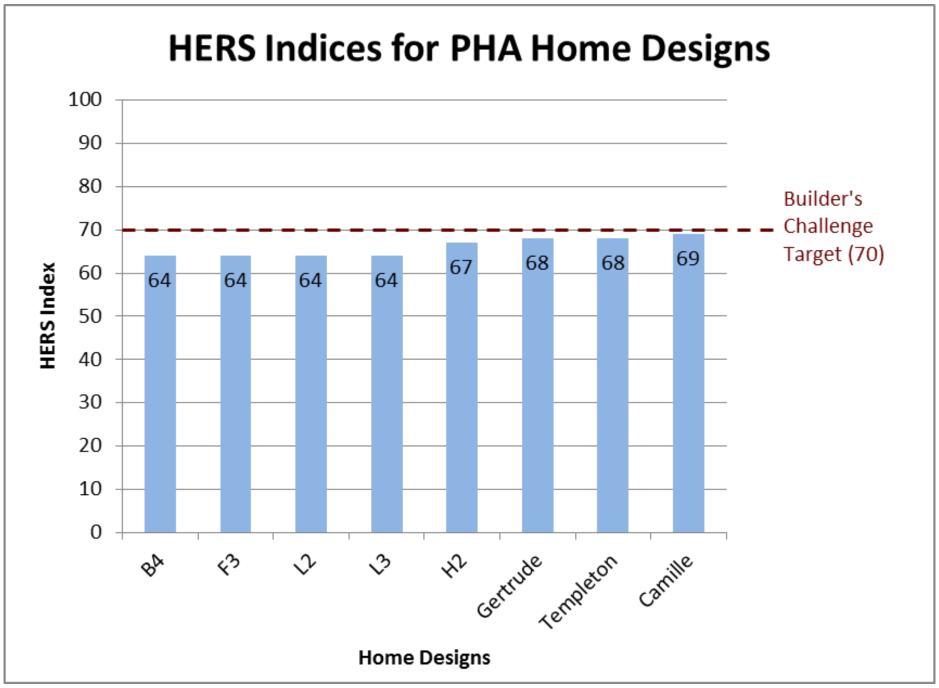

Figure 18. HERS indices for the eight designs evaluated

Figure 19 plots yearly utility bill reported electricity use compared to both BEopt and EGUSA models. As mentioned Section 2.2, an attempt was made to account for the amount of energy per year that the dehumidification system would use when operating as intended. Nine hundred seventy kilowatt-hours were added to the yearly energy use calculated by each EGUSA and BEopt model. Homes of the same design are shown by points forming vertical lines on the graph; homes with design “H2” have been highlighted as an example. These vertical series of points show the wide variation in energy use that can typically be observed among homes with identical designs (BSC 2008).

As shown, BEopt and EGUSA underpredict site electricity use with similar distributions about the reference lines showing a 1:1 correlation between models and bill data, and bill data at 150% of model data. Only one BEopt model overpredicts energy use over a year, as all other data points fall above the 1:1 correlation line. Additionally, BEopt and EGUSA results are generally quite close, with a relatively even mix of BEopt results exceeding those of EGUSA and vice versa. This increases confidence about the consistency of commonly used energy modeling software.

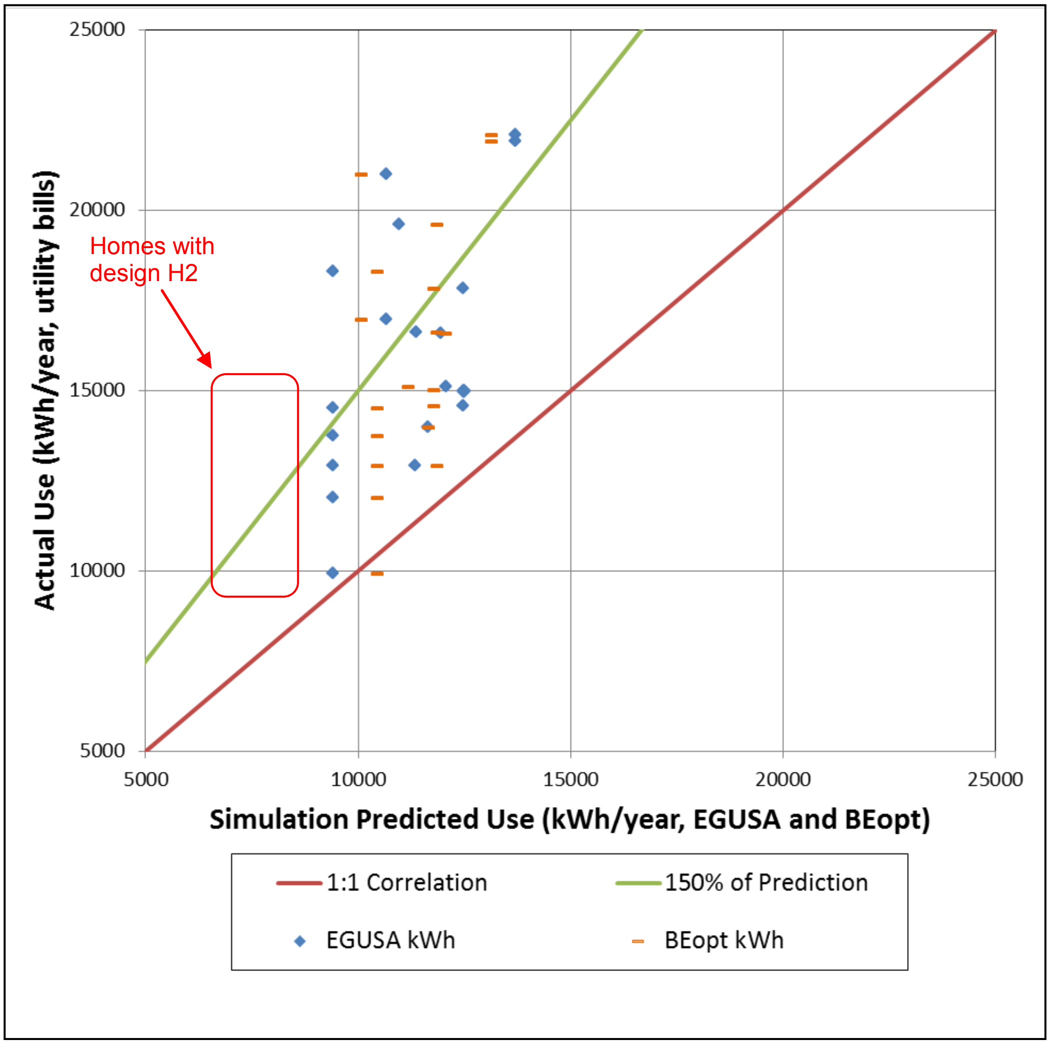

Figure 19. One year of utility bill electricity use compared to EGUSA and BEopt model predictions

Table 7 shows the range of modeling data points compared to those reported in the utility bills for the homes plotted in Figure 19.

Table 7. Utility Bill Energy Use Percent of Modeling Predictions Using EGUSA and BEopt

	EGUSA	BEopt
Minimum % of model prediction	105%	95%
Maximum % of model prediction	197%	208%
Average % of model prediction	144%	142%

In addition to energy use and cost optimization, BEopt can automatically model a B10 Benchmark building to compare to the design. The B10 Benchmark is meant to represent a home built to compliance with the 2009 IECC with other characteristics typical of 2010 new construction. For hot-humid climates, the current goal is to achieve a 20% source energy reduction below the size-adjusted B10 Benchmark according to the U.S. Department of Energy

Residential Research Program/Building America Program Overview (April 2010). The size-adjusted source energy number is meant to account for the wide variation in home sizes and help to give credit to smaller homes while penalizing homes that are larger. According to BEopt documentation, a typical home size is 2,400 ft^2 with three bedrooms. Because all PHA homes are far smaller (1,016–1,551 ft^2), their corresponding adjusted B10 Benchmark source energies are higher to give credit for the energy benefit of smaller home size.

As with the energy models of the prototype homes, the estimated supplemental dehumidification energy use of 970 kWh was converted to source energy and added to the B10 Benchmark values.

The size-adjusted B10 Benchmark source energy use for each building type is compared to actual yearly energy use from utility bills and using the 3.365 site-to-source energy ratio for electricity (Figure 20). Source energy from BEopt models of the homes is also included.

