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Greenbelt Homes Pilot Energy Efficiency Program Phase 1 Summary: Existing Conditions and Baseline Energy Use

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NAHB Research Center

February 2013

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Definitions

A/C	Air conditioning
B	An acronym used in this report to designate a unit in a block building (8" CMU)
BA	U.S. Department of Energy's Building America Program
BV	An acronym used in this report to designate a unit in a block building with vinyl siding
CMU	Concrete masonry unit
Co-op	Cooperative
CT	Current transducer
DOE	U.S. Department of Energy
EE	Energy efficiency
° F	Temperature in degrees, Fahrenheit
FB	An acronym used in this report to designate a unit in a wood frame brick-veneered building
ft^2	Square foot
FV	An acronym used in this report to designate a unit in a wood frame vinyl-sided building
GHI	Greenbelt Homes, Inc.
GPM	Gallons per minute, a rate of water flow
HDD	Heating degree day
IECC	International Energy Conservation Code
IRC	International Residential Code
kWh	Kilowatt hours (typical measure of electricity usage; equal to 1,000 watt hours)
HVAC	Heating, ventilation, and air conditioning
NAHBRC-IP	NAHB Research Center Industry Partnership

NREL	National Renewable Energy Laboratory, a national laboratory of the U.S. Department of Energy. www.nrel.gov
Research Center	NAHB Research Center
RH	Relative humidity, ratio of water vapor in the air to its temperature

Executive Summary

A multiyear pilot energy efficiency retrofit project has been undertaken by Greenbelt Homes, Inc, (GHI) a 1,566 co-operative of circa 1930 and 1940 homes in Greenbelt, Maryland. The three predominant construction methods of the townhomes in the community are materials common to the area and climate zone including 8 in. concrete masonry unit (CMU) block, wood frame with brick veneer and wood frame with vinyl siding. GHI has established a pilot project that will serve as a basis for decision making for the rollout of a decade-long community upgrade program that will incorporate energy efficiency upgrades to the building envelope from the exterior and equipment with the modernization of other systems like plumbing, mechanical equipment, and cladding.

The pilot project has three phases focused on identifying the added costs and energy savings benefits of energy efficiency features that are to be installed during a planned community-wide replacement program commencing in 2015. Phase 1 consists of a baseline evaluation of the current operation, use, environmental conditions, and energy costs for a representative set of 28 townhomes sited in seven buildings. Phase 2 will consist of the installation of the building envelope improvements identified in Phase 1, continued monitoring of the energy consumption for the heating season both before and after installation, and performing energy simulations supporting recommendations for HVAC and water heating upgrades to be implemented in Phase 3.

Phase 1 of the GHI pilot program efforts, detailed herein, included field walk-through evaluations (recording existing conditions), energy simulations for projected savings with exterior insulation upgrades, building envelope energy improvement cost estimates and recommendations, and installation and maintenance of monitoring equipment and data.

Simulation results combined with estimated upgrade costs and ongoing maintenance costs for a 30-year period indicate a positive net cash flow for one or more of the selected options for each building type. (Building envelope upgrades that were acceptable to the membership required exterior application with the new claddings because occupants required limited disturbance.) Payback periods for the least cost approach for each building type are less than 20 years (net of reserves). Energy savings estimates for the analyzed envelope improvements in Phase 1 range from 9% (per each frame brick building) to nearly 30% for each block building.

Average indoor temperatures for the baseline heating season range from 58ºF to 70°F with two-thirds of the homes having an average temperature less than 68°F. Anecdotal homeowner comments have indicated that reduced energy bills is the predominant reason for the unusually low indoor temperatures.

Energy use data is being recorded and analysis of the data that was captured for a period of the 2010/2011 heating season is presented. Average heating energy across all units in a given building type ranges from over 6,000 kWh for the block buildings to just over 4,000 kWh for the wood frame vinyl buildings. The wood frame brick veneer buildings averaged about 5,000 kWh. The wood frame buildings average about 4.5 kWh/ft^2, the block buildings with vinyl siding averaged about 5.0 kWh/ft^2, and the uninsulated block buildings average about 6.2 kWh/ft^2.

One of the questions that arise from this and similar analyses is the comparison of simulated energy use estimates with actual field measurements. In general, the initial measurement period indicated an acceptable level of confidence that energy simulations developed for these older homes are generally representative of actual energy use in the homes. Therefore, it can be surmised that estimated energy savings of simulated upgraded energy features will represent the expected energy savings. Furthermore, an analysis of the utility meter data also shows a correlation between measured energy use and heating energy estimates from utility data. The utility data however, is based on weekly or bi-weekly records.

1 Introduction

Greenbelt Homes Inc. (GHI) is a 1,600-home private housing cooperative (co-op) located on over 250 acres in Greenbelt, Maryland, about 12 miles from the nation's capital. The co-op is comprised of 1,571 homes originally constructed by the federal government between 1936 and 1941; with 29 more that were added in the ensuing years. These homes are primarily arranged in rows of two-story (and a small number of three-story) townhouses. All 1,600 GHI member-owners together own the cooperative and share the operating costs. A monthly fee covers the operating expenses of the cooperative and funds replacements. The co-op maintains and repairs plumbing, electrical wiring, and building structural components. The homes are individually metered for electricity. Natural gas is not available inside the community.

Because of comfort issues and high energy costs, GHI established a multiyear pilot program to assist in determining the best performing and lowest cost options for improvements to the existing homes. The pilot program coincides with scheduled window and siding replacement. This report details Phase 1 of the GHI pilot program including field walk-through evaluations, energy simulations, building envelope upgrade recommendations, and baseline monitoring.

The Building America (BA) Program and the stated community goals for the GHI pilot program converge both in desired performance levels and cost effectiveness. The NAHB Research Center (through the BA program) is providing support to identify the combination of highest energy performance to least cost ratio while considering related needs of comfort and minimal lifestyle disruption during upgrades. The BA program also supports effort in monitoring the performance of the homes to detail pre- and post-retrofit energy use.

This report summarizes the initial condition of each home, the energy simulations and estimated costs of upgrades to assess cost effectiveness of energy improvements, and the initial pre-upgrade heating season energy use and indoor environmental condition results for the pilot homes. This data is intended as baseline data for use in comparison of ongoing monitoring results when the efficiency upgrades are implemented. The energy use measurements include both utility meter data and data from installed sensors and transducers. The data is analyzed to develop baseline performance curves for each of the seven buildings in the GHI pilot program. The energy use and curve fits will later be used to analyze energy use following the upgrades and to develop the retrofit cost analyses including estimated payback periods and a return-on-investment for the energy upgrades.

The pilot program analysis will guide the GHI community in the future housing revitalization to more energy efficient homes.

2 Background

GHI is working to identify opportunities to upgrade the existing homes in the community for energy savings, durability, and good indoor environmental quality. The community's housing stock not only provides shelter but a connection to a unique lifestyle that spans and transcends generations. Many communities of homes aged over 50 years old have continued service life expectations well into the future, and for GHI, maintaining and improving their 60- to 70-year-old homes is a clear directive of the cooperative. However, these vintage homes, while well built, have construction features that often frustrate energy efficiency and indoor comfort goals. Residents of some of the homes have chosen to maintain colder-than-desired interior temperatures in the heating season to reduce energy bills. Other residents have added numerous space heaters to supplement the main heating equipment. Most residents currently pay high energy costs and have the experience and expectations to believe that these costs will increase over time.

Given the age of the buildings, occupant complaints of discomfort and high energy costs, and strong sense of community that includes the housing style itself, an effort to improve the performance of the community housing stock is a growing priority. In addition, just as important as energy efficiency are indoor environmental quality and affordability goals that necessarily include a positive net present value requirement for the 30-year project.

GHI has established a pilot program that will provide results to aid in decision making for the roll out of a decade-long community upgrade program to improve efficiency of the building envelope and modernize equipment such as plumbing, mechanical equipment, and cladding. The GHI Buildings Committee determined initial criteria for pilot program eligibility: all four units in a building had to be represented; the homes were required to be owner occupied; and each of the three predominant building types were to be represented in the pilot group. GHI staff sent letters soliciting volunteers for the program and 32 members responded. One building had to be dropped when an owner moved overseas.

The pilot project has three phases focused on identifying the added costs and benefits of energy efficiency features that are to be installed during a planned community-wide replacement program commencing in 2015.

Phase 1 of the GHI pilot program consists of a baseline evaluation of the current operation, use, environmental conditions, and energy costs for a representative set of 28 townhomes sited in seven buildings. Efforts conducted during 2010/2011 included field walk-through evaluations (recording existing conditions), energy simulation for projected savings, building envelope energy improvement cost estimates and recommendations, and installation and maintenance of monitoring equipment and data. This report summarizes these efforts and includes the results of energy use monitoring over the 2010/2011 winter season.

Phase 2 will consist of the installation of the building envelope improvements identified in Phase 1, monitoring energy consumption for the heating season following installation, and performing energy simulations supporting recommendations for HVAC and water heating upgrades.

Phase 3 will include the installation of the HVAC and water heating upgrades identified in Phase 2 and monitoring energy consumption for the heating season following installation.

The community embarked on a similar upgrade in 1980. At that time, central building oil boilers were abandoned in place. The homes were individually metered with 125-amp electric panels and heat was supplied to each home by wall-mounted electric baseboard units and fan-coil ceiling-mounted heaters in the bath and kitchen. Homes do not have central air-conditioners (A/C). Typically, one or more room-capacity A/C units are installed in wall openings or windows. The boiler rooms now house many of the circa-1990 50 or 52 gallon electric water heaters that provide hot water to individual homes. Hot water pipes in the crawlspaces of the brick and block units are 90% insulated. Water heaters in the wood frame vinyl-sided units are located inside the homes. Vinyl or aluminum double-pane windows were installed in the 1980 upgrade. Table 1 details the general conditions predominate in the community’s housing today.

Table 1. Typical GHI Construction and Pre-Retrofit Conditions.

Construction Type	General Conditions	Total No. of Units
Block - 8 in. CMU **(B or BV)**	• Formed concrete crawlspace foundations[1], with structural concrete first floors over common crawlspaces • Crawlspaces are 4 ft and retrofitted as closed crawlspaces with 1 in. to 2 in. of rigid extruded polystyrene foam applied to the perimeter walls • Crawlspace walls extend under front and rear porch slabs (many exposed to ambient conditions) • Structural concrete floors (1st and 2nd levels) • Main house and porch slabs lack thermal breaks • CMU walls, finished with plaster • Some interior common walls are wood-framed (where party walls breach the adjacent units' footprint). • Double glazed vinyl windows (1980) • Exterior walls are painted (B) or have vinyl siding (BV) • Flat concrete roofs retrofitted with 3 ¾ in. of polyisocyanurate insulating tapered sheathing and EPDM roofing, R-26 • Electric baseboard heating • Room through-the-wall air conditioning • Electric water heat	256
Wood frame Brick-Veneer **(FB)**	• Formed concrete crawlspace foundations, with structural concrete first floors over common crawl spaces • Crawl spaces are 4 ft and retrofitted as closed crawlspaces with 1 in. to 2 in. of rigid extruded polystyrene foam applied to the perimeter walls • Crawlspace walls extend under front and rear porch slabs (many exposed to ambient conditions) • Structural concrete first floor • Main house and porch slabs lack thermal breaks • Balloon- framed 2 × 4-16 in. o.c. walls with plasterboard interior finish • Blown-in cellulose/rock wool insulation in walls (1980) • Board wall and roof sheathing (1 × 6/1 × 8) • Exterior brick veneer, no WRB	318

[1] Several units have full, rear walkout basements of CMU.

Construction Type	General Conditions	Total No. of Units
	• Double glazed vinyl windows (1980) • Gable roofs with slate shingles • Ventilated attic with rock wool, cellulose, or fiberglass floor insulation, R-16 (1980) • Electric baseboard heating • Room through the-wall air conditioning • Electric water heat	
Wood frame Vinyl-Sided **(FV)**	• Common ventilated crawlspace of 8 in. CMU block, 4 ½ courses high (3 ft) • 2 × 8-16 in. o.c. floor joists with mid-span dropped beam 3-2 × 10 in. on CMU piers • R-11 kraft-faced fiberglass batt insulation in floor joists (1980) • Balloon-framed 2 × 4-16 in. o.c. walls • Blown-in cellulose insulation in walls (1980) • Board wall and roof sheathing (1 × 6/1 × 8) • Double glazed vinyl or aluminum windows (1980) • Vinyl siding, no WRB • Gable roof with asphalt shingles • Ventilated attic • Attics insulated with rock wool, cellulose, or fiberglass floor insulation, R-16 (1980) • Electric baseboard heating • Room through-the-wall air conditioning • Electric water heat	992 (140 of these are apartments)

3 Baseline Condition

The first step of Phase 1 of the pilot program was to determine the existing condition of the 28 homes to aid in developing energy simulations and upgrade recommendations. The pre-retrofit condition of the 28 homes was established through occupant interviews, compilation of the previous years' utility bills, physical inspections, and air infiltration and water flow testing. Representative pre- and post-retrofit data for three of the seven buildings are covered in Table 2 through Table 4. Building elevations are shown in Figure 1 through Figure 6. Data for all of the buildings in the pilot program can be found in Appendix A.

Figure 1. Block building, one end unit, front.

Figure 2. Block building, one end unit, rear.

Table 2. Typical Build Specifications – 8 in. CMU Block Building (B-1 through B-4).

Greenbelt Homes, Inc.				
Walk-through:	**11/18/2010**	**11/18/2010**	**11/18/2010**	**11/18/2010**
Unit Code	**B-1**	**B-2**	**B-3**	**B-4**
Feature/ Component	**Before**	**Before**	**Before**	**Before**
Year Built	1936	1936	1936	1936
House Type	Town - End: C 3.9	Town - Interior C2.6	Town - Interior C 2.6	Town - End C 3.9
Structural Wall Type	8 in. CMU	8 in. CMU	8 in. CMU	8 in. CMU w/wood frame add
Front Orientation	South	South	South	South
Finished ft^2, Main	1,168	844	787	1,168
Ft^2 Addition				77
No. Stories	2	2	2	2
Bedrooms	3	2	2	3
Baths	1	1	1	2
Ceiling Ht	8'-4"	8'-3"	8'-2"	
Foundation	Concrete Crawl - 4'	Concrete Crawl - 4'	Concrete Crawl - 4'	Concrete Crawl - 4'
Insulated Foundation?	Yes- 2 in. xps- to 3 ft	Yes- 2 in. xps- to 3 ft	Yes- 2 in. xps- to 3 ft	Yes- 2 in. xps- to 3 ft
Heated	No	No	No	No
Foundation R-value	R-5	R-5	R-5	R-5
Floor R-value	0	0	0	0
Vented Crawlspace	No	No	No	No
1st Floor	5 in. structural slab	5 in. structural slab	5 in. structural slab	5 in. structural slab
2nd Floor	5 in. structural slab	5 in. structural slab	5 in. structural slab	5 in. structural slab
Attic Ceiling	5 in. structural slab	5 in. structural slab	5 in. structural slab	5 in. structural slab
Attic R-value	26	26	26	26
Roof Rafter	Flat Concrete Roof	Flat Concrete Roof	Flat Concrete Roof	Flat Concrete Roof
Structural Wall	8 in. CMU	8 in. CMU	8 in. CMU	8 in. CMU
Siding	Painted CMU	Painted CMU	Painted CMU	Painted CMU
Building Dimensions	25 × 20	16 × 20	16 × 20	25 × 20
Addition Dimensions				11x7
Window Material	Vinyl Slider	Vinyl Slider	single glazed vinyl sliders w/storms	vinyl sliders
Ft^2 Windows	54/36/85/0	65/0/55/0	65/0/56/0	37/7/100/36
Window U-/SHGC	.55/.70	.55/.70	.55/.70	.55/.70
Wall R-value	0	0	0	10
Front Door	3070 wood	3070 wood	3070 wood	3070 wood
Rear Door	3070 wd/gls	3070 wd/gls	3070 wd/gls	3070 wd/gls
Right Door				2868 ins.
Storm Door	Yes, F&R	Yes, F&R	Yes, F&R	Yes, F&R
Air Leakage, ACH50	4.7	3.3	2.4	4.8
Mech. Vent., Run time	none	none	none	none-unused
Water Heater	50 gal. State	50 gal. Rheem	50 gal. State	50 gal. State
Model	CD065220RTV	RHEPro52	CD065220RTV	CD065220RTV
Energy Factor Use	.88 eff/4952k	4724 kWh	.88 eff/4952k	.88 eff/4952k
Location	Boiler Rm.	Boiler Rm.	Boiler Rm.	Boiler Rm.
Cooling Type	wall unit	wall unit	wall unit	wall unit
Manufacturer	Haier 24 × 15	Fedders Estar	Kenmore	Sharp
Model	2nd Gibson	A7U08W2A	30 × 24	ACQ189XPO
Location	1st rear and 2nd	2nd wall	2nd wall	2nd wall
Heating Type	Elec. Base.	Elec. Base.	Elec. Base.	Elec. Base.
Linear feet (@250 watts/foot)	32	21	23	36
Ceiling Heat (K, Kitchen; B, Bath)	K,B	K,B	B	
Thermostat Location	on wall	on units	on wall	on wall
Toilet flush (gallons per flush)	2.4	2.4	1.6	1.6
Shower/Sink Flow (gpm)	2.0/2.2	2.25/2.5	1.5/1.5	3.0/1.6

Figure 3. Wood frame brick building, front elevation, two units.

Figure 4. Wood frame brick building, front elevation, two units.

Table 3. Typical Building Specifications – Wood Frame with Brick-Veneer (FB-5 through FB-8).

Greenbelt Homes, Inc.

Date: Unit Code Feature/ Component	11/4/2010 FB-5 Before	FB-6 Before	FB-7 Before	FB-8 Before
Year Built	1941	1941	1941	1941
House Type	Town-End; C2.8	Town-Interior; C2.7	Town-Int; C2.6	Town-End Left
Structural Wall Type	2 × 4 Frame w/Brick	2 × 4 Frame w/Brick	2 × 4 Frame w/Brick	2 × 4 Frame w/Brick
Front	Southwest	Southwest	Southwest	Southwest
Finished ft^2, main	1,067	1,067	833	1,234
Addition, ft^2		70	n/a unconditioned	n/a unconditioned
No. Stories	2	2	2	2
Bedrooms	2	2	1	2
Baths	1	1.5	1	1
Ceiling Ht.	7 ft-11 in.	7 ft-11 in.		
Foundation	Unvented Crawlspace	Unvented Crawlspace	Unvented Crawlspace	Unvented Crawlspace
Insulated Walls	R-7.5	R-7.5	R-7.5	R-7.5
Heated	no	no	no	no
Vented	no	no	no	no
1st Floor	Structural slab 5"	Structural slab 5"	Structural slab 5"	Structural slab 5"
2nd Floor	2 × 8 joists	2 × 8 joists	2 × 8 joists	2 × 8 joists
Attic Ceiling	2 × 8	2 × 8	2 × 8	2 × 8
Attic R-value	R-19	R-19	R-19	R-19
Roof Rafter	2 × 6; 8/12	2 × 6; 8/12	2 × 6; 8/12	2 × 6; 8/12
Roof Sheathing	1 × 6 T&G	1 × 6 T&G	1 × 6 T&G	1 × 6 T&G
Structural Wall	2 × 4 Frame R-11?	2 × 4 Frame R-11?	2 × 4 Frame R-11?	2 × 4 Frame R-11?
Siding	Painted Brick Veneer	Painted Brick Veneer	Painted Brick Veneer	Painted Brick Veneer
Windows Material	vinyl	vinyl dbl glazed	vinyl dbl glazed	vinyl dg
Building Dimensions	26.67 × 20	26.67 × 20	19.17 × 20	33.83 × 20
Addition, Dim.		7x10		
Windows, ft^2	81/0/95/36	66/0/81/0	62/0/61/0	73/27/96/0
Window SF Front	.55/.75	66	62	73
Wall Sheathing	1 × 6 T&G	1 × 6 T&G	1 × 6 T&G	1 × 6 T&G
Wall R-value	R-11	R-11	R-11	R-11
Front Door	wood 3070	wood 3070	wood 3070	wood 3070
Rear Door	3070wd/gl	3070wd/gl	3070wd/gl	3070wd/gl
Storm Door	F&R	F&R	F&R	F&R
Air leakage, ACH50	6.1	8.8	11.9	5.5
Water Heater	State 50gal.	GE 50gal.	GE 50gal.	GE 50gal.
Model	P6522ORTZ	CD6522ORTV	CD6522ORTV	GE
Energy Factor/Use		4952 watts	4952 watts	CD6522ORTV
Location		Boiler Room	Boiler Room	Boiler Room
Cooling Type	Unknown	Friedrich	Amana	Carrier
Manufacturer		KM24L30-A	120722IA	XCE183D 8/05
Location	2nd hallway	2nd floor	2nd floor	2nd floor
Heating Type	Elec. Bsebd.	Elec. Bsebd.	Elec. Bsebd.	Elec. Bsebd.
Linear Ft. (@250watts/ft)	31	32	21	35
Ceiling Heat (K, kitchen; B, bath)	K, B	B	K, B	K, B
Toilet Flush (gal./flush)	2.4	1.6	2.0	2.4
Shower/Sink Flow	2.5/no test			3.0/1.8

Figure 5. Wood frame vinyl building, front elevation, three units.

Figure 6. Wood frame vinyl building, rear elevation, three units.

Table 4. Typical Building Specifications – Wood Frame with Vinyl Siding (FV-5 through FV-8).

Greenbelt Homes, Inc.

Date: Unit Code Feature/ Component or Status	11/5/2010 FV-5 Before	FV-6 Before	FV-7 Before	FV-8 Before
Year Built	1941	1941	1941	1941
House Type	Town-End G-2R	Town -Interior, G-2L	Town -Interior, G-2R	Town-End, G-2L
Structural Wall Type	Frame 2 × 4	Frame 2 × 4	Frame 2 × 4	Frame 2 × 4
Front	Northwest	Northwest	Northwest	Northwest
Finished ft^2, Main	792	792	792	792
Addition ft^2.	378	0	264	264
No. Stories	2	2	2	2
Bedrooms	2	2	2	2
Baths	1.5	1	1.5	1.5
Ceiling Ht.		96 in.	96 in.	96 in.
Foundation	Vented Crawl	Vented Crawl	Vented Crawl	Vented Crawl
Insulated Floor	R-13	R-13	R-13	R-13
Heated	No	No	No	No
Vented	8 × 16 vents (2)	8 × 16 vents (2)	8 × 16 vents (2)	8 × 16 vents (2)
1st Floor	2 × 8 joists	2 × 8 joists	2 × 8 joists	2 × 8 joists
2nd Floor	2 × 8	2 × 8	2 × 8	2 × 8
Attic Floor	2 × 6	2 × 6	2 × 6	2 × 6
Attic R-value	18.85	18.85	18.85	18.85
Roof Rafter	2 × 6	2 × 6	2 × 6	2 × 6
Roof Sheathing	1 × 8 T&G	1 × 8 T&G	1 × 8 T&G	1 × 8 T&G
Attic R-value	16	16	16	16
Building Dimensions	22 × 18	22 × 18	22 × 18	22 × 18
Addition Dimensions	21 × 18	n/a	22 × 12	22 × 12
Structural Wall	2 × 4	2 × 4	2 × 4	2 × 4
Siding	Vinyl / 1/2" EPS	Vinyl / 1/2" EPS	Vinyl / 1/2" EPS	Vinyl / 1/2" EPS
Windows Material	Vinyl - 1980	Vinyl - 1980	Vinyl – 1980	Vinyl - 1980
Windows, ft^2	45/26/117/0	34/0/95/0	33/0/90/0	33/0/67/40
Window U-/SHGC	.55/.75 & .29/.21	.55/.75	.55/.75	.55/.75
Wall Sheathing	1 × 8 T&G	1 × 8 T&G	1 × 8 T&G	1 × 8 T&G
Wall R-value	R-11	R-11	R-11	R-11
Front Door	3070 wd 1/2 glass and storm	3070 wd 1/2 glass and storm	3070 wd 1/2 glass and storm	3070 wd 1/2 glass and storm
Addition Front Door	Ins. 3068	none	None	none
Rear Door	Ins. 21068	3068 Vinyl	3068 wood	none
Rear/Side Storm Door	no	yes	No	yes
Right Door	none	none	None	Ins. 21068
Air Leakage, ACH50	14.0	14.8	10.1	11.2
Mech. Vent., run time	no	no	No	no
Water Heater	50/State	50/Ruud	50/State	50/Ruud
Model	P65220RT2	RU 0902227702	P65220RT2	PF52C
Energy Factor Use	4,946	4,992	4,946	4,992
Location		2nd floor near bath	Powder Room	
Cooling Type	NIHD1406A (heat pump)	Rear BR wdw LG71EX0953	through wall A/C	through wall A/C
Manufacturer	York	Hallwdw GE AEH08FMG1	Unknown	unknown 24 in. × 12 in.
Efficiency		9.8 EER; 820 watts	air infiltrating through	
Location	Stored in attic	Front through window		1st floor - rear
Removed out of season?		no		
Heating Type	Heat Pump, York;	Electric Baseboard	Electric Baseboard	Electric Baseboard
Linear feet (@250 watts/foot)	18	19	20	20
Ceiling Heat (K, Kitchen; B, Bath)	B	K,B	B	K,B
Thermostat Location	interior walls	interior walls	interior walls	interior walls
Toilet flush (gal. per)	1.6	1.6	2.4	1.6
Shower/Sink Flow (gpm)	1.6/1.6	1.5/1.6	2/1.4	3.5/2.2

4 Simulation Results and Energy Upgrade Cost Estimates

The next step of Phase 1 was to use the baseline conditions to develop energy simulations and cost estimates for the energy upgrade recommendations. A simulation tool, BEopt[2] v1.01, was used to calculate annual energy usage based on the pre-retrofit conditions noted. GHI provided support data about the pilot homes including limited architectural plans, general information on wall and roof composition that was not visible through inspection, a copy of the Reserves Policies and Analysis (dated 9/15/2008)[3], and other background information. Equipment specifications, dimensions, building orientation, and other apparent features were recorded by NAHB Research Center staff during site walk-through evaluations and short-term testing of the pilot project units.