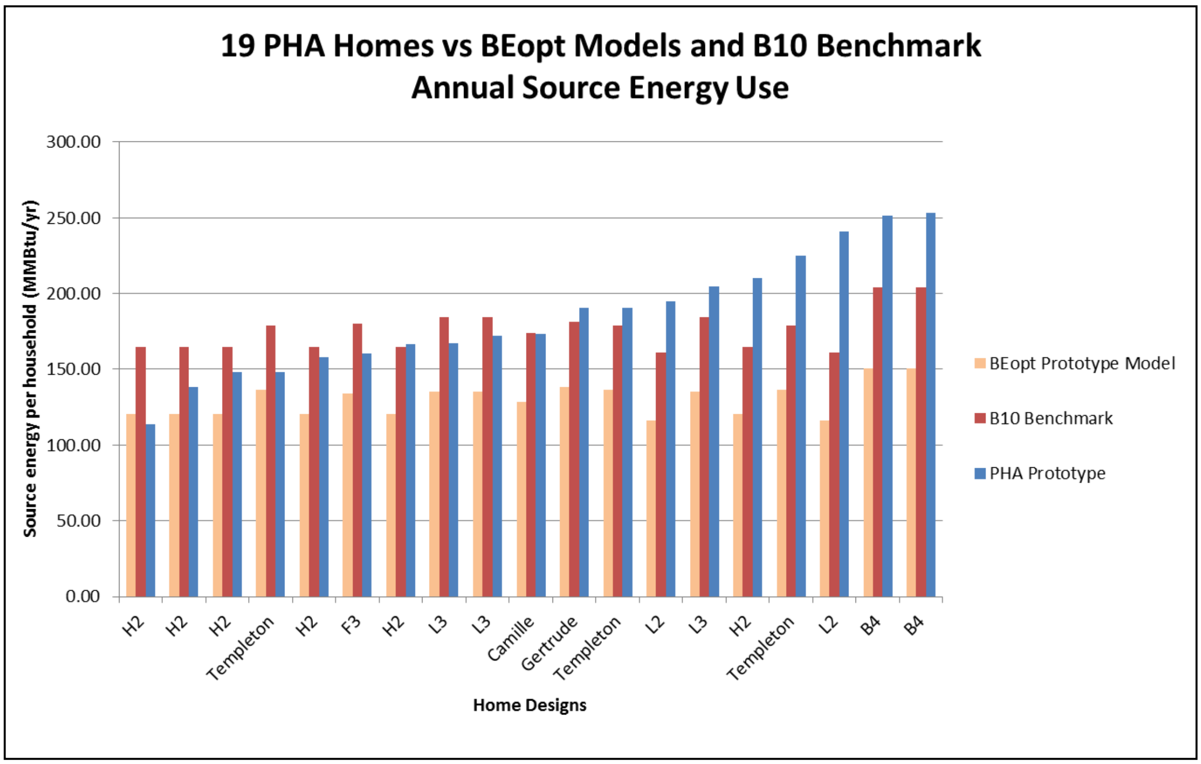

Figure 20. Source energy use from BEopt models, B10 Benchmark models, and actual utility bills

As can be observed, the "predictive" PHA BEopt models achieve an average source energy use reduction of 26% below their corresponding B10 Benchmark models, exceeding the 20% goal. The average source energy use reported by utility bills (PHA Prototype) exceeds the BEopt design models by an average of 27% and is an average of 5% over B10 Benchmark models, with most exceeding the Benchmark. Eight of the 19 real homes do achieve a small reduction below the B10 Benchmark, but only the first home (H2) exceeds the 20% goal with 31% savings. Two other homes come close at 16% and 17% savings. It is interesting to again note the wide variation in performance among the six identically designed H2 homes.

Weather data discrepancies are another important factor to note for the comparison in Figure 20 as well as in Figure 19. As noted in Table 6, HDDs and CDDs collected during the January 2010 to December 2010 period exceed those of the TMY3 files by 27.4% and 14.6% respectively. For this climate there are almost twice as many CDDs as HDDs, so any corresponding energy adjustment would be closer to the CDD discrepancy. If real 2010 weather data were to be used in BEopt models, the actual homes' performance against the B10 Benchmark would likely improve; however, it is still unlikely that the goal of 20% source energy savings would be achieved in all homes.

In addition to annual energy comparisons, a more detailed comparison was made by looking at monthly energy use. Monthly analysis also allows the observation of utility use data for more than one year, available for some homes. The monthly energy use in kilowatt-hours calculated by EGUSA and BEopt models was plotted alongside utility bill tabulations. For this more detailed monthly comparison, the rough estimate of the supplemental dehumidifier's yearly energy use was not included. HDDs and CDDs from actual weather data and TMY3 files were included as well.

Figure 21 shows a plot with this information. This H2 home design is the same as that displayed in Figure 12. This is also the home whose January–December 2010 yearly energy use came closest to that predicted by both BEopt and EGUSA models.

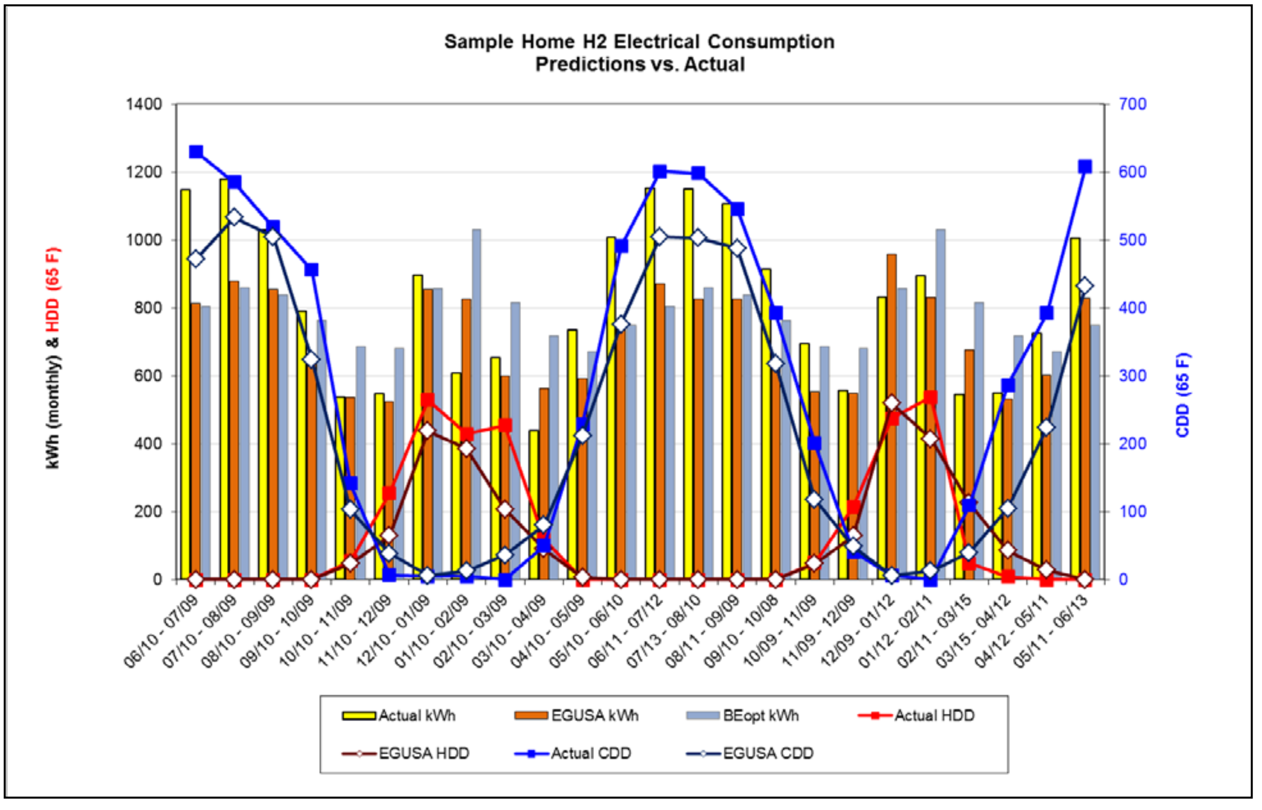

Figure 21. BEopt, EGUSA, and utility bill monthly energy use for a sample H2 home

Several observations can be made from the comparison between bills and models. Although the bill-reported yearly energy use during the time period observed is only 95% and 105% of that predicted by BEopt and EGUSA, respectively (Table 7), relatively large discrepancies appear during winter months for the BEopt model. As shown in Figure 21, the BEopt model substantially overpredicts energy use during winter months. One possible reason for this is that the two occupants of the home were observed to be at home often during the day, while the BEopt model likely assumes some reduction in occupancy during working hours. If occupants are home during the day, they are likely to be using items such as lights, computers, and televisions. These electric end uses as well as the body heat of occupants will decrease the need for winter heating. However, the winter temperature set point for this home is known to be 75°F, while that of the BA Benchmark (used in the models) is 71, which would increase heating load above that seen by the models.

In contrast with Figure 21, Figure 22 shows the home whose energy use was farthest away from model predictions, at 208% and 197% of that predicted by BEopt and EGUSA, respectively (Table 7).