A minimum of one end and one interior unit was modeled in each building. Savings and costs for the whole building (four units) were estimated from these outcomes. Several buildings, such as BV-3 through BV-6 and FV-1 through FV-4 were made up of unique homes, thus modeling more than two of the four units was warranted. The global assumptions underlying the modeling were developed in consultation with GHI, as these economic factors are common to the administration's decision making. Air infiltration testing results and global modeling assumptions that were used in the compilation of upgrade features and costs are shown in Table 5 and Table 6, respectively.

House leakage was measured using multipoint and single-point testing in accordance with ASTM E779-10 and ASTM E1827-96, depressurization only. Leakage to outdoors was determined using a pressure equalization method utilizing two blower door setups. Starting with an end unit, blower doors were set up in this first unit and the adjacent second unit. The first unit was depressurized to measure total leakage and then the second unit was depressurized at the same time and to the same value to cancel leakage between units and thereby showed leakage to outdoors for the first unit. The difference provided the leakage between the first and second units. The blower door from the first unit was then installed in the third unit. The second unit was depressurized to measure total leakage, the third unit was depressurized to cancel out leakage between the second and third units, and the leakage between the first and second units from the previous test was deducted to determine the leakage to outdoors for the second unit. The blower door from the second unit was then installed in the fourth unit and the leakage to outdoors for the third unit was determined in the same way. The fourth unit simply needed the total leakage to determine leakage to outdoors because the leakage between the third and fourth units was already known.

[2] *BEopt™ Software*, NREL, http://www.nrel.gov/buildings/energy_analysis.html.

[3] Developed and maintained by GHI, the Policies and Analysis outlines the reserve fund for improvements by each GHI home type.

Table 5. Tested Air Infiltration.

Building	Unit	Location	Area	Volume	Net Leakage to Outdoors (ACH50)	% of Total Leakage to Adjacent Unit(s)
Block	B-1	End	1,168	9,344	4.7	16%
	B-2	Interior	844	6,752	3.3	32%
	B-3	Interior	844	6,752	2.4	42%
	B-4	End	1,245	9,960	4.8	16%
	B-5	Interior	844	6,752	4.3	23%
	B-6	Interior	921	7,368	8.4	9%
Block w/Vinyl	BV-1	End	1,528	12,224	7.2	8%
	BV-2	End	1,245	9,960	4.8	11%
	BV-3	End	1,112	8,896	7.5	16%
	BV-4	Interior	1,080	8,640	3.5	37%
	BV-5	Interior	1,596	12,768	4.3	18%
	BV-6	End	1,596	12,768	4.0	12%
Frame Brick	FB-1	End	1,080	8,640	10.4	18%
	FB-2	Interior	1,080	8,640	6.8	27%
	FB-3	Interior	1,080	8,640	7.4	n/a
	FB-4	End	1,080	8,640	8.0	16%
	FB-5	End	1,080	8,640	6.1	28%
	FB-6	Interior	1,136	9,088	8.8	25%
	FB-7	Interior	841	7,288	11.9	18%
	FB-8	End	1,173	9,384	5.5	20%
Wood frame Vinyl	FV-1	End	936	7,488	9.7	12%
	FV-2	Interior	782	6,256	13.1	14%
	FV-3	Interior	782	6,256	9.3	29%
	FV-4	End	870	6,960	14.1	15%
	FV-5	End	1,170	9,360	14.0	7%
	FV-6	Interior	792	6,336	14.8	9%
	FV-7	Interior	1,056	8,448	10.1	15%
	FV-8	End	1,056	8,448	11.2	13%

Table 6. Global Simulation Parameters.

Parameter	Value
Annual Rate of Inflation [A]	3.30%
Discount Rate [A]	5.00%
Interest Rate [B]	7.00%
Fuel Escalation Rate [B]	0.50%
Heating Set Point	68 °F
Air/Conditioning Set Point	not modeled
Number of Occupants per Home	Number of Bedrooms on the Architectural Plans
Cost of Electricity	$0.15/kWh

[A] Provided by GHI staff
[B] Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2010, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709, NISTIR 85-3273-25.
Office of Management and Budget Circular A-94 Appendix C, Revised December 2010.
Office of Management and Budget, Fiscal Year 2010 Analytical Perspectives, Budget of the U.S. Government.

The block buildings were consistently of tighter construction than any of the others. Block buildings that tested higher than 5ACH50 had wood frame additions that likely accounted for the higher leakage. (Two of the homes that tested for leakage of 4.8ACH50 also had additions.) Both the wood frame brick and wood frame vinyl buildings are balloon framed of 2 × 4s with 1 × 6 horizontal board floor, wall, and roof sheathing. Thus, the wood frame buildings' construction significantly contributes to the air infiltration pathways. (The wood frame brick units have poured concrete foundations and structural first floor slabs, which likely account for the tighter average construction of these compared to the wood frame vinyl buildings.)

The units located in block buildings are of the tightest construction yet built of the least thermally-resistant materials because only the roofs and crawlspace walls have insulation (R-26 and R-5, approximately). Software simulations confirmed that the block buildings were estimated to have the highest annual energy usage load, and therefore, the best outlook for energy efficiency improvement with the addition of wall insulation.

GHI's Buildings Committee saw the opportunity to add exterior wall insulation to the homes with the pending siding, window, and door replacement scheduled to begin in 2015. The plan included bringing the block buildings' wall insulation in line with that of frame buildings (R-11 to R-13) and investigating the performance versus cost of adding additional exterior insulation to the frame brick and frame vinyl buildings. The community consensus was that energy upgrades should be accomplished with minimal inconvenience to the occupant, thus access from the outside was emphasized.

The completion of conditioned crawlspace wall insulation in the block and frame brick buildings, addition of ventilated crawlspace ceiling insulation in the frame vinyl buildings, and addition of air seal and insulation in the attics of frame brick and vinyl buildings were added to simulations to complete each whole building envelope energy efficiency upgrade. Table 7 covers the presentation that the Buildings Committee shared with the pilot program participant owners. Numbers have been compiled by building (set of four townhomes). Row 1 indicates building type and cladding alternative. Row 2 indicates the added wall R-value. Column 1 outlines the features of the upgrade which are detailed more extensively in Appendix C.

Table 7. Estimated Costs Per Building for Retrofits Proposed for the GHI Pilot Program.

Building Construction	Masonry Block (EIFS)[B]	Masonry Block (EIFS With Stencil)[B]	Masonry Block Fiber Cement[B,C]	Masonry Block with added Vinyl Siding[B]	Masonry Block Vinyl Siding[B]	Masonry Brick Frame Buildings	Frame Vinyl-Sided Buildings	Frame Fiber Cement Buildings[C]	Frame Vinyl-Sided Buildings
Approximate Wall R-value	R-12	R-12	R-12	R-12	R-12	R13ex[F]	R13exF+R-7	R13exF+R-7	R13exF+R-12
Unit Code	B	B	B	B	BV	FB	FV	FV	FV
Installed Features									
Cladding & Insulation	$39,473	$50,659	$53,333	$26,019	$29,822		$25,000	$36,576	$28,638
Crawlspace/Slab Insulation	$3,076	$3,076	$3,076	$3,076	$3,076	$3,076			
Windows	$16,400	$16,400	$16,400	$16,400	$16,400	$16,400	$16,400	$16,400	$16,400
Exterior Doors	$5,200	$5,200	$5,200	$5,200	$5,200	$5,200	$4,280	$4,280	$4,280
Attic Insulation						$7,392	$6,037	$6,037	$6,037
Floor Insulation[D]							$7,729	$7,729	$7,729
Subtotal	$64,149	$75,335	$78,009	$50,695	$54,498	$32,069	$59,446	$71,022	$63,084
	Less Reserves Per GHI 2008 Report								
Vinyl Siding							($13,860)	($13,860)	($13,860)
Windows	($16,400)	($16,400)	($16,400)	($16,400)	($16,400)	($16,400)	($16,400)	($16,400)	($16,400)
Doors	($5,200)	($5,200)	($5,200)	($5,200)	($5,200)	($5,200)	($4,280)	($4,280)	($4,280)
Net Cost after Reserves are Applied to Subtotal	$42,549	$53,735	$56,409	$29,095	$32,898	$10,469	$24,906	$36,482	$28,544
	Estimated Annual Cost of Energy Efficiency Features and Building Cladding not Reserved								
Annual Mortage (Net of Reserves), 5%	($3,397)	($4,290)	($4,503)	($2,323)	($2,626)	($836)	($1,988)	($2,913)	($2,279)
Average Annual Mortage Interest Deduction (30 years @ 28% rate)	$554	$700	$734	$379	$428	$136	$324	$475	$372
Cladding, (Annual Maintenance - Maintenance Saved)[G]	($228)	($228)	$595					($571)	
Estimated Annual Energy Savings[B]	$2,680	$2,680	$2,680	$2,680	$2,058	$702	$1,331	$1,331	$1,621
Present Value of Mortgage Payment (30 year period)[H]	$17,415	$6,516	$22,768	$35,743	$17,165	$6,588	$7,567	($16,793)	$10,965
Present Value of Cash Payment (30 year period)[I]	$16,321	$5,135	$21,318	$34,995	$16,319	$6,319	$6,926	($17,731)	$10,231
Simple Payback in Years[E]	17.4	21.9	17.2	10.9	16.0	14.9	18.7	48.0	17.6

[B]EIFS and fiber cement shown with B1-B4 savings. Masonry block with vinyl siding added is shown with B1-4 savings. Masonry block vinyl-sided building shown with BV3-BV6 savings (a building currently clad with vinyl siding.) Frame brick modeled after FB-1 & 2. Frame vinyl-sided and frame fiber cement modeled after FV1-4. BV-5 and BV-6 (walkout basements) were modeled with R-13 adjacent the crawlspace and end walls. No cost to include this has been included in the tables. The B building with added vinyl is a model of a block building with vinyl siding added. The difference in installation cost between B and BV buildings is the cost to remove and dispose of the existing vinyl cladding. Note that there is also a modeled difference in energy savings between a masonry block building without vinyl siding (B) vs the BV building with existing vinyl siding installed.

[C]The fiber cement product estimated for the B buildings carries a 50-year warranty on the material in the stone/brick-look finish. The fiber cement product estimated for the FV buildings is James Harde horizontal lap siding and its maintenance cost covers painting every 10 years.

[D]Floor insulation in the FV buildings is shown net of allocated costs to remove and install R-19 FG batts ($6-$1.44 = $4.56 per sf), the cost of installing the foam insulation is estimated at $10,170.

[E]The Net Cost after Reserves are Applied to the Subtotal divided by the Estimated Annual Energy Savings minus the increased annual maintenance.

[F]R13ex refers to an existing frame wall with R-13 already retrofitted in the wall cavities (1980's upgrade program)

[G]Annual maintenance includes new maintenance costs for the installed cladding materials minus the current maintenance costs for the building.

[H]The Present Value of the Cash flow based on a home mortgage to finance the upgrades. The Present Value includes a calculation of the mortgage interest tax deduction.

[I]The Present Value is calculated based on the cash flow of a one-time investment in the upgrades and annual savings and net maintenance costs.

5 Phase 1 Energy and Environmental Monitoring

In addition to the baseline conditions and simulations, a monitoring effort was implemented to quantify the energy performance of the pilot buildings and to establish the pre-retrofit energy usage in the homes. Ongoing data collection for energy, temperature, and relative humidity (RH) is being logged in 15-minute intervals in the buildings. The equipment will remain in place through all three phases of the pilot program which is expected to encompass three heating seasons. Research Center staff performs weekly site visits to download data from loggers and record data from utility meters. Programmed equipment downloads log energy data for processing and storage at the National Renewable Energy Laboratory (NREL, a Department of Energy laboratory and partner in the pilot program). The data is processed biannually and summarized for each heating season. Table 8 indicates the areas of interest, data collection devices, and expected use for the information gathered during the monitoring phases of the pilot study.

Table 8. Monitoring the Pre-Retrofit Units.

Parameter of Interest	Test Method	Purpose
Whole House Electric Energy Use	Current transducer and recording devices	• Record whole house electricity use • Develop use profile for winter months • Integrate energy use data with general weather data • Provide comparison with energy simulation results
Space and Water Heating and Dryer Energy Use	Current transducers and recording devices	• Proportion heating energy use as a fraction of total energy use • Summarize total internal heating energy and major loads
Indoor Environment	Temperature/Relative Humidity sensors – 2 to 4 devices per unit, located 1st and 2nd floors	• Provide indoor conditions for energy analysis • Assess interior moisture loading/dilution • Support ventilation option development and control • Assess range of indoor temperature settings
Foundation Environment	Temperature/humidity loggers, at least 2 sensors in crawlspace	• Provide crawlspace foundation conditions for energy analysis • Assess potential moisture issues • Compare with air sealing/ventilation/insulation options in pilot renovation plan

Weather data has been obtained from a National Weather Service station located at College Park Airport, within five miles of the GHI project center; station KCGS.[4] A shielded outdoor temperature and RH sensor was installed at the GHI office on Hamilton Place. The data on site is very similar to that from the weather station. Weather data is used to calculate heating degree-days and directly for use in the analysis of the energy performance of homes.

[4] The station was selected for its proximity to the project and the fact that it was likely to be well-maintained due to its location at a busy municipal airport. See http://www.wunderground.com.

5.1 Data Collection Equipment

Each of the seven buildings in the GHI pilot study were fitted with Onset Computer wireless ZW sensors[5] to record temperature or RH, placed in several locations and on each level inside the units. In many cases, two sensors have been placed on each level in rooms on each side of the central stairway. The sensors are designed to record the data in a preset interval and transmit the data wirelessly to a receiver located in the crawlspace. Due to varying signal reliability, ZW routers, which also function as sensors, were installed in crawlspaces to boost the signal from the individual sensors. Data transmitted from the individual sensors to the central receiver is retrieved weekly via a site visit and a direct computer link to the receiver (see Figure 7) to retrieve the stored data.

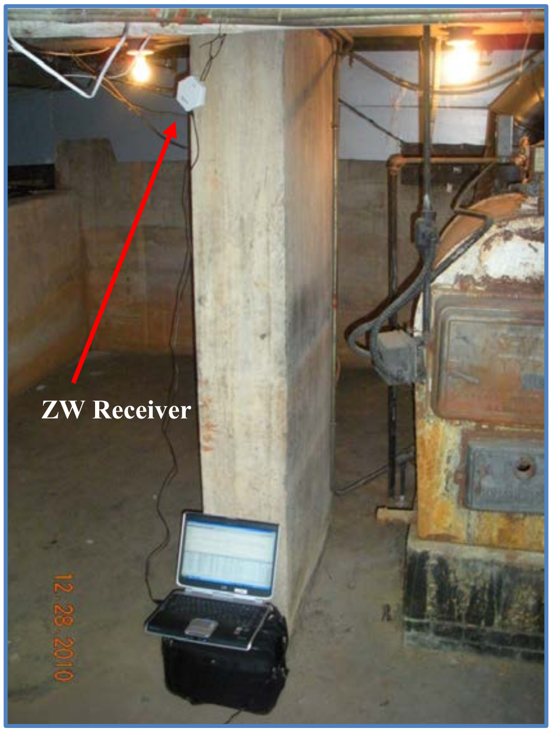

Figure 7. Onset receiver (data download in progress).

The homes in three selected buildings, B-1 through B-4, FB-5 through FB-8, and FV-5 through FV-8, are equipped with WattNode watt hour transducers[6] which were installed in the electrical panel boxes of each home in the fall of 2010. The transducers monitor the energy use of the primary heating circuits, dryer, water heater, and whole house. Electric usage is recorded by the transducers as a pulse output proportional to the electric watt-hours consumed by equipment connected to the circuit. Transducer signal pulse data is recorded on a per minute basis by a data logger, also located in the crawlspace/boiler rooms beneath the buildings. The remaining four buildings in the pilot program were outfitted with watt-hour transducers in May of 2011. The monitoring plan calls for all energy transducers to remain in place through two or more heating seasons. Due to lack of electric panel access in two of the 28 pilot homes, a supplemental whole-house energy monitor was installed at the main electric distribution equipment to record whole house electric use. In addition, electric meter readings were obtained on a weekly basis for all homes so that a comparison of energy use could be made following the first heating season, given that not all homes were monitored in detail for electric energy consumption.

5.2 Measurement of Energy Use

The GHI pilot program is designed to measure the energy consumption, primarily in heating seasons, and ultimately evaluate the affordability of retrofit technologies selected specifically for each of the GHI building types in the pilot project. The recommended building envelope retrofit technologies selected for the energy upgrade have been based in part on the use of software simulations to estimate energy use in the buildings before and after the upgrade installations.[7] Homes within the pilot project group have been equipped to compile actual data that can be

[5] Manufacturer, Onset Computer, http://www.onsetcomp.com
[6] Continental Control Systems, LLC, manufacturer, http://www.ccontrolsys.com/w/Advanced_Pulse_WattNode
[7] NAHB Research Center, *Greenbelt Homes Inc. Pilot Project Energy Analysis*, April 2011. See Appendix C

analyzed both to the simulation estimates and to the actual ongoing measured results as the retrofits are implemented in each phase of the energy efficiency retrofit program.

Pilot program homeowners were also asked to submit utility bills covering the 2009-2010 heating season for use as an approximate check of energy model accuracy. The utility bills and the recorded data have already served as a "reasonableness" check of software model outcomes for establishing baseline conditions used for the building envelope energy efficiency recommendations. At the pilot program completion, the measured utility data, along with utility bills, will provide a straightforward method for evaluating realized total energy and cost savings relative to retrofit costs and to provide a comparison with the cost savings estimated by the software models.

Another commonly used method of isolating the heating and cooling energy used within a home lies in analyzing the utility bills on an annual basis. Where each monthly invoice indicates actual usage for the period, utility bills will generally show that during April-May and September-October in this climate, energy use is lower than the other months due to a decreased use of space conditioning energy. Usage in these "shoulder" or "swing" months is a good indication of the basic electrical loads within a home for water heating, lighting, appliance, and miscellaneous loads. The observed "base" load can then be subtracted from each month's usage to determine the electric energy attributable to heating and cooling. As a comparison, the watt-hour transducers that were installed in the electric panels measure the energy use of the circuits supplying the baseboard and ceiling heaters.[8] Table 9 summarizes energy usage data for the pilot program homes from November 2010 through March 2011 and incorporating various analytical methods:

- Heating energy based on previous years' utility meter readings multiplied by estimated percentage of heating use (column 9, available for all homes)
- Measured heating use for a subset of homes (column 11)
- Estimated heating use predicted by simulation software (column 12).

The data presented in Table 9 compares estimated heating energy based on actual whole-house energy use measurements, and for 12 of the 28 homes in the study (reduced by one month of heating energy, October 2010) the direct measured heating energy to the software heating energy use estimates. As noted by the measured data results, each building equipped with transducers appears to have an outlier—a unit with temperature and electric usage much lower than expected, indicating the home may be unoccupied. As far as the severity of the winter heating data, for the period measured (November 2010 – March 2011) the actual heating degree day (HDD) for the period was 1% higher than the long-term average data used in the simulation software. In addition to the various electricity consumption analyses that have been outlined in this report, energy use will be compared relative to the outdoor temperature in each year of the study so that seasonal variations in the seasonal weather patterns will not distort real results.

[8] Not all ceiling heaters were able to be monitored. Electrical energy to dryers and water heaters was also measured, as these can be sources of indoor heat gain; supplementing the baseboard heaters. (Supplemental portable space heaters used on other circuits also provide heat gains to the home; however this data is not captured directly.) In homes where the water heaters are not located within the units, the water heater energy is not added to the indoor heat gains. Water heater data may be used to evaluate the savings from use of more efficiency water heating equipment in subsequent phases of the project.

Table 9. Pilot Study Homes Energy Usage Summary.

Heating Season Summary Energy Data Table[1]

Evaluation Period – November 2010 - March 2011 (October heating not included)

Unit Code	Unit Type	Floor Area (ft^2)	Days in Period	Meter Electric Use, kWh	Cost @ $0.15	Average Cost/day Heating Season	Utility Meter Estimated		Data Logger Estimate		Simulated Heating Energy kWh
							Heating Percent of Total	Heating Energy kWh	Heating Percent of Total	Heating Energy kWh	
B-1	Block	1168	169	12,580	$1,887	$11.17	69%	8,707	72.4%	9,108	9,773
B-2	Block	844	169	8,260	$1,239	$7.33	82%	6,794	79.8%	6,591	6,113
B-3	Block	844	169	2,390	$359	$2.12	82%	1,966	35.5%	848	6,113
B-4	Block	1245	169	16,620	$2,493	$14.75	69%	11,503	80.8%	13,429	9,773
FB-5	Frame/Brick	1080	171	8,840	$1,326	$7.75	64%	5,691	72.5%	6,409	5,587
FB-6	Frame/Brick	1136	171	10,392	$1,559	$9.12	46%	4,730	43.3%	4,500	3,880
FB-7	Frame/Brick	911	171	1,983	$297	$1.74	46%	903	65.8%	1,305	3,880
FB-8	Frame/Brick	1250	171	9,600	$1,440	$8.42	66%	6,379	71.2%	6,835	5,587
BV-1	Block/Vinyl	1528	171	12,120	$1,818	$10.63	67%	8,068			7,660
B-5	Block	844	171	4,140	$621	$3.63	60%	2,503			6,113
B-6	Block	921	171	6,746	$1,012	$5.92	73%	4,935			6,113
BV-2	Block/Vinyl	1245	171	9,190	$1,379	$8.06	83%	7,615			9,020
BV-3	Block/Vinyl	1112	166	11,020	$1,653	$9.96	62%	6,876			7,660
BV-4	Block/Vinyl	1080	166	5,455	$818	$4.93	51%	2,794			5,220
BV-5	Block/Vinyl	1596	166	13,605	$2,041	$12.29	64%	8,657			7,447
BV-6	Block/Vinyl	1596	166	10,500	$1,575	$9.49	62%	6,552			9,020
FB-1	Frame/Brick	1080	169	10,100	$1,515	$8.96	69%	6,928			5,587
FB-2	Frame/Brick	1080	169	5,900	$885	$5.24	69%	4,096			3,880
FB-3	Frame/Brick	1080	169	7,865	$1,180	$6.98	60%	4,695			3,880
FB-4	Frame/Brick	1080	169	3,710	$557	$3.29	70%	2,608			5,587
FV-1	Frame/Vinyl	936	170	5,705	$856	$5.03	67%	3,842			5,387
FV-2	Frame/Vinyl	782	170	6,589	$988	$5.81	53%	3,518			2,787
FV-3	Frame/Vinyl	782	170	5,890	$884	$5.20	53%	3,145			2,787
FV-4	Frame/Vinyl	870	170	7,760	$1,164	$6.85	65%	5,052			5,240
FV-5	Frame/Vinyl	1170	166	8,105	$1,216	$7.32	65%	5,305	71.2%	5,771	6,013
FV-6	Frame/Vinyl	792	166	5,835	$875	$5.27	45%	2,649	49.4%	2,882	3,570
FV-7	Frame/Vinyl	1056	166	9,220	$1,383	$8.33	56%	5,151	43.0%	3,965	4,760
FV-8	Frame/Vinyl	1056	166	6,570	$986	$5.94	65%	4,282	71.5%	4,698	6,013

[1] Notes:
Simulated heating energy based on a constant 68°F interior temperature for the whole house
FB7 unoccupied, BV4 unoccupied for partial period
B3, B6, BV2, B6, FV1. FV8 have atypical heating set-points and/or total use
Estimated percent meter heating energy based on utility bills for previous year where available
Simulation Heating Energy is for full heating season
B ≡ Block Buildings; BV ≡ Block Vinyl Buildings; FB ≡ Frame Brick Buildings; FV ≡ Frame Vinyl Buildings

The summary energy consumption details for the first heating season of the GHI pilot program indicate a wide range of energy usage in the homes:

1. Based on 2009-2010 heating season utility bills and estimates for non-heating uses, the heating energy as portion of total energy is ranges from 45% to 83% (Table 9, column 8).

2. Applying these estimated heating use percentages to the recorded utility meter data for the 2010-2011 (Table 9, column 9) heating season shows estimated heating use for the period from November through March of between 2,503 kWh and 8,707 kWh, a factor of about 3.5 (excluding the homes that are primarily unoccupied and one home where the energy use is well above all other homes).

3. A comparison of the estimated heating energy based on meter readings to the 12 homes where data logger data is available shows an average of 102% data logger to meter readings (Table 9, column 11 and column 9) across the 12 homes and a standard deviation of 24%. The large standard deviation indicates that there are outlier homes, as is known. Removing the three outlier homes from the set shows an average energy use ratio data logger to meter estimate again of 102% with a standard deviation of 11%, indicating a very good approximation of the heating energy based on utility meter readings.

4. When comparing the simulation data estimates to the utility meter readings, the results are more varied with an average ratio of 148% for across all of the homes and a standard deviation of 109%. When removing the three outlier homes from the data set, the average ratio of simulated to meter energy use is 106% with a standard deviation of 21%, indicating a somewhat good approximation of energy use by the homes from the simulation estimates.

Figure 8 charts the data as described in the four summary points above.