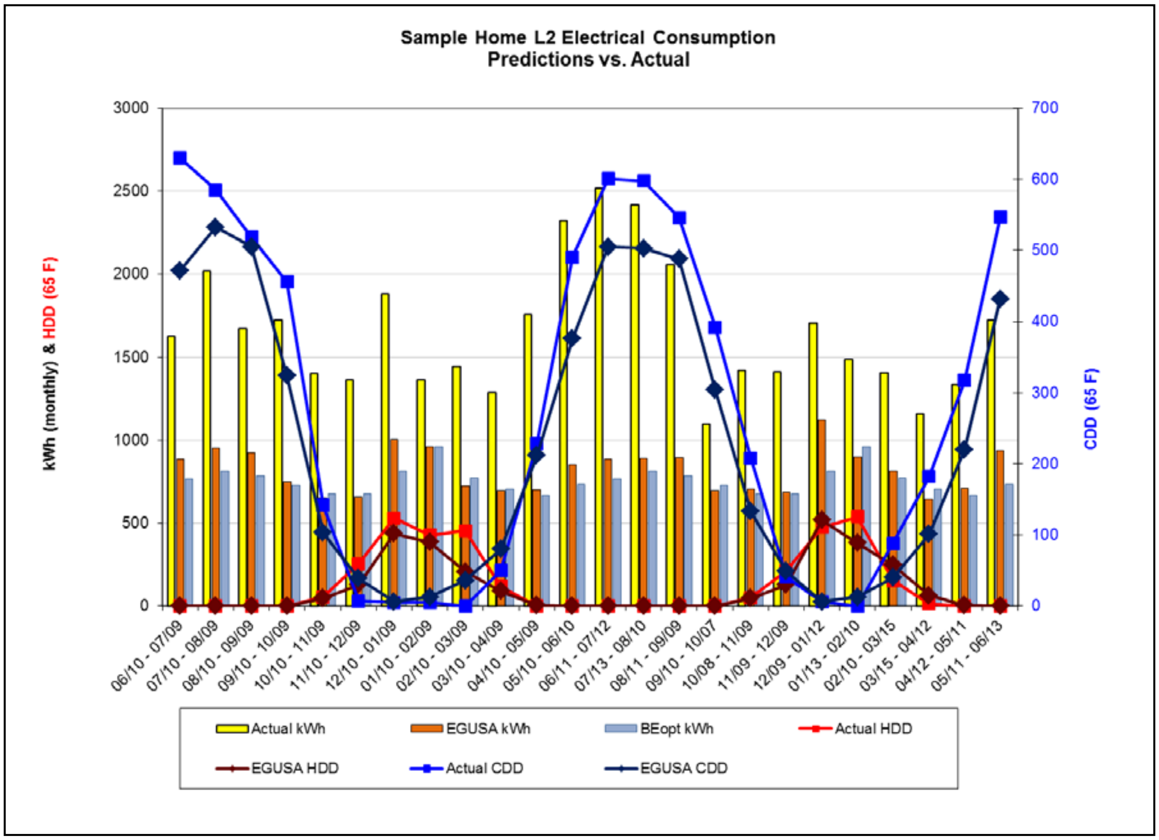

Figure 22. BEopt, EGUSA, and utility bill monthly energy use for a sample L2 home

In this case, it is difficult to know exactly what accounts for such high energy use over that predicted by models. It is known that the home has three occupants, which is the same as modeling assumptions for a two-bedroom home. One retired adult is known to be home during the day. Heating and cooling set points are kept at about 70°F in the summer and 73°F in the winter, which will result in higher energy use than the BA Benchmark values of 76°F summer and 71°F winter used by the energy models. Additionally, the Aprilaire dehumidification unit was originally turned to the 4.5 setting, out of a maximum of 5 (maintaining RH in the mid-30% range), but set back to 2 by a BSC representative (to maintain RH in the 55%–60% range) to prevent excessive energy use by over-dehumidification. Although energy use appeared to decrease after this August 31, 2010 adjustment, data are available only up to June 2011. A 25%

decrease in monthly energy use is observed when comparing the 2011 May–June period to that of 2010. Data from the remainder of the summer of 2011 are needed to better judge whether this adjustment of the Aprilaire unit significantly reduced energy use from the previous summer. However, the trend after the correction still indicates generally high energy use compared to that of the models and other homes.

Another home included in the dataset, using the Templeton design, serves as a good example of lowered energy use after systems have been adjusted to operate as intended. In this case, the homeowner noticed extremely high utility bills during her first summer of occupancy. In August 2010, the builder inspected the heat pump and noticed that the refrigerant in the split system had not been fully charged. With split-system heat pumps, refrigerant needs to be added onsite as each unit consists of two parts connected by the refrigerant line. This can leave more room for installation errors than for packaged units assembled in controlled factory settings. In the same month that this was corrected, a BSC representative found that the Aprilaire dehumidification unit had been set to a level of 5, over-dehumidifying the space. He adjusted the unit to a setting of 1 to maintain the 55%–60% RH recommended.

Figure 23 shows the difference in energy use before and after these adjustments were made. Energy use from the BEopt and EGUSA models is shown for reference. Although only the first half of the summer of 2011 is available to compare to that of 2010, comparison of the first warm weather months shows a significant decrease after the system adjustments were made, as well as a closer correlation with the models. For the May–June period, electricity use went from 1,504 kWh in 2010 to 1,249 kWh in 2011, a decrease of 17%; CDDs actually increased by 5% over the previous year. For the June–July period, electricity use went from 2,500 kWh in 2010 to 1,331 kWh, a decrease of 47%, while CDDs during that month increased by 10%. A similarly dramatic decrease in the energy use during the July–August period in 2011 will further support the conclusion that the newly adjusted cooling and dehumidification systems use much less energy when properly calibrated.

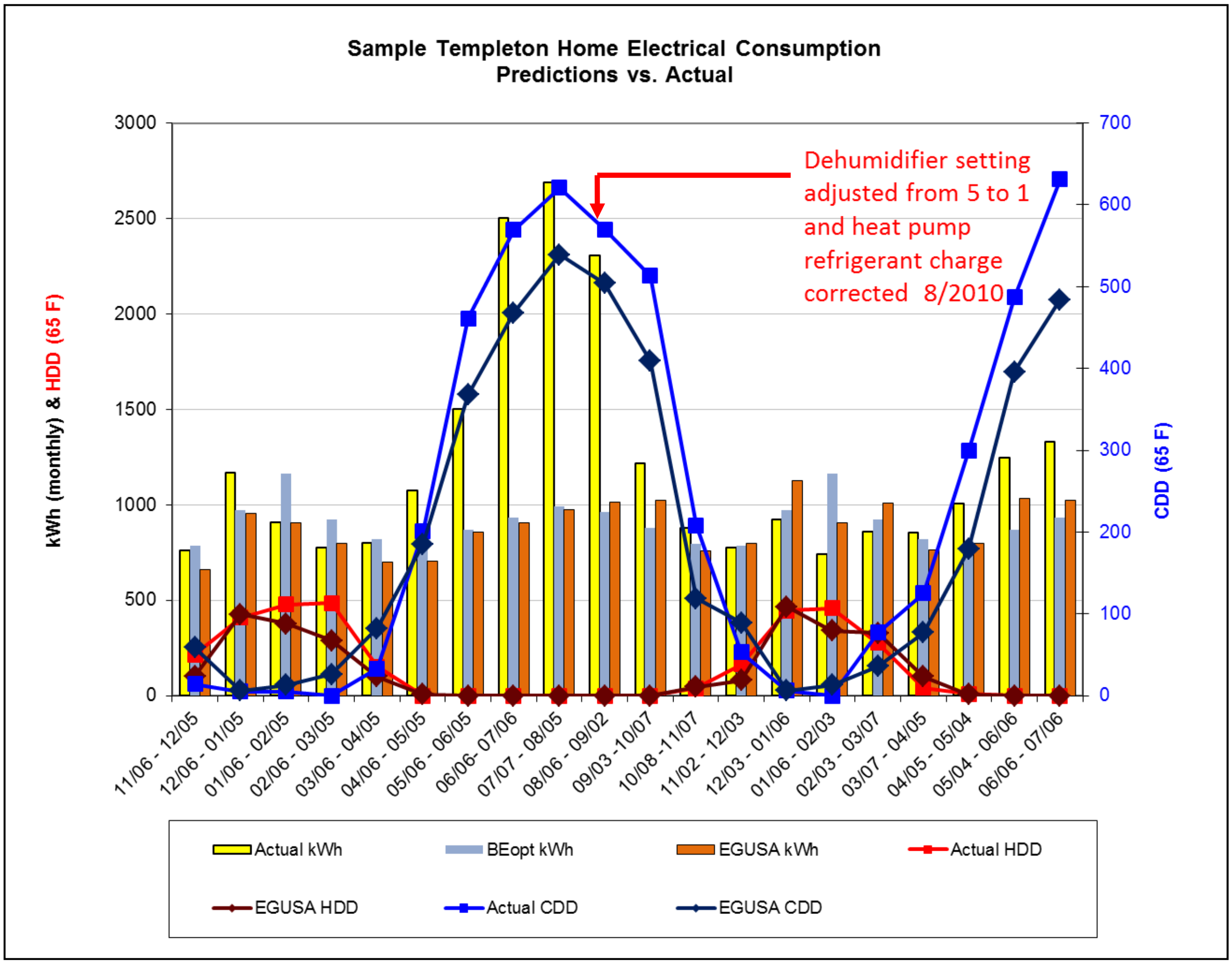

Figure 23. BEopt, EGUSA, and utility bill monthly energy use for a Templeton home where dehumidifier set point and refrigerant charge were corrected

This example underlines the importance of proper inspection of completed homes to ensure correct installation and operation. In addition to the dehumidification issue, it is possible that other homes' heat pumps were—and may continue to be—improperly charged with refrigerant.