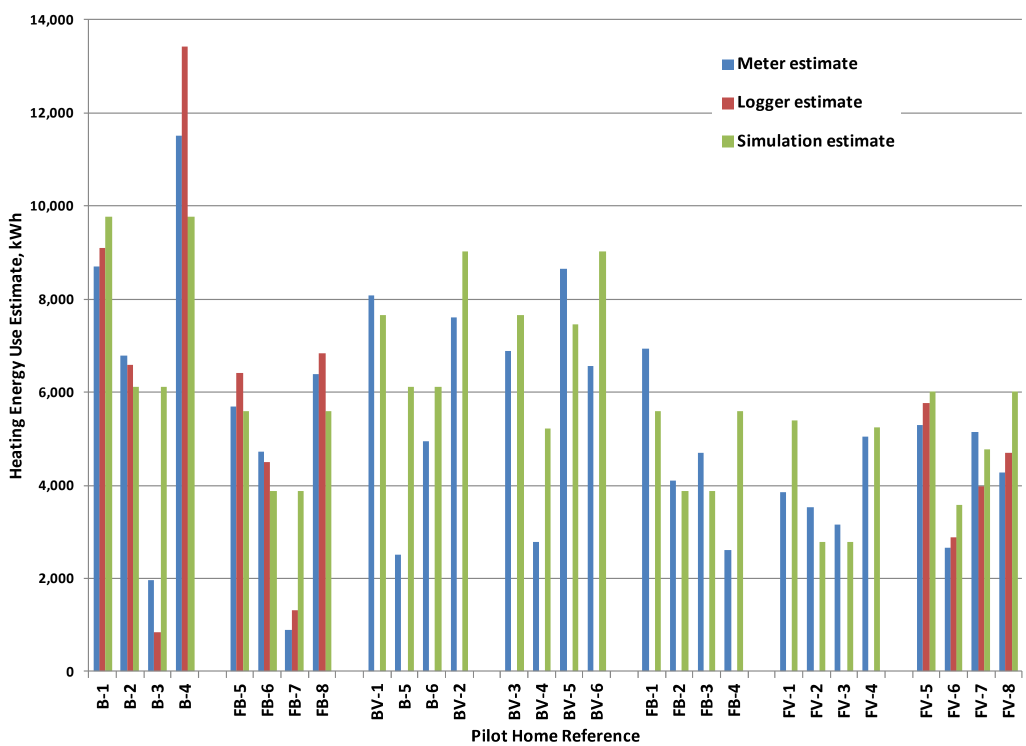

Figure 8. Summary comparison of heating energy use estimates for the heating period November 2010 – March 2011.

The average energy use (meter estimates) for all homes for the heating period from November 2010 to March 2011 is 64% of the total energy use in the homes. Table 10 summarizes the meter estimate heating energy use data based on building type.

Table 10. Average Heating Energy for Building Types.

Home Type	Heating Energy, kWh	Size, ft^2	Ratio, kWh/sf
Average Block	6,068	978	6.21
Average Block/Vinyl	6,760	1,360	4.97
Average Frame/Brick	5,018	1,112	4.51
Average Frame/Vinyl	4,118	931	4.43

6 Summary Indoor Temperature and Relative Humidity

Additional long-term monitoring includes indoor temperature and RH. The indoor temperature monitoring period for the 2010/2011 heating season started in early December for some homes and late January for the remaining homes and extended through most of April, 2011. The ending dates coincide with the last data download prior to commencing data analysis for the second report that was submitted to GHI, as well as a weather warming trend where daily highs started averaging in the 70's (°F) and lows stayed above 50°F. Table 11 is a summary of the actual indoor temperatures recorded for the periods.

Table 11. Indoor Temperature/Humidity Conditions during the 2010/2011 Heating Season.

Unit I.D.	Front Faces	Sensor Data Time Period		Days in Period	Average Daily Temperatures by Floor Level				Average Household Indoor Conditions		
					First Floor Temperature		Second Floor Temperature				
		From	To		Average (°F)	Average Minimum (°F)	Average (°F)	Average Minimum (°F)	Temperature (°F)	Temperature Standard Deviation, °F	Percent Relative Humidity
B-1	South	11/18/2010	4/26/2011	160	70.0	68.5	68.6	67.7	69.3	2.1	n/a
B-2	South	11/18/2010	4/26/2011	160	69.6	68.2	68.1	67.1	68.9	2.2	n/a
B-3	South	11/18/2010	4/26/2011	160	61.7	60.0	61.6	60.5	61.6	4.4	67.4
B-4	South	11/18/2010	4/26/2011	160	72.3	70.7	68.5	67.8	70.4	4.1	36.5
BV-1	North	1/31/2011	4/26/2011	86	66.4	64.4	64.8	63.4	65.6	3.1	52.8
B-5	North	1/31/2011	4/26/2011	86	59.0	57.0	59.0	57.5	59.0	4.0	62.3
B-6	North	1/31/2011	4/26/2011	86	60.8	59.7	63.2	61.7	62.0	4.5	55.1
BV-2	North	1/31/2011	4/26/2011	86	63.8	62.2	64.4	63.2	64.1	6.7	41.0
BV-3	Northeast	1/28/2011	4/26/2011	89	68.0	66.4	70.3	69.4	69.1	2.9	43.9
BV-4	Northeast	1/28/2011	4/26/2011	89	64.0	62.2	64.2	63.5	64.1	2.9	54.6
BV-5	Northeast	1/28/2011	4/26/2011	89	74.6	72.6	73.8	72.8	70.4*	5.2	31.7
BV-5 - Bsmt.					62.8	61.7					
BV-6	Northeast	1/28/2011	4/26/2011	89	68.0	65.8	66.6	65.6	66.2*	3.3	43.3
BV-6 - Bsmt.					63.9	62.3					
FB-1	South	1/31/2011	4/26/2011	86	70.0	68.2	69.4	68.1	69.7	4.6	30.2
FB-2	South	1/31/2011	4/26/2011	86	64.8	63.0	64.9	63.5	64.9	4.2	35.6
FB-3	South	1/31/2011	4/26/2011	86	64.5	62.8	67.3	65.6	65.9	4.8	44.0
FB-4	South	1/31/2011	4/26/2011	86	57.7	55.6	58.3	56.6	58.0	6.6	46.5
FB-5	Southwest	12/14/2010	4/26/2011	134	67.1	65.2	64.6	63.2	65.8	3.3	37.9
FB-6	Southwest	12/14/2010	4/26/2011	134	65.0	62.5	65.6	62.5	65.3	2.5	41.1
FB-7	Southwest	12/14/2010	4/26/2011	134	55.2	54.2	55.2	54.3	55.2	8.0	38.6
FB-8	Southwest	12/14/2010	4/26/2011	134	63.2	61.8	68.2	65.2	65.7	3.7	42.0
FV-1	North	1/31/2011	4/26/2011	86	60.5	54.9	63.1	59.9	61.8	5.4	46.5
FV-2	North	1/31/2011	4/26/2011	86	68.9	64.8	68.5	66.3	68.7	4.8	36.8
FV-3	North	1/31/2011	4/26/2011	86	68.2	64.7	67.7	65.4	68.0	4.8	40.3
FV-4	North	1/31/2011	4/26/2011	86	67.2	62.0	68.5	65.8	67.8	4.8	39.9
FV-5	Northwest	12/15/2010	4/26/2011	133	67.8	64.0	69.2	67.2	68.5	2.1	34/33**
FV-6	Northwest	12/15/2010	4/26/2011	133	65.0	62.2	65.5	63.6	65.2	3.4	39.8
FV-7	Northwest	12/15/2010	4/26/2011	133	68.1	65.6	66.4	63.5	67.2	3.5	39.9
FV-8	Northwest	12/15/2010	4/26/2011	133	64.6	62.7	61.3	59.6	62.9	3.8	39/44**

*Average includes Basement; **First Floor/Second Floor RH; n/a = data not available

B ≡ Block Buildings; BV ≡ Block Vinyl Buildings; FB ≡ Frame Brick Buildings; FV ≡ Frame Vinyl Buildings

Table 11 indicates a range of indoor temperatures in the pilot program homes between 58ºF to 70°F, except for FB-7 which was unoccupied and unheated for part of the season and has the lowest daily average temperature of 55°F and highest standard deviation. Gauged by the standard deviation calculated for the other homes in the group, the daily indoor average temperature swings are modest. The most significant finding, based on the recorded building conditions, is that 64% of the occupied units maintained average indoor winter temperatures less than 68°F; a threshold generally viewed as the minimum set point for energy simulations (and comfort) and that which was used for the GHI pilot program simulations.

7 Detailed Data Summary Energy Use: Measured and Utility Meter Readings for Three Building Types

The baseline performance of each of the 28 homes was determined from the monitored data and the utility meter readings for each of the building types including block, wood frame with brick façade, and wood frame with vinyl siding.

7.1 Masonry Block Building – Units B-1, B-2, B-3, B-4

The masonry block building was the first equipped with sensors and transducers. Data was recorded for a five month period—a large portion of the 2010/2011 heating season. By chance, two adjacent units in the building maintained similar average indoor temperatures of 68.1°F (B1) and 68.9°F (B2) during the period. Records show one unit in the building at an average indoor temperature of 70.4°F (B4), and another one at 61.6°F (B3). The energy use for the whole house and just heating energy use relative to the difference between daily outdoor and indoor temperatures is plotted on the graphs in Figure 9 through Figure 12, which represent the four houses in Building B. In most homes, the relationship between the heating energy and the temperature difference is expected to be much more linear than between the whole house energy use and the temperature difference. However, in this building type the relationship is generally consistent due in part to the large heating percentage of the total energy use. Whole house energy use is included to indicate the daily consumption levels for the home.

All of the graphs show increasing energy use as the temperature difference between outdoors and indoors increases. The energy use for heating in masonry homes such as these may be somewhat out-of-sync with weather patterns because the large thermal mass of the building tends to cause a lag in transferring thermal energy across the walls and floors. However, use of a daily summary is necessary when actual measured temperature data is used because homes are usually operated on a cycle of usage patterns that recurs every 24 hours (diurnal).

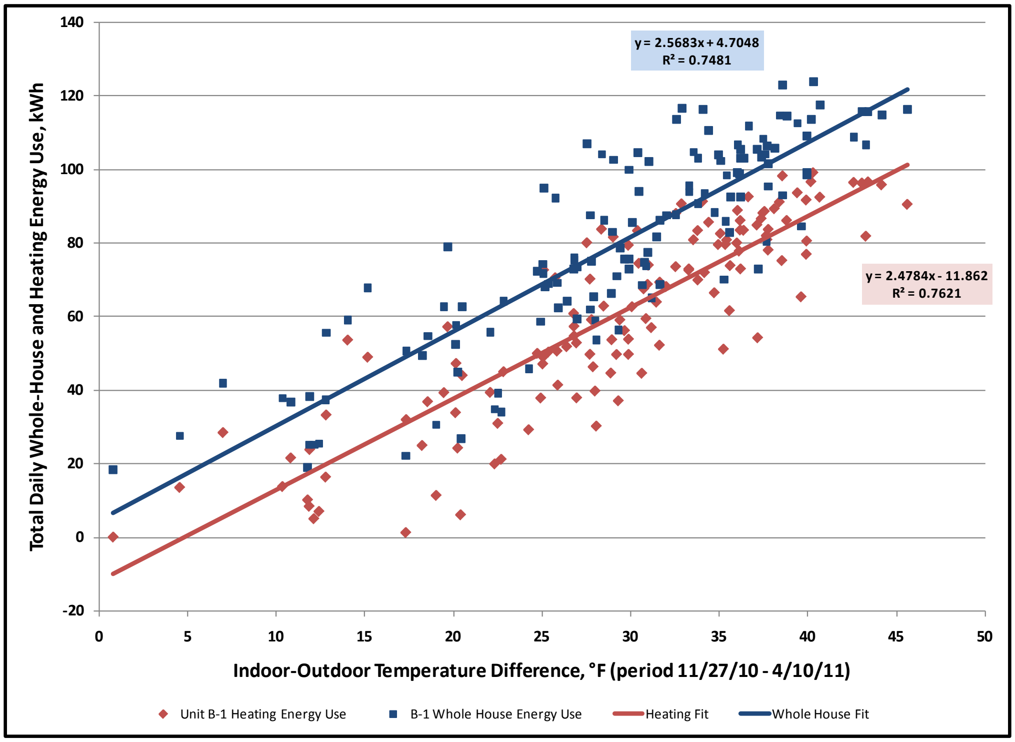

Figure 9. B-1 Whole house and heating electric use analysis.

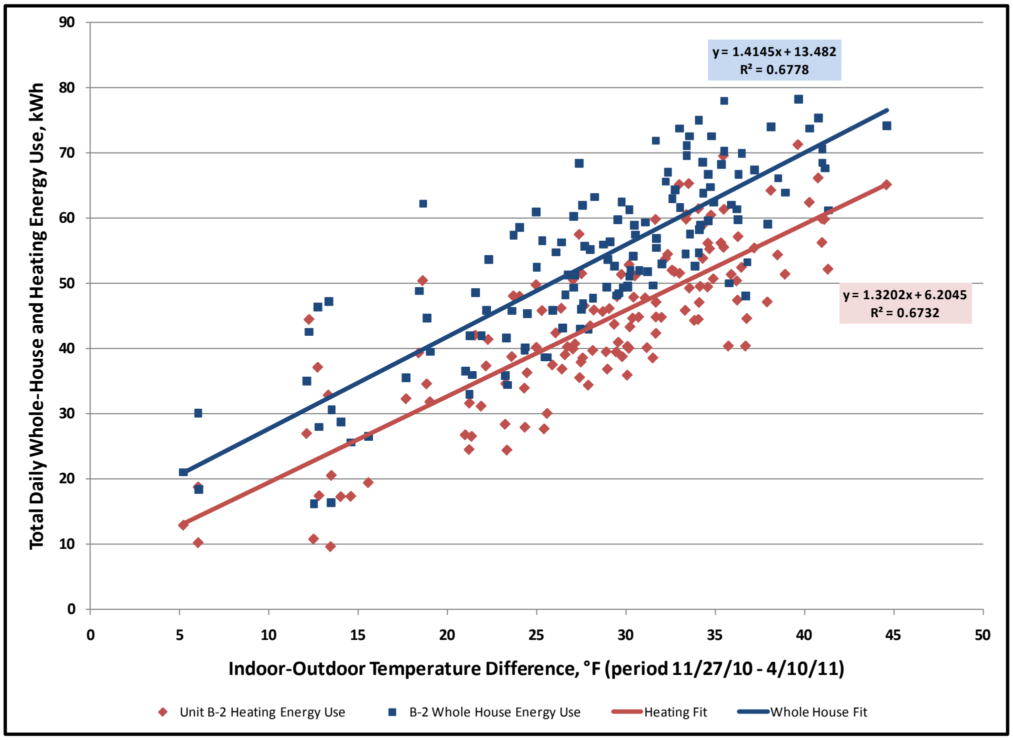

Figure 10. B-2 Whole house and heating electric use analysis.

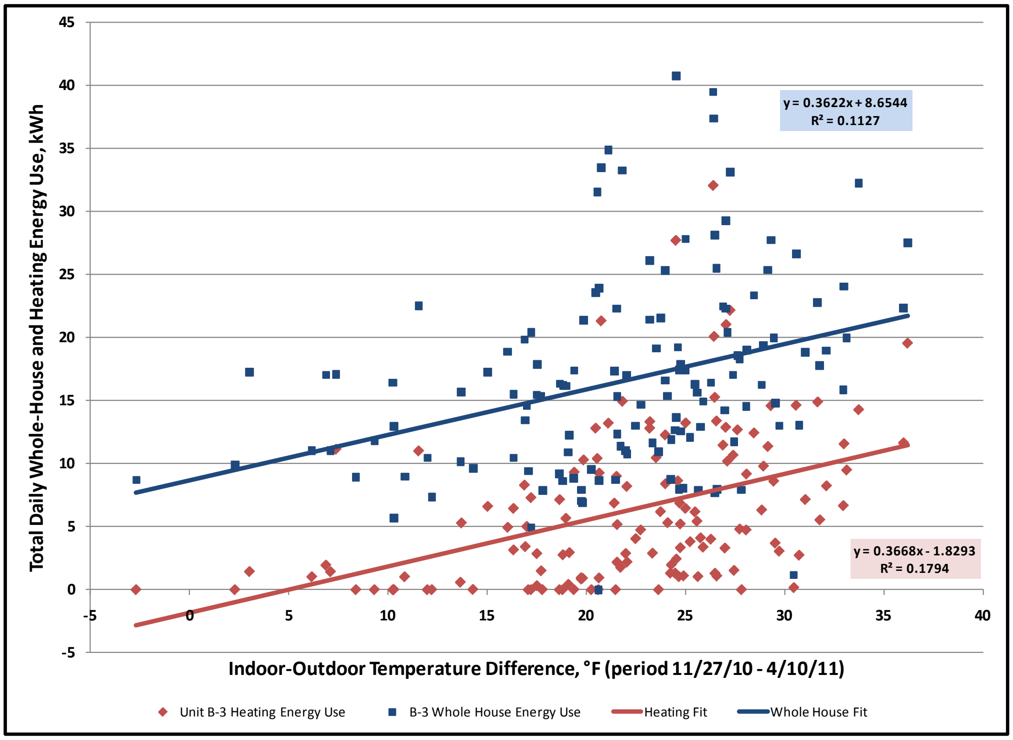

Figure 11. B-3 Whole house and heating electric use analysis.

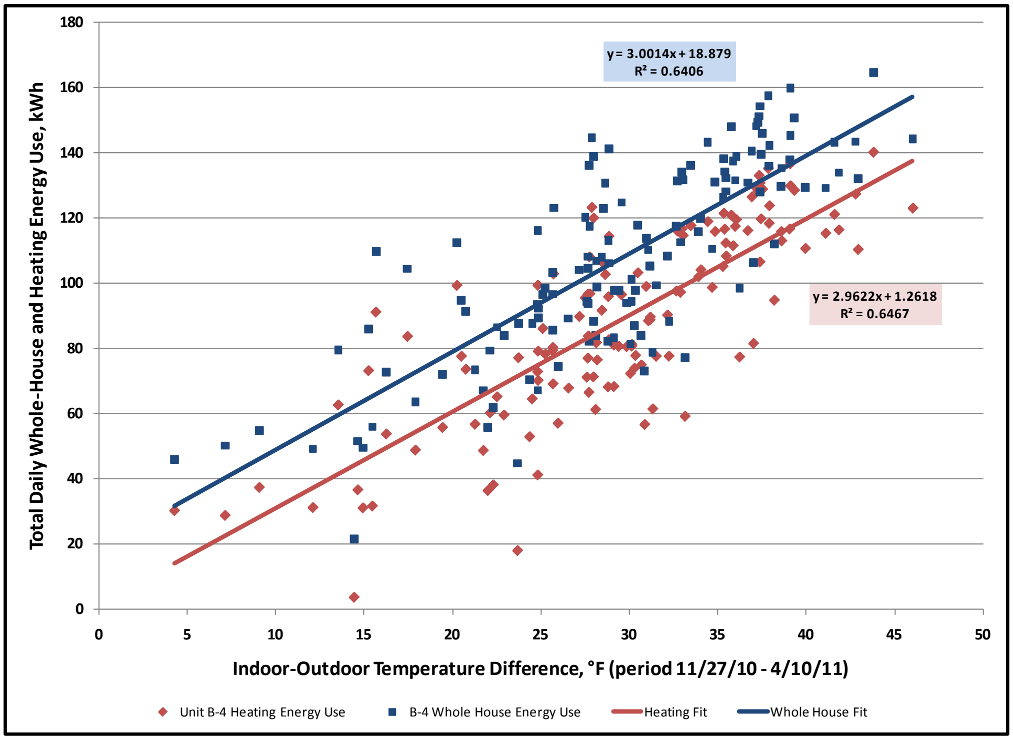

Figure 12. B-4 Whole house and heating electric use analysis.

Figure 9, Figure 10, and Figure 12 indicate similar performance because the whole house and heating energy use are consistent as evidenced by the whole house and heating energy fit lines being parallel, or having a similar slope. The area between the fit lines is generally indicative of energy use for appliances, lights, water heating and miscellaneous. When the area is consistent, as shown by these graphs, it indicates that usage is more or less routine from day to day.

The linear fit formulas describe the relationship between temperature difference and energy use of the two data sets in each graph; therefore, the difference in the offset of the fit lines' formulae approximates the daily average energy consumption within the home for uses other than heating. For example, in Unit B-2, the offset difference between the whole house energy use and the heating energy use is approximately 7 kWh, and is representative of the average daily use for all loads other than heating energy.

Unit B-3, Figure 11, is unique in that it appears that the occupant(s) was/were either away for a large portion at the beginning of the heating season or simply did not use much heating. (Table 10 indicates an average winter season indoor temperature less than 62° F.) The whole house energy use does not increase with the same proportion as the other homes in the building when outdoor temperatures decrease.

The vertical axis on all of these graphs represents the daily heating and whole house electric energy usage. The range of electricity usage for these four homes is large—40 kWh to 160 kWh—with interior points of 80 and 125 kWh. The maximum energy use for heating any one home in this group ranges from 32 kWh–140 kWh during the more severe weather period. The interior units use less electricity for heating because of the reduced exterior wall and window area and the reduced interior living area (interior units in this building are approximately 28% smaller than the end units).

In addition to the data measured by the transducers, the utility meter readings were logged weekly for each of the units. The utility meter data correlates well with the measured data. The utility meter data has been used to analyze the heating energy use compared to the number of HDDs in Figure 13. The use of HDD helps to compare the temperature severity (or the difference between indoor and outdoor weather) when the time period is greater than one day. HDD is the cumulative measurement (for a period) of the difference between 65°F and the average daily temperature below 65°F. Each point on the graph indicates the average daily energy usage and the average daily HDD in a period defined by meter readings. The trend line for each unit indicates the relationship between the outdoor temperature severity and the average daily electric energy consumption.

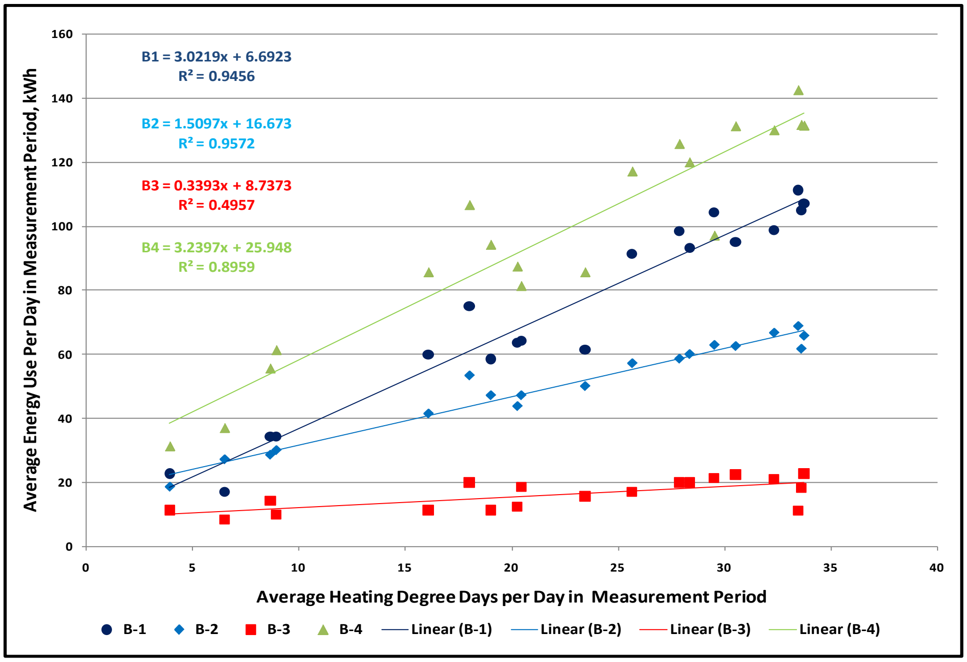

Figure 13. B-1 through B-4 average daily electricity use based on HDDs in the period.

Units B-4 and B-1 demonstrate the highest daily energy usage during the heating period. These are end units with approximately 25% more exterior wall surface, nearly 50% more roof surface area, and 28% more heated area than B-2 and B-3, thus higher energy usage for space conditioning is expected.

7.2 Wood Frame Brick-Veneered Building – FB-5 through FB-8

The wood frame brick-veneered building that received temperature sensors and energy transducers in November 2010 shows similar average indoor temperatures in three of the units—66°F, 65°F, and 66°F (Table 11). One of the units was unoccupied for the heating season, but the heat was on for some of the period and its average temperature was 55°F.

Figure 14 through Figure 17 chart the transducer data on whole house and heating energy use during the 2010/2011 heating season. Figure 18 compares the metered data and the HDD for a period.

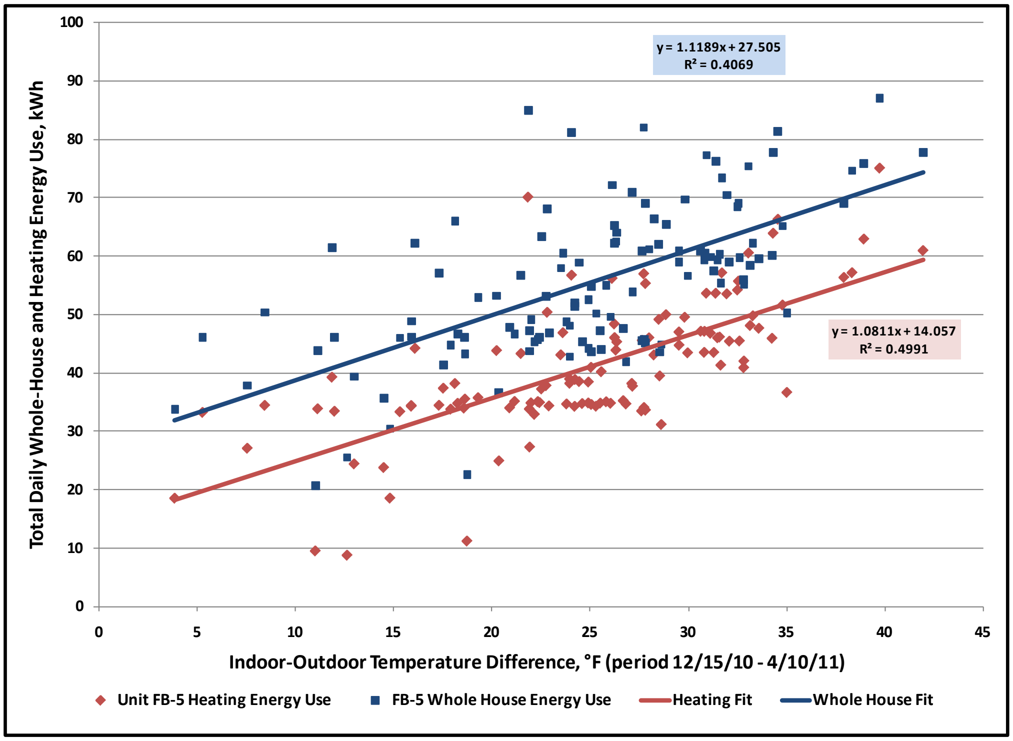

Figure 14. FB-5 Whole house and heating electric usage.