Even with known discrepancies that could cause higher energy use than predicted by models, the full amount of extra energy use is unlikely to be caused by these factors alone. Internal loads and other occupant behavior are likely to play a large role. This example underlines the difficulty of understanding home energy use without submonitoring of end uses or detailed homeowner surveys. The likely range of discrepancy caused by the lack of separate dehumidification in the energy models is discussed in the next section.

As previously mentioned, it is harder to estimate the energy use of individual HVAC system components with homes that use only electricity. However, insights about base electrical loads (lighting, appliances, and miscellaneous loads) can be gleaned by looking at energy use during months when little heating or cooling is needed. In this case, base loads also include any ventilation or separate dehumidification that occurs during these periods. Base loads were calculated by taking the average kilowatt-hours of the lowest three months available from the 19 homes, removing any outliers that appeared in the first month or two of residency. Again, the addition of the supplemental dehumidification was not included in the monthly EGUSA estimates. All received utility bill data were used, including those falling outside the period of January–December 2010 when available.

Figure 24 shows monthly base loads for the 19 homes ranked in order of lowest to highest utility bill base load. EGUSA was used for this comparison as it is easier to obtain monthly data.

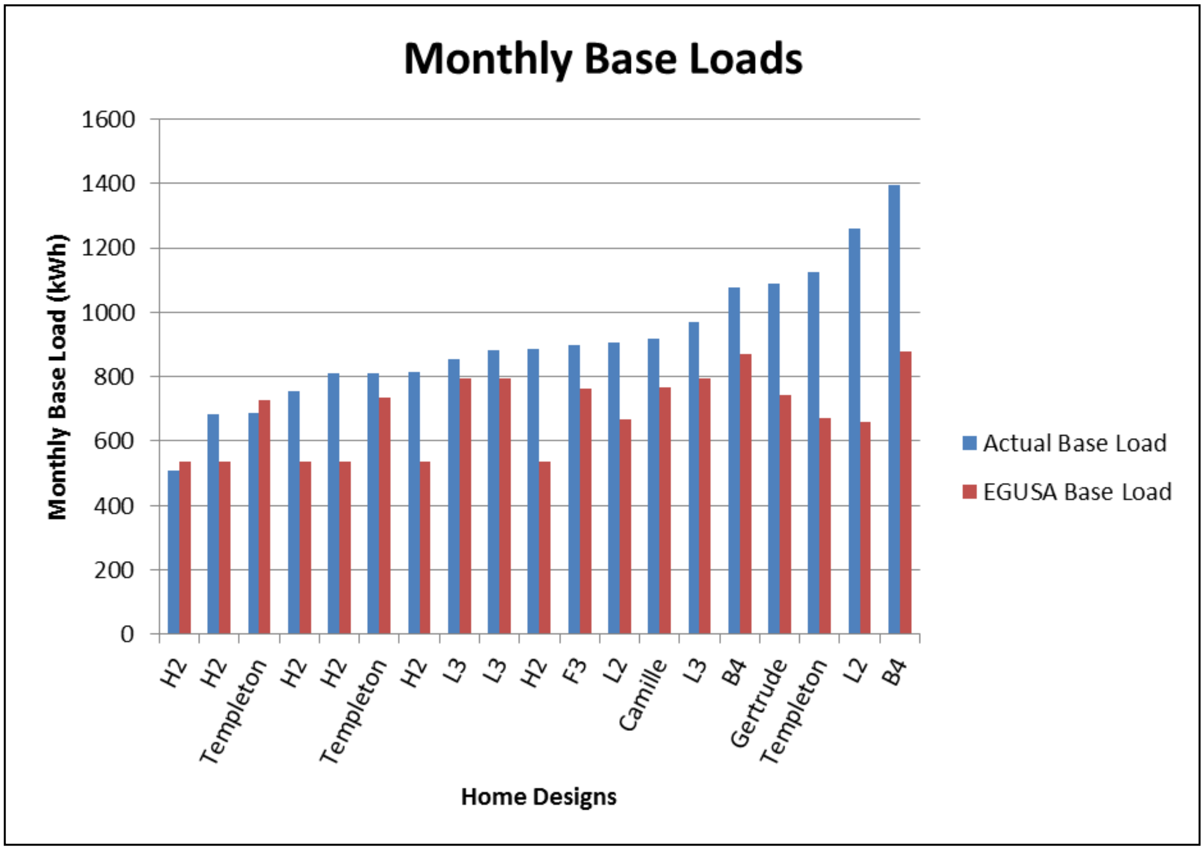

Figure 24. Monthly base loads from utility bills versus EGUSA models

As shown in Table 8, utility bill base loads substantially exceeded those calculated by the models using B10 Benchmark internal load assumptions. ENERGY STAR appliances and CFLs were installed in all homes as part of PHA design specifications, appliances, but other miscellaneous electrical loads, and lights are likely to be in use more often than assumed.

Table 8. Base Electrical Loads From Utility Bills and Models

	Utility Bills (kWh)	EGUSA Models (kWh)
Average	912	689
Standard Deviation	204	117

To better understand the portion of home energy use resulting from these base loads, utility bill monthly base loads were multiplied by 12 to get a rough estimate of base load energy use over a whole year. These values were then subtracted from total yearly energy use to estimate the yearly energy used by heating and cooling. Figure 25 shows estimated heating and cooling energy beside that of the base load; each column adds up to total yearly site energy use in kWh. Seasonal differences in miscellaneous loads were not accounted for.

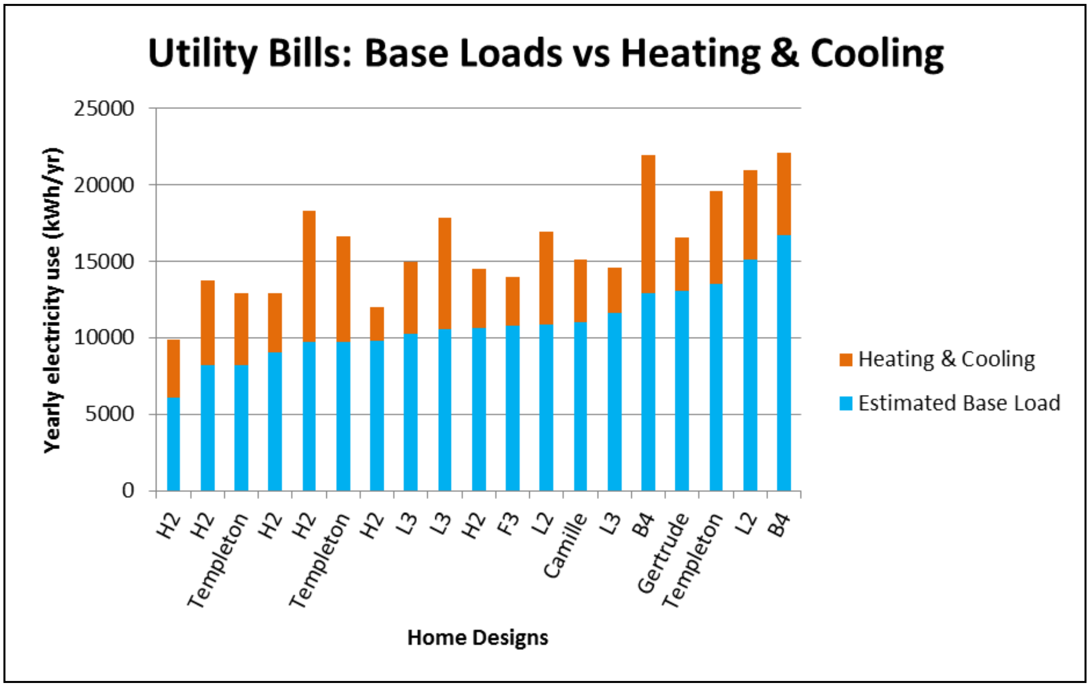

Figure 25. Total yearly site electricity use divided into estimated base loads and estimated heating and cooling

This comparison shows estimated base load energy use of 53%–81% of total energy use. This high percentage of miscellaneous loads compared to heating and cooling is expected for homes with advanced thermal enclosures such as those implemented in PHA. When heat gain and loss through the enclosure are significantly reduced, miscellaneous loads become a much larger piece of the pie. This means that the biggest energy variable is the one that the home designers cannot affect through low-energy design.

3.4 Weather Normalization

As presented in Table 6, actual HDDs and CDDs during the January–December 2010 period exceeded those in the TMY3 files used for the models discussed in the previous section. Although differences in weather are a common and expected cause of differences between design-phase energy model predictions and actual use, such as that shown in Figure 19, an effort was made to normalize the weather difference factor for the B10 Benchmark comparison shown in Figure 20. The goal of this effort was to approximate the amount of energy the actual homes would have used if exposed to the TMY3 weather data used in the B10 Benchmark and Prototype energy models. Rerunning the models using actual weather data was also an option. However, the decision was made to normalize actual energy use to the TMY3 weather to preserve the definition of B10 Benchmark energy use. TMY3 is the B10 Benchmark and energy modeling industry standard weather data input for the estimation of long term energy performance.

Linear regression of actual energy use versus actual degree days (base 65°F) was performed using Microsoft Excel. Energy use was plotted on the Y axis and degree days on the X axis for each of the 19 homes. The dataset for the heating degree correlation consisted of months whose

HDDs exceeded CDDs. The remaining dataset was used for the CDD correlation. Linear regression was performed on the data; best linear fit equations were generated along with R^2 values to understand how closely energy use is correlated with base 65°F days. R^2 values above 0.7 indicate a reasonably good correlation between two variables. Only four of the 19 homes achieved R^2 values above 0.7 for both the HDD and CDD correlations, though other homes showed values above 0.7 for one or the other. Figure 26 and Figure 27 are included as sample graphs for one of the four homes showing both HDD and CDD R^2 values above 0.7.

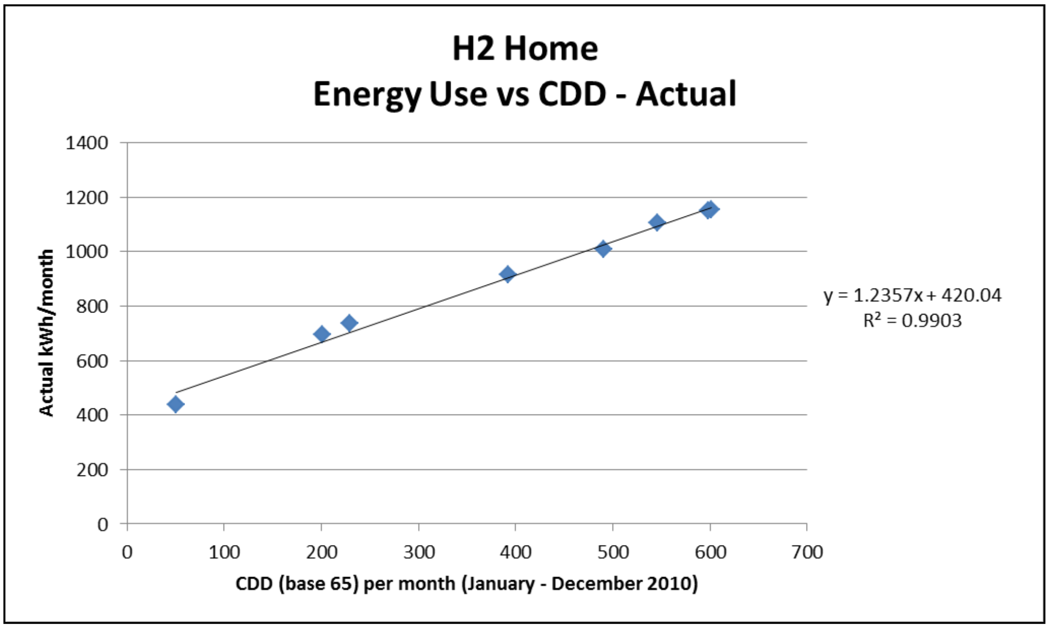

Figure 26. Actual energy use versus CDDs

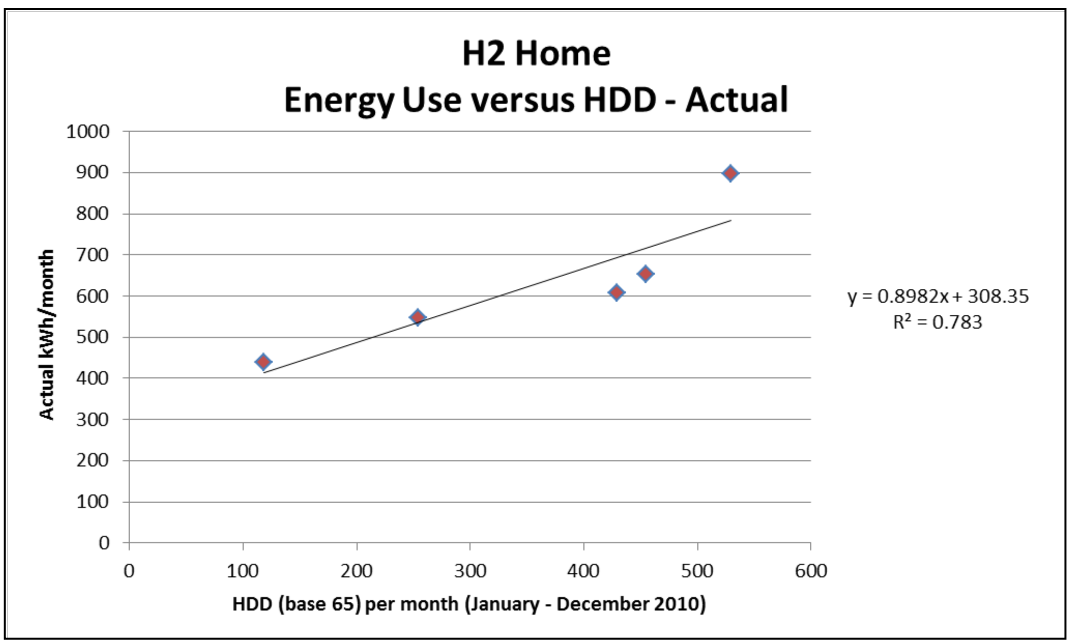

Figure 27. Actual energy use versus HDDs

For the four homes that showed R^2 values above 0.7, degree days from TMY3 files were plugged into the "x" value of the Excel-generated linear regression equations shown beside the graphs in Figure 26 and Figure 27. The HDD correlation equation was used for months with more HDDs than CDDs and vice versa. New monthly energy use data were generated using the equations. Because modeled degree days were lower than actual degree days (Table 6), this resulted in an adjusted yearly energy use lower than the actual energy use tabulated from bills. For the four homes with a good linear regression correlation, energy use reductions of 8%–13% were calculated for the scenario of subjecting the homes to TMY3 weather in place of real January–December 2010 weather. By coincidence, two of the homes showed an 8% reduction and two showed a 13% reduction, an average of 10.5% reduction.

To roughly estimate how TMY3 weather conditions might have affected real energy use of all 19 the homes during the January–December 2010 period, a 10.5% reduction was applied to the yearly energy use of the whole set of 19 homes. A modified version of the original Figure 20 graph was created to compare energy use of the BEopt Prototype Model, the B10 Benchmark, and the PHA Prototype adjusted to incorporated TMY3 weather (Figure 28). The color of the TMY3-adjusted PHA Prototype has been changed to light blue to distinguish it from the dark blue of the equivalent Figure 20 graph.

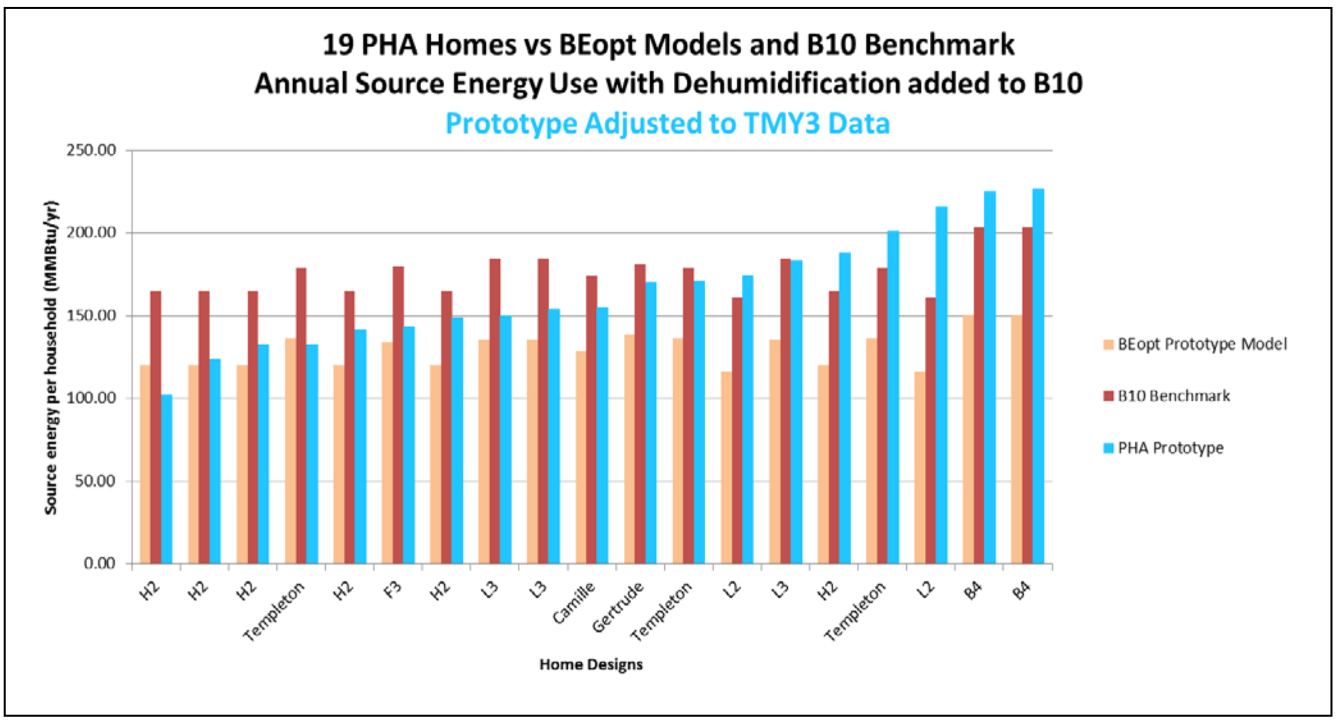

Figure 28. Comparison of Figure 20 with prototype energy use adjusted to incorporate TMY3 weather data