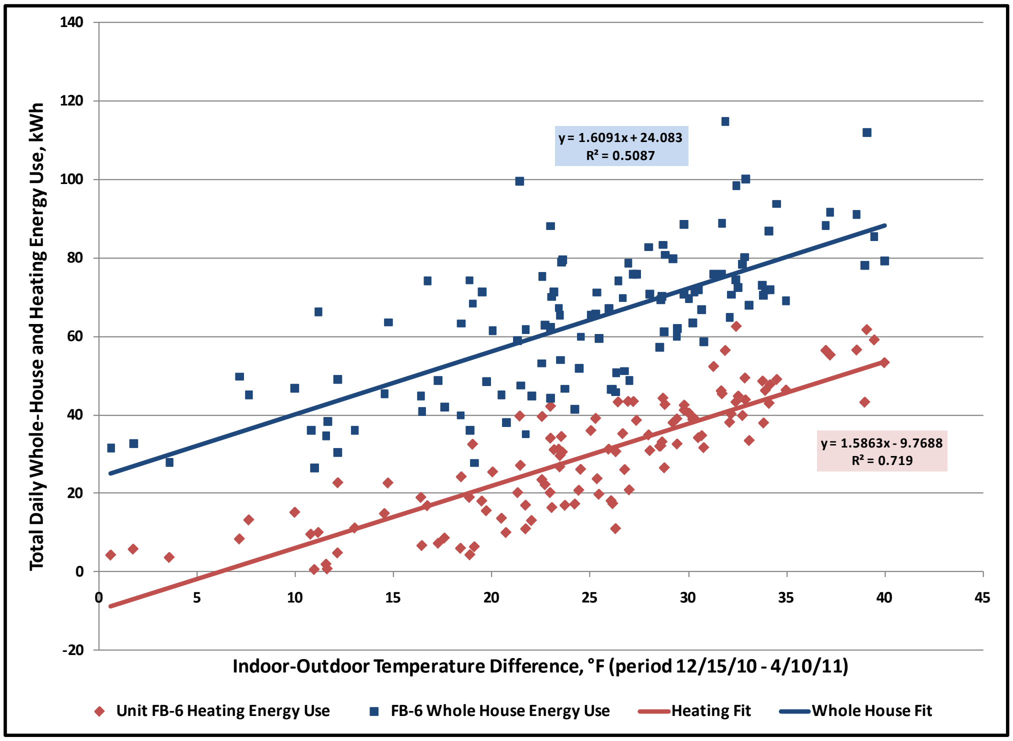

Figure 15. FB-6 Whole house and heating electric usage.

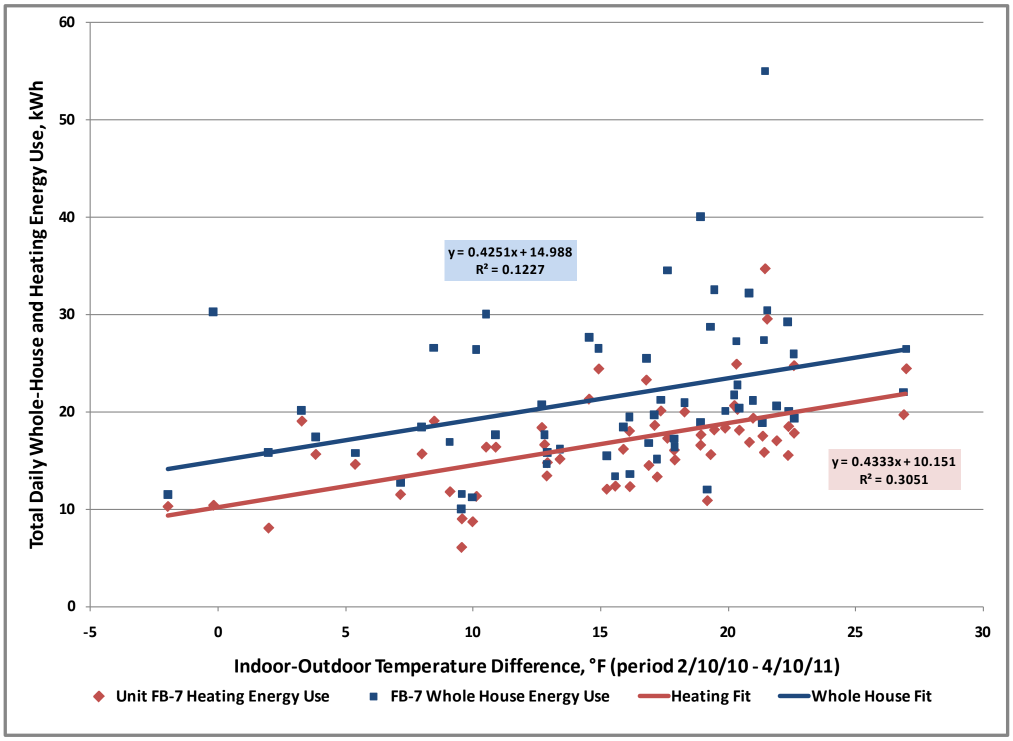

Figure 16. FB-7 Whole house and heating electric usage.

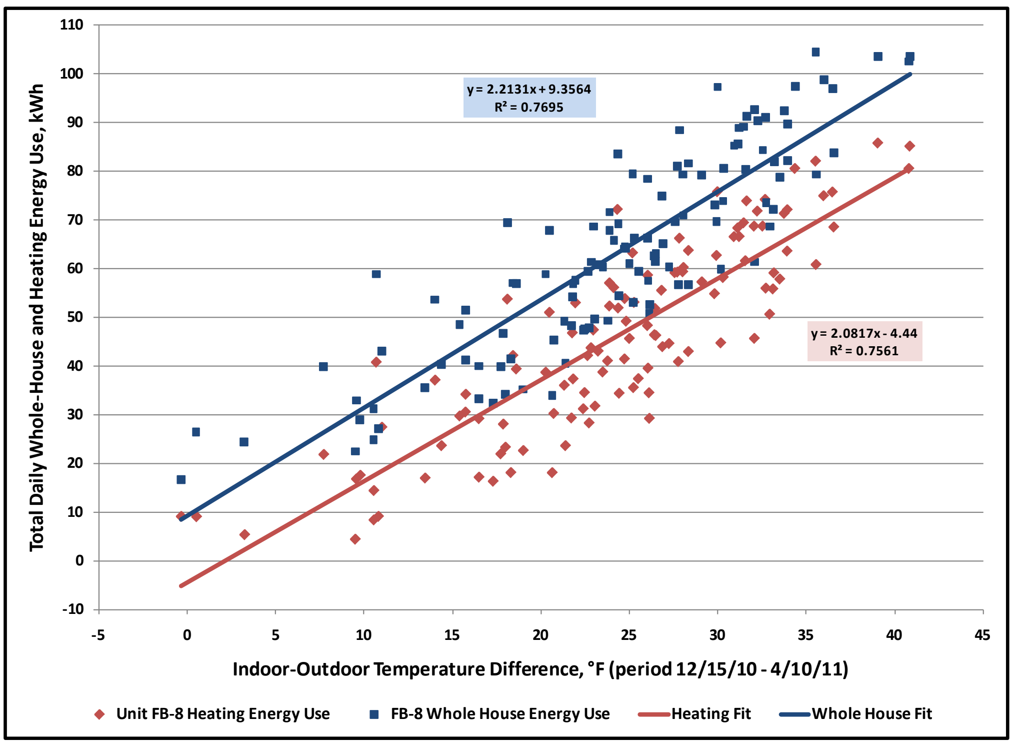

Figure 17. FB-8 Whole house and heating electric usage.

The daily energy usage range for the occupied homes is not large—90 to 115 kWh per day—and homes are of similar area. The maximum energy for space heating is, as would be expected, higher for the exterior units (75 to 85 kWh maximum daily usage) than the interior occupied unit

(65 kWh). The larger-than-normal difference between the whole house and heating energy use (more than 20 kWh usage per day) for unit FB-6 (Figure 15) is generated by heating hot water.

Figure 18 compares the energy use recorded at the meter with the HDD for the period. The data correlates well with that presented in the previous graphs (Figure 14-Figure 17).

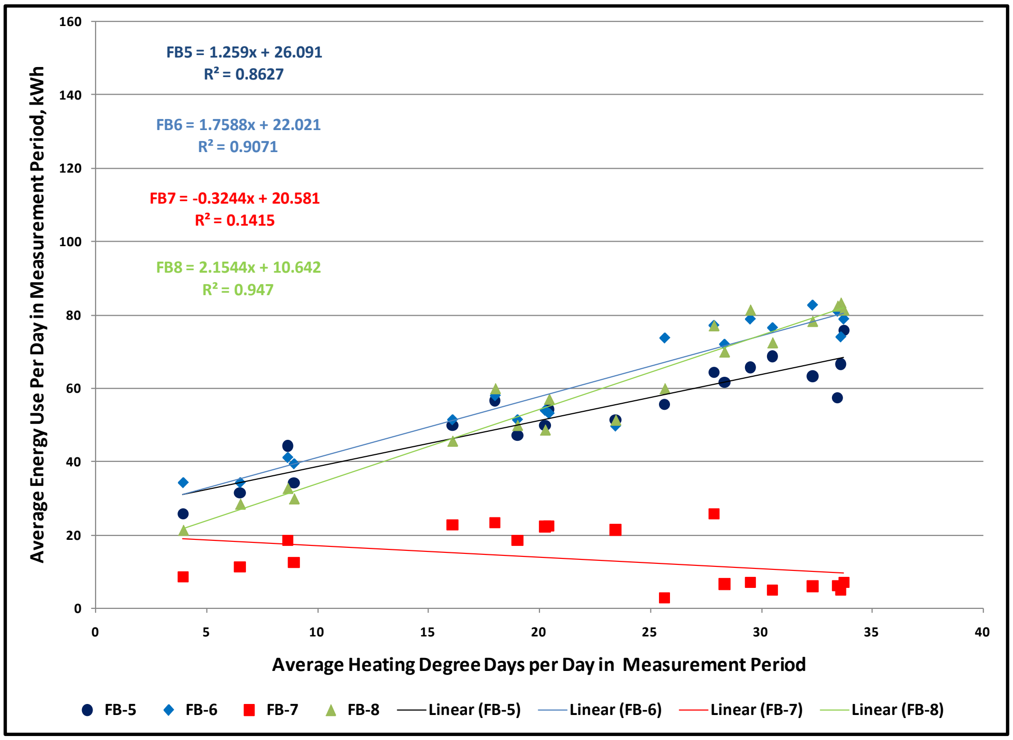

Figure 18. FB-5 through FB-8 average daily usage and HDD during the period.

The energy used in these wood frame brick (FB) units is significantly lower than for the block (B) units (Figure 9 through Figure 12) due the former having wall insulation. FB-5 and FB-8 are the end units with approximately 340 more square feet of exterior wall surface than interior units; however, all of the homes in this building have similar conditioned area (Table 3).

7.3 Wood Frame Vinyl Building – FV-5 through FV-8

One of the wood frame vinyl-sided buildings in the pilot program was also instrumented during the same week as the block building. The average indoor temperature for the four units ranged from 63°F to about 69°F (Table 10). One of the units has an air source heat pump and the homeowner does not use the baseboard heaters. The average indoor temperature of three of the four units was from 1 to 5 degrees below the 68°F simulation set point.

Figure 19 through Figure 22 indicate the detailed daily data for whole house and heating energy use. The maximum energy use recorded for any day is similar to that of the wood frame brick building but, the range for these wood frame vinyl homes is not as great as those of the other building types. The range of maximum daily use was 74–119 kWh per day (used in FV-6, and FV-5, respectively). The two other homes in the building recorded maximum daily energy use of 75 and 104 kWh. The maximum heating energy use, however, was as would be expected, higher for the exterior units (108 and 63 kWh), than the interior units (47 to 52 kWh). The difference in heating energy use in the end homes can be attributed to the 6°F difference in average indoor heating set point.

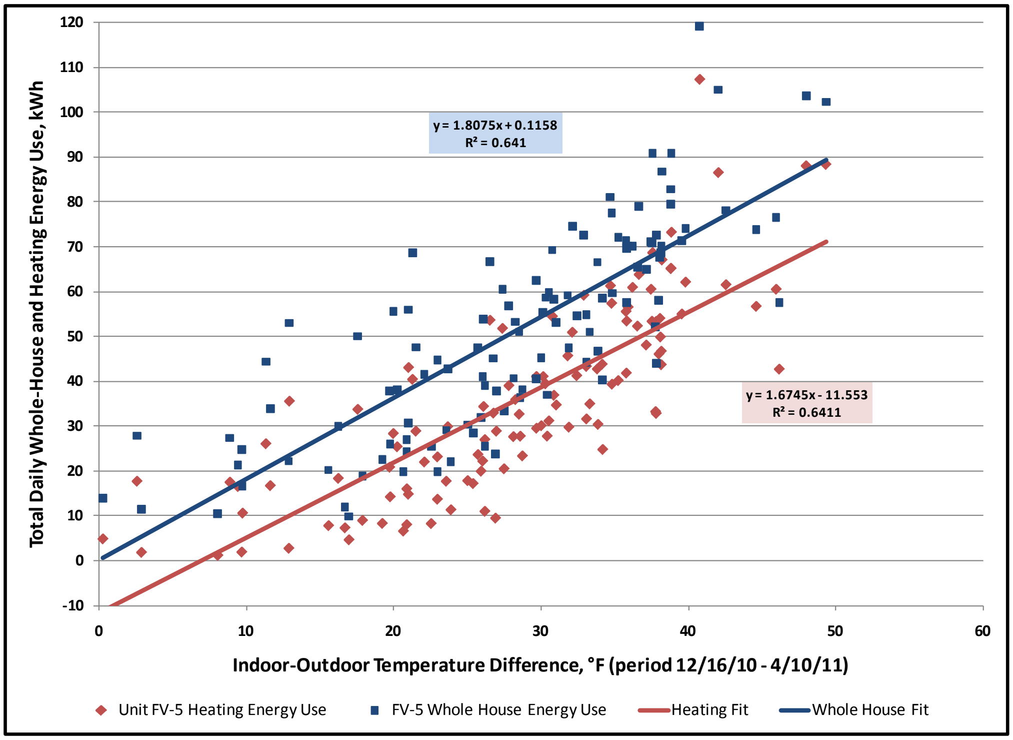

Figure 19. FV-5 Whole house and heating electric usage.