In contrast to the comparison shown in Figure 20, the average source energy use from TMY3-adjusted adjusted utility bill energy use (PHA Prototype) exceeds the BEopt design model energy use by an average of 18% and shows an average saving of 6% compared to B10 Benchmark models. This 6% average saving is an improvement over the average –5% calculated before the TMY3 weather adjustment estimation was made. In the adjusted scenario, five homes achieve the 20% reduction goal, with three homes in the 14%–19% saving range. As shown, other homes show much smaller improvements over the B10 Benchmark and six homes still use more energy than the B10 Benchmark.

This exercise also highlighted the poor correlation between outdoor dry bulb temperature and energy use, another point of interest for home performance. Several possible factors contribute to the weak correlations observed in 15 of 19 homes. These include:

- Base miscellaneous loads vary significantly by month.
- Excessively low dehumidification set points caused much higher cooling loads during humid periods (further discussed in Section 3.6).
- Outdoor humidity levels significantly affect cooling loads in hot-humid climates; a correlation to CDDs based on dry bulb temperature alone will not capture the influence of humidity levels.

The optimal base temperature may be a value other than 65°F; this value probably varies by month and varies widely between homes depending on base miscellaneous load.

A comprehensive base temperature optimization for each of the 19 homes was outside the scope of this project and considered to be of relatively low value because of the estimated minor contribution of weather and nonseasonally based use patterns observed in many of the homes. However, future work is likely to include a more detailed examination of these relationships through submonitoring of cooling and heating end use.

It was also interesting to note that that the slopes calculated by linear regression varied significantly in the dataset, from about 0.7 to as high as 3.3 when a more consistent slope might be expected. Slopes also varied between each actual building and the equivalent design phase energy model. The slope represents how much energy use is caused by each additional degree day. The y intercepts also varied as expected; this variable can be used as an estimate of the base miscellaneous load. Y intercepts calculated by linear regression were in close range of those estimated by taking the average of the lowest three months (Table 8).

This weather data adjustment exercise shows a rough estimation of the effect that normalizing the weather data would have on the B10 Benchmark savings goals. However, it is unlikely that a more precise analysis within the constraints of the limited data available would show that all of the homes achieve the 20% savings goal. Planned submonitoring of energy end uses will allow a more detailed exploration of the correlation between weather conditions and energy use.

3.5 Cost Optimization

In addition to energy simulations, BEopt was used to generate a cost optimization curve for a representative home design, the Templeton design of Phase II (see Figure 29). Costs for the BEopt modeling options were taken from RSMeans or from the BEopt default library when unavailable. Several less expensive but lower performance wall, roof, and floor insulation options were included in the optimization, as well as the option to leave out ENERGY STAR appliances and varying percentages of CFLs. Additionally, the heat pump options of 15 and 16 SEER were included to compare to the 14 SEER actually installed.

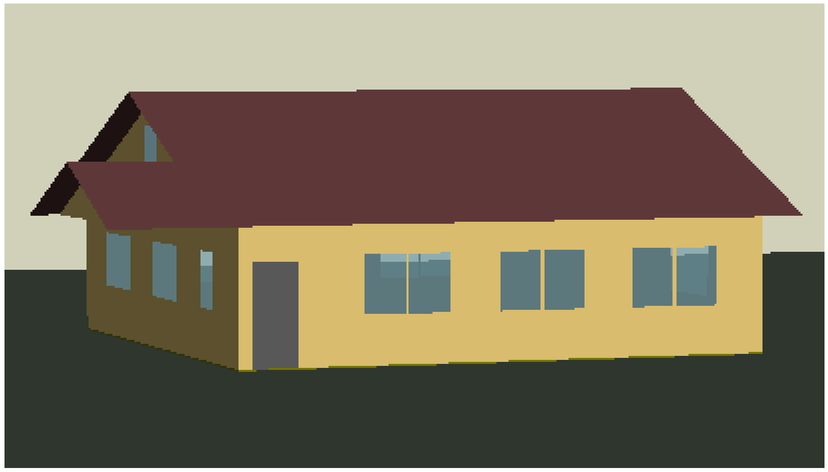

Figure 29. Screenshot of Templeton BEopt model

Figure 30 shows the results of the cost optimization model. The particular combination of building properties in the real design could not be found among the set of dots generated by the model, as not all possible combinations are generated. However, a representative dot was selected with most of the properties of the actual design and with a similar percentage savings from the Benchmark. Next, a combined graph was created showing both the cost optimization curve and the design (Figure 31).

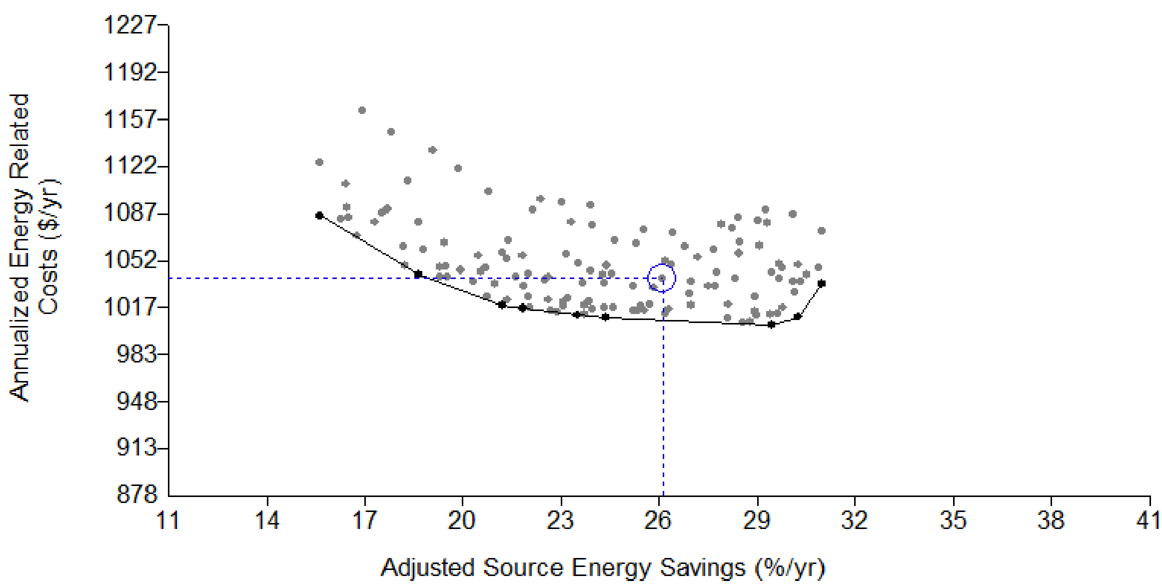

Figure 30. BEopt cost optimization curve for Templeton design

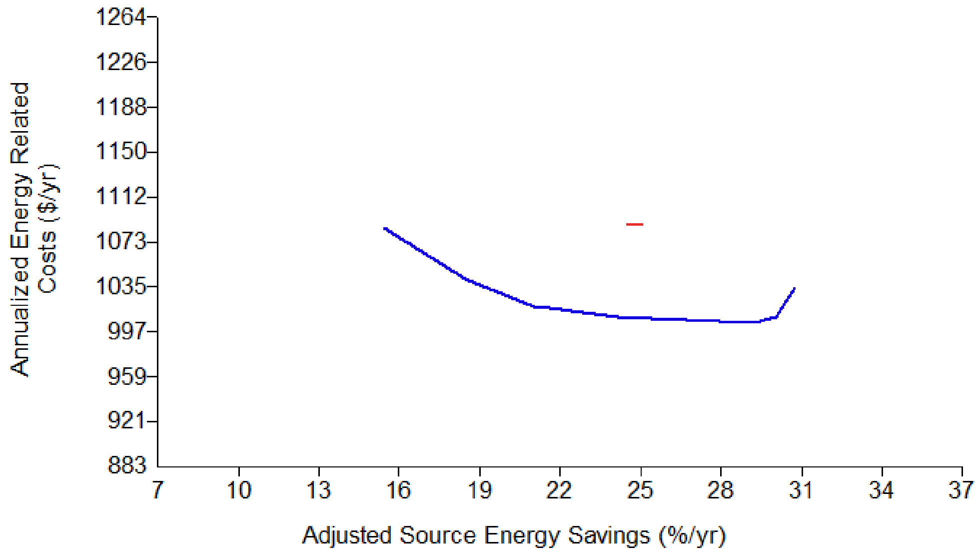

Figure 31. BEopt combined graph showing cost optimization curve (blue) and design (red)

As shown, the actual design is not the highest energy saver or lowest cost; however, it performs reasonably well compared to the other options. Spray foam insulation compared to conventional options is an important contributor to the increased cost. Although conventional insulation options are less expensive, spray foam has the advantage of greater water resistance. In a flooding event, it will dry out without becoming moldy, in contrast with other options that would need to be removed entirely to refurbish the home. This flood recoverability design is a highly recommended feature in areas with high flood risk.

3.6 Dehumidification

The first two phases (32 homes) of PHA were constructed with a ducted whole-house dehumidifier installed in the unvented cathedralized attic and integrated with the HVAC system. This was to ensure that indoor humidity levels could be controlled year round, not just during the cooling season, to a maximum of 55%–60%. The unit is specifically intended to operate during the shoulder seasons, when cooling is not needed. A study conducted by BSC showed the need for supplemental humidity control in a hot humid climate during the shoulder seasons (Rudd 2004).

BSC recommended the installation of a remote dehumidistat to be installed next to the thermostat in the main living space to allow for more accessible occupant control. However, the builder chose to rely solely on the onboard controls that are located directly on the whole-house dehumidifier up in the unvented cathedralized attic. After installation, it was discovered that some of these dehumidification dials were set to maintain an extremely low RH (mid-30% range) instead of BSC's design recommendation of 55%–60% RH. This resulted in the dehumidifier operating significantly more than intended. The dehumidifier's output air is around 80°F. This additional sensible load resulted in around a 70% cooling load increase, which was enough to overcome the capacity of the cooling system. Not only did the dehumidification units use more energy than necessary, but the cooling system needed to compensate for the additional heat, and was operating much more often than designed. This resulted not only in excessive electricity use, but a handful of homeowners began complaining about high temperatures. BSC worked with the builder to troubleshoot the problem and made the recommendation that the dehumidifier settings be altered to a higher humidity setting (~55% RH). BSC was able to gain access to 12 of the 32 homes and confirmed that the dehumidifier settings were corrected. BSC recommended that either the builder or the homeowner adjust the settings on the remaining dehumidifiers. It is not known whether this has been accomplished in the rest of the Phase I and II homes.

PHA did decide to forego the installation of supplemental dehumidifiers in Phases III through VI, as the units are expensive and the initial problems were costly for this affordable development. For Phases III and beyond, the builder was able to take the $2000 saved on the whole-house dehumidifier and reinvest it in a higher efficiency heat pump. Although BSC maintains that supplemental dehumidification is necessary to maintain year-round comfort levels in low-energy housing, the cost, maintenance, and energy drawbacks are always being cited by builders and architects as reasons not to invest in the technology.

BSC is hoping to conduct a research project to investigate the differences in performance and interior comfort conditions between homes with and without supplemental dehumidification. Many factors affect thermal comfort, and there is a wide range of tolerance among different people. Residents of New Orleans may be accustomed to—or even prefer—higher humidity than those used to living in drier climates. If any occupants of homes without dehumidification feel uncomfortable, some may be reluctant to complain about the homes they received as gifts after their unfortunate experience with Hurricane Katrina. The purpose of additional research will be to glean further insights into whether supplemental dehumidification is a necessary investment in affordable housing in hot-humid climates.

Although most homes in Phase III have only been occupied for a few months, a full year of data were available for two of the homes. Phase III homes have nearly identical attributes to those of Phases I and II, with the exception of slightly more efficient heat pumps (SEER 14.5 versus SEER 14) and the lack of supplemental dehumidifiers. The energy use of the two homes was compared to that of the 19-home set discussed in this report. Although this is a small sample size, the goal was to take a preliminary look whether the lack of supplemental dehumidification significantly affects energy use.

The energy use of the set of 19 homes from Phases I and II covers the period from January to December 2010, but the data available for the two Phase III homes span August 2010 to July 2011. It is important to consider that degree days differ for these two time periods. CDDs for the Phase III set exceed those of the Phases I and II set by 8% but the number of HDDs is 23% lower.

Figure 32 is the same as Figure 16 but includes the two available Phase III homes (Camille Phase III and Gertrude Phase III). The homes are ranked in order of source energy use per year and compared to U.S. and southern averages. As shown, these two homes fall above the average source energy use of the 19 Phase I and II homes.

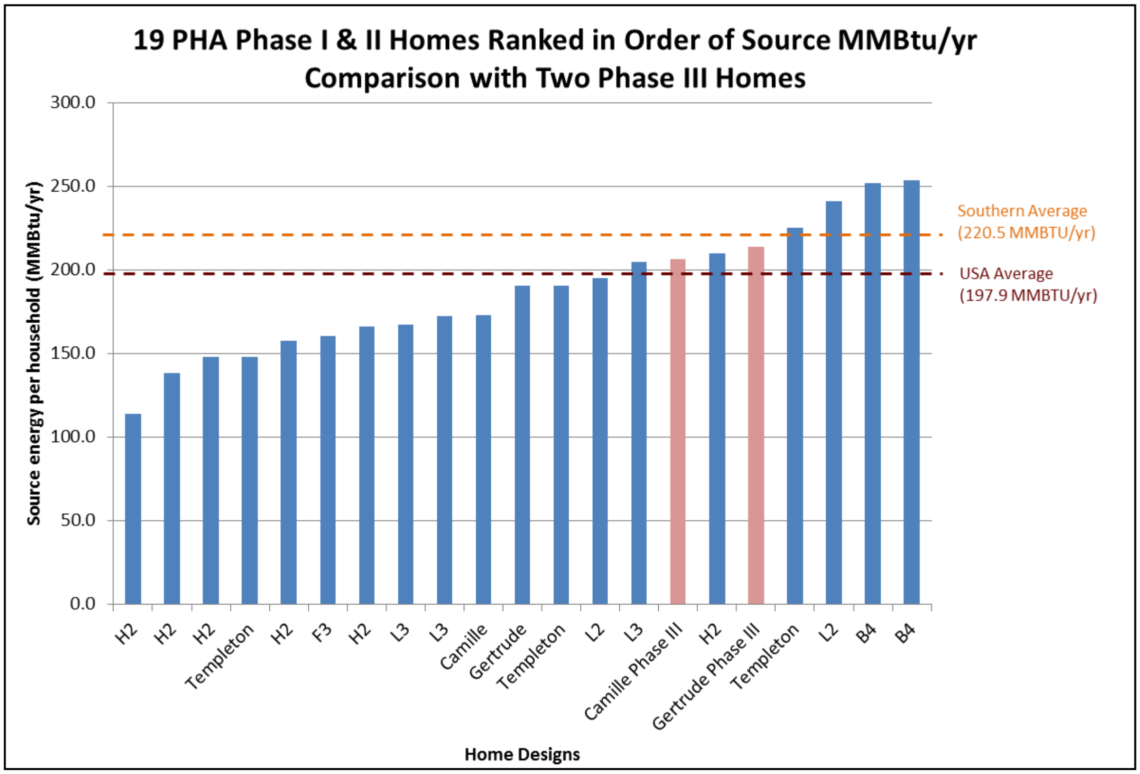

Figure 32. PHA home source energy compared to U.S. and southern averages. Two Phase III homes (without supplemental dehumidifiers) are included in the set.

Figure 33 is the same as Figure 25 but includes the estimated base loads of the Phase III homes. Again, monthly base electrical loads were estimated by taking the average of the lowest three months of electrical use. Yearly base load electrical use was estimated by multiplying this value by 12. Heating and cooling energy was estimated by subtracting the base load estimation from the total energy.

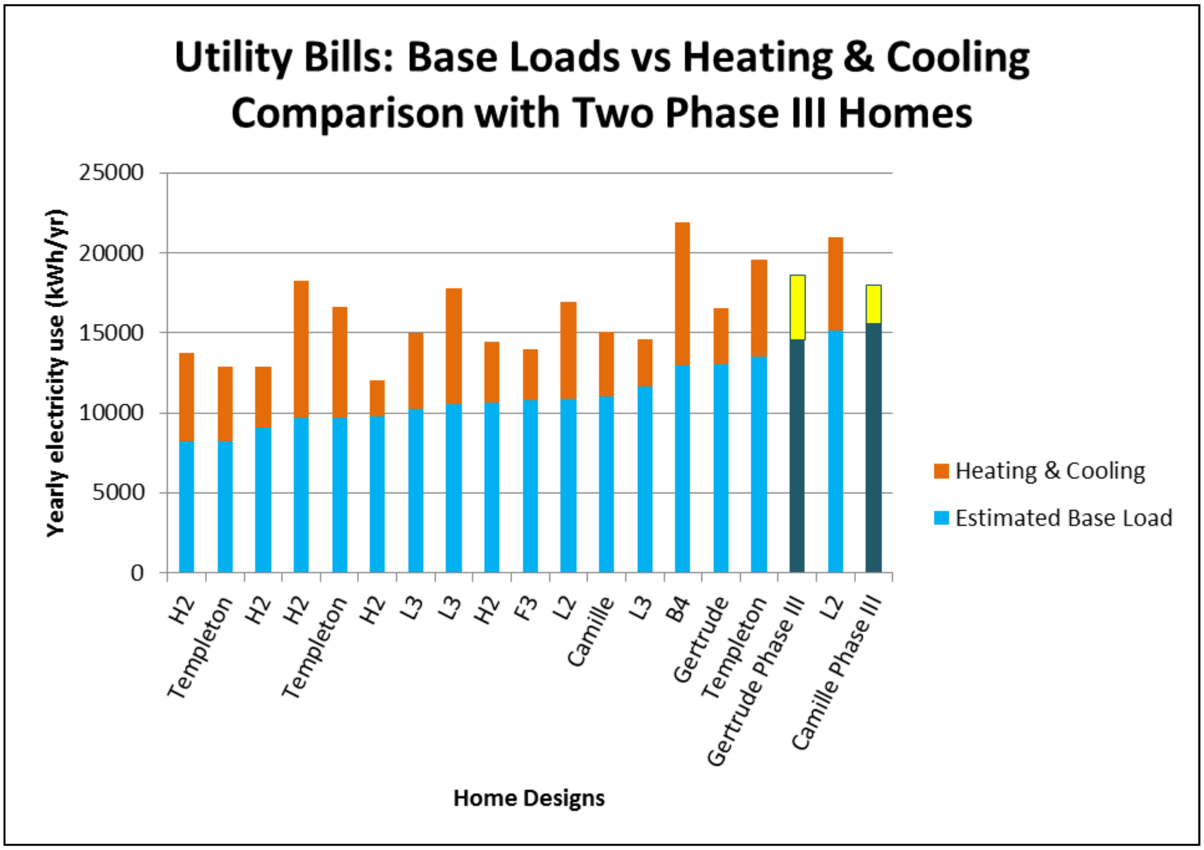

Figure 33. Estimated base electrical loads of the Phase I and II set compared to those of the two Phase III homes

As previously discussed, the yearly energy use of some of the 19 Phase I and II homes includes periods of time when dehumidification set points in several homes were incorrectly set to very low RH, and faulty refrigerant charge existed in at least one home. Although a whole year of data were available for only two Phase III homes, the data available so far from two additional Phase III homes indicate similar monthly performance. The data currently available do not support the theory that supplemental dehumidification increases yearly energy use. However, a larger sample size is needed to better compare the performance of different phases of homes within the community. Once the over-dehumidification has been corrected in most of the Phase I and II homes and at least a year of data are available for a similar sample size of Phase III homes, a better comparison of home energy use with and without supplemental dehumidification can be made.

BSC is also studying the effect of the supplemental dehumidification on the indoor comfort conditions it is intended to maintain. Remote temperature and RH monitoring devices were installed in 12 homes to gather data about the indoor living conditions. There is a correlation between homes that are maintaining very low RH and are experiencing higher utility bills. More HOBO data will be downloaded around September 2011.

4 Discussion

The utility bill analysis of PHA is useful for ongoing performance analysis of these new homes. Designed to be energy efficient but cost effective to build, the home designs showcase many BSC best practices. These integrate building technologies that positively impact the durability and efficiency of the residences and ensure higher levels of comfort and health in the living space. Significant aspects of the design include the high-density spray foam enclosure, LowE^3 glazing and supplemental dehumidification. HDPE spray foam is being installed throughout the entire enclosure. This results in very airtight buildings, achieving BSC leak ratio goals. The home designs all meet the Builder's Challenge goal of achieving HERS ratings under 70.

Despite the high-performance thermal enclosures and low-energy mechanical systems, utility bill analysis shows that the homes are not performing as well as hoped compared to yearly energy use benchmarks such as regional and country-wide household averages, the B10 Benchmark, and the 2030 Challenge targets. Energy models using B10 Benchmark use assumptions also drastically underpredicted energy use in the real homes.

As shown in Figure 24, approximately 50%–80% of total energy comprises base loads. These loads include lights, appliances, ventilation, and the dehumidification energy. This large percentage of total energy is expected because of the high-performance thermal enclosure and mechanical systems that significantly reduce heating and cooling energy. PHA included ENERGY STAR appliances and CFLs; the remainder of variables affecting miscellaneous use depend on the user. Heating, cooling, and dehumidification set points are controlled by users as well, affecting heating and cooling energy.

The dehumidification issues discussed in the previous section shed some light on one component of the additional energy use. Energy used by a correctly operating supplemental dehumidifier is estimated to be a relatively small percentage of yearly energy use (approximately 5%–10%), which positively contributes to occupant comfort in a hot-humid climate. However, initial comparison with similarly performing Phase III homes (without supplemental dehumidification) suggests that even the excessive over-dehumidification discovered in some of the Phase I and II homes does not fully account for the overall high energy use of the community compared to various U.S. benchmarks.

To help meet PHA's energy efficiency goals, future work could include mailings or educational sessions designed to help homeowners save energy. Although some of this information was included in homeowners' manuals, refresher materials containing recommended seasonal temperature and humidity set points along with tips about turning off lights and miscellaneous loads when not in use could lead to a significant reduction in community energy use. The educational materials could include estimations of how money could be saved on utility bills by making these changes, as well as interesting carbon footprint reduction analogies. These estimations could be generated with reasonable accuracy using existing energy models calibrated to the ongoing monthly tabulation of utility bill data. Competitions to achieve certain low energy goals each year could further raise awareness of the issue. Additionally, homeowner surveys, continuing HOBO monitoring and submonitoring of different end uses in test homes could provide further insight into occupant behavior.

In addition to continued monitoring of all PHA homes' electricity bills, BSC's planned work involves more detailed submonitoring of a small group of homes. Energy end uses such as heating, cooling, ventilation fan energy, and domestic hot water will be monitored individually with the goal of gleaning insight into the components of the observed high energy use. This submonitored energy use data will also allow more precise correlation of energy use to weather data, helping to pinpoint high baseload energy use that is independent of outdoor conditions.

It is important to note that not all of PHA's investments in high-performance building practices reduce energy use; in fact, elements such as centralized mechanical ventilation, dehumidification, and air conditioning increase it. Other important attributes of the project, such as spray foam insulation, increase home durability and ability to recover from flooding events. However, the thermal comfort and durability benefits of these additions are important contributions to home value and occupant satisfaction.

5 Conclusions

PHA is a useful example of continued monitoring of a community of homes constructed with similar attributes. Several high-performance building techniques were implemented with the intent of creating durable, comfortable, and low-energy buildings. However, the measured energy use of the buildings has been higher than expected, showing disappointing comparisons to various benchmarks.

Most of the 19 homes utilized less source energy than the U.S. and regional averages. None of the homes' EUIs achieved the stringent 2030 Challenge target of 16.6 kBtu/ ft^2/yr. All homes achieved HERS ratings below 70 based on their design and post construction blower door test results, achieving the Builder's Challenge goal.

Although all design prototype models achieve the goal of 20% savings below the B10 Benchmark model, only one home's actual utility data achieve the 20% savings below Benchmark. It was noted that significantly more HDDs and CDDs were recording during the monitoring period than in the B10 Benchmark model's TMY3 file. When an adjustment calculation was made to account for this weather data discrepancy, four more homes achieve the 20% goal, but most homes show very low or negative energy savings compared to the B10 Benchmark goal.

Several possible reasons for the observed high energy use were explored. An examination of base load estimates points to high miscellaneous loads as the major factor. Supplemental dehumidification is expected to modestly increase energy use, but is unlikely to be a primary culprit. However, the excessively low dehumidification settings observed in some homes could have contributed; improvements were observed after the issue was corrected in several homes. Even though the group of 19 Phase I and II homes included examples where this over-dehumidification was known to have occurred, it was interesting to note the comparable performance of the two Phase III homes (lacking supplemental dehumidification) for which a year of data was available. Incorrect refrigerant charge was also noted as another likely contributor to high energy use; it is unknown whether the issue has been corrected in all homes.

As future phases of the project are completed and more utility bills are received, the sample size of homes will increase. This will allow more detailed and accurate analysis of the homes' performance, providing greater insight into project successes and areas for improvement. Future BSC work involves the detailed end use submonitoring of a smaller number of homes, allowing a closer look at the causes of high energy use, correlation to weather conditions, and other factors.

This study underlines the role of home occupants in high-performance buildings. Although advanced enclosures and mechanical systems can be installed, it is up to the user to operate the home in an energy-conscious manner to achieve efficiency goals. It is important for homeowners to understand how their behavior impacts the energy use of both HVAC systems and miscellaneous end uses. Even after design and construction of the community is complete, ongoing outreach education as well as continued performance monitoring is necessary to achieve PHA's full potential.

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