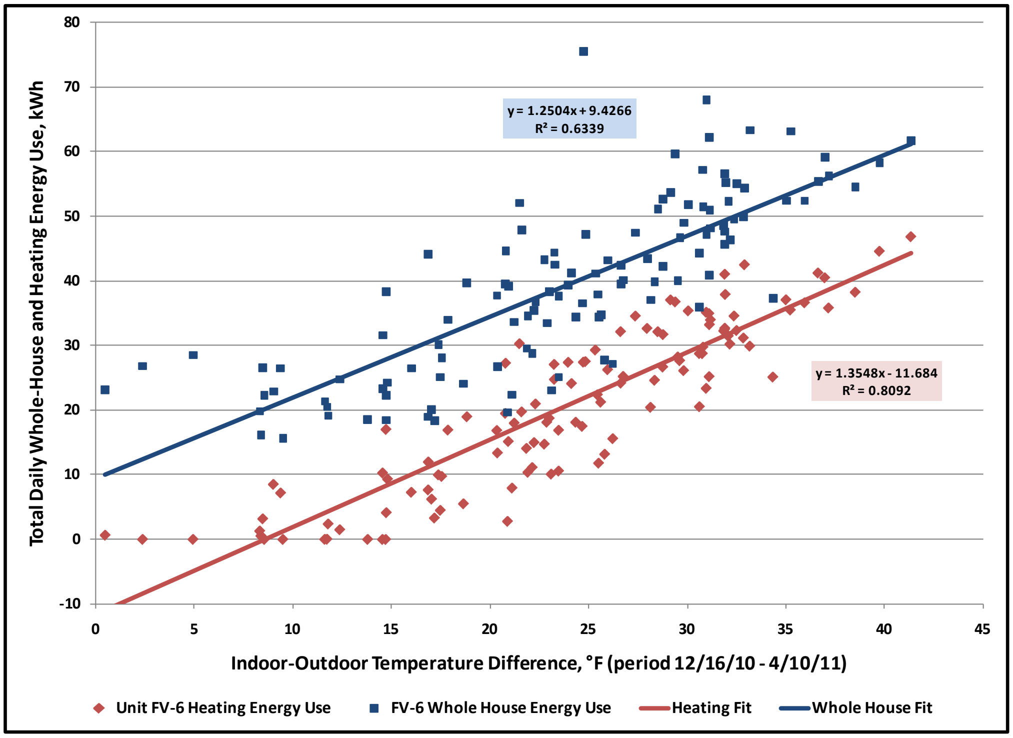

Figure 20. FV-6 Whole house and heating electric usage.

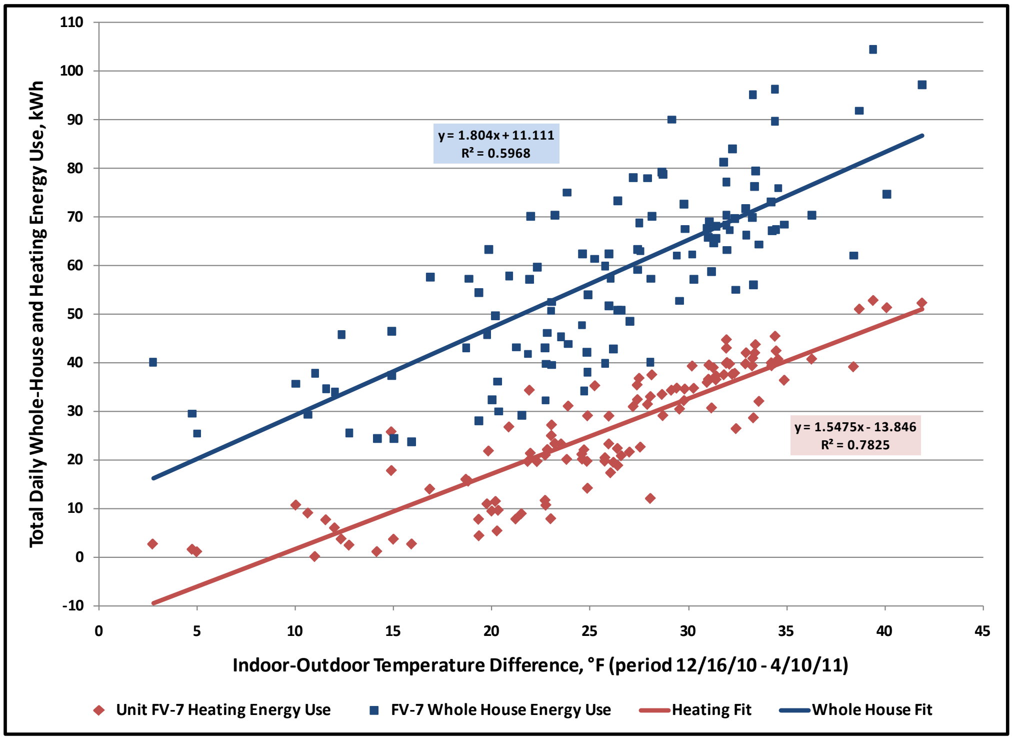

Figure 21. FV-7 Whole house and heating electric usage.

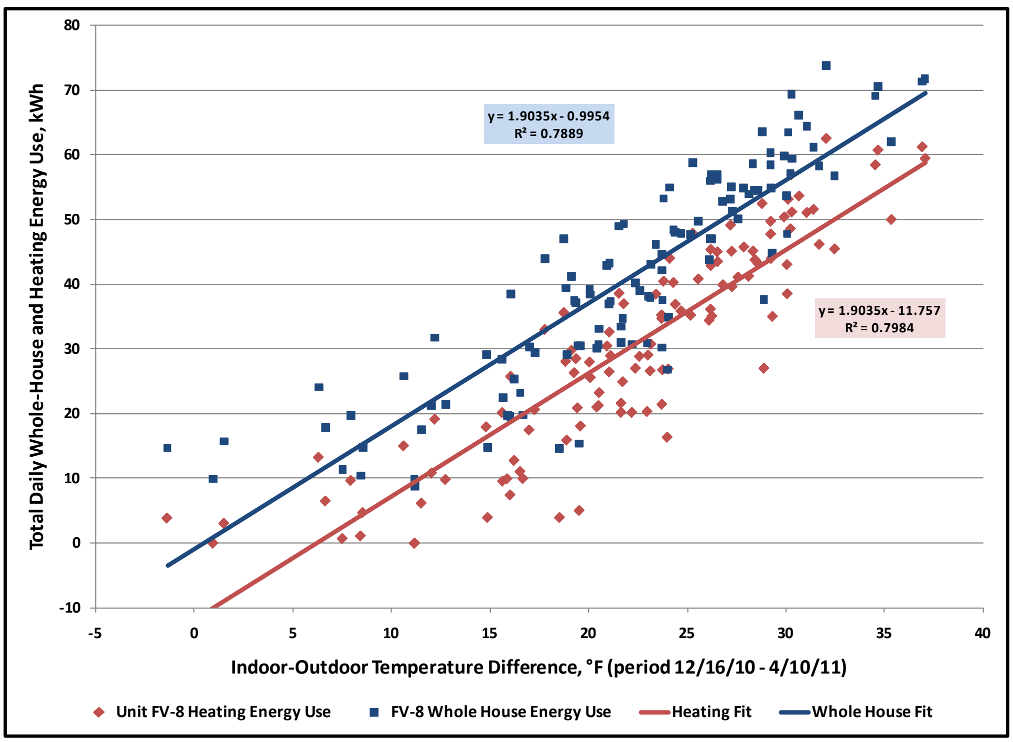

Figure 22. FV-8 Whole house and heating electric usage.

Comparison between the daily energy data recorded by the transducers (Figure 19 through Figure 22) to the utility meter records (Figure 23) indicates the agreement between the two methods. Figure 23 is a graph of the relationship between periodic utility meter records and the weather severity measured in HDD for the brick veneered building consisting of units FB-5 through FB-8.

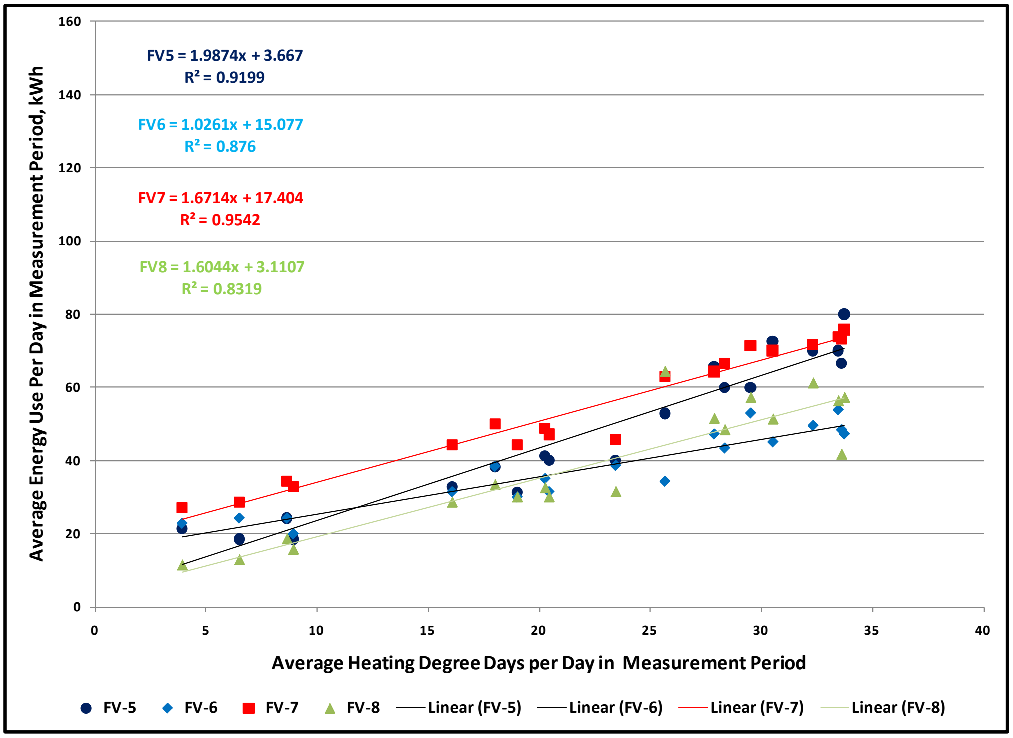

Figure 23. Average daily usage and HDD during the period; FV-5 through FV-8.

The whole house energy used in the FV and FB units is similar since these units all have similar wall and ceiling insulation. The interior unit, FV-7 shows the overall highest energy use; however, the energy use is greater for non-heating loads and is consistent for energy used for heating as with other interior units.

8 Detailed Data Summary Energy Use: Utility Meter Readings for Four Building Types

Four buildings were unable to be outfitted with the electric energy transducers in time for the 2010-2011 heating season. As with the previous three building types, electric meter readings were recorded for the remaining four buildings in the pilot study at regular intervals. The whole house energy use of the four buildings that were not outfitted with current transducers for the 2010/2011 heating season are analyzed here based on observed meter readings and can be compared with the similar analysis above.

8.1 Block Vinyl-Sided and Block Building Units BV-1, B-5, B-6, BV-2

Vinyl siding has been installed on the end units of the block building (thus, they are named BV-1 and BV-2). The two interior units remain constructed of 8 in. CMU block that has been painted (B-5 and B-6). Temperature sensors were installed in each of the homes for part of the heating season (February through April 2011). Energy use data was obtained via periodic utility meter readings (because energy transducers were installed in May 2011; after the heating season). The average indoor temperatures vary significantly from unit to unit. All are lower than the 68°F set point used in the simulation models. Figure 24 charts the whole house energy use during the period of the heating season against the HDDs in the period on each unit. The trend line for each unit indicates the relationship between the severity of the outdoor temperature and the average daily whole house energy consumption.

The end units, BV-1 and BV-2, indicate the highest maximum daily energy usage during the period; however B-6, an interior unit, is a close third in energy usage. These three units have considerably different conditioned areas of 1,528, 1,245, and 921, respectively. Like the other block end units, the two in this building have more than twice as much exterior wall surface area as the interior units.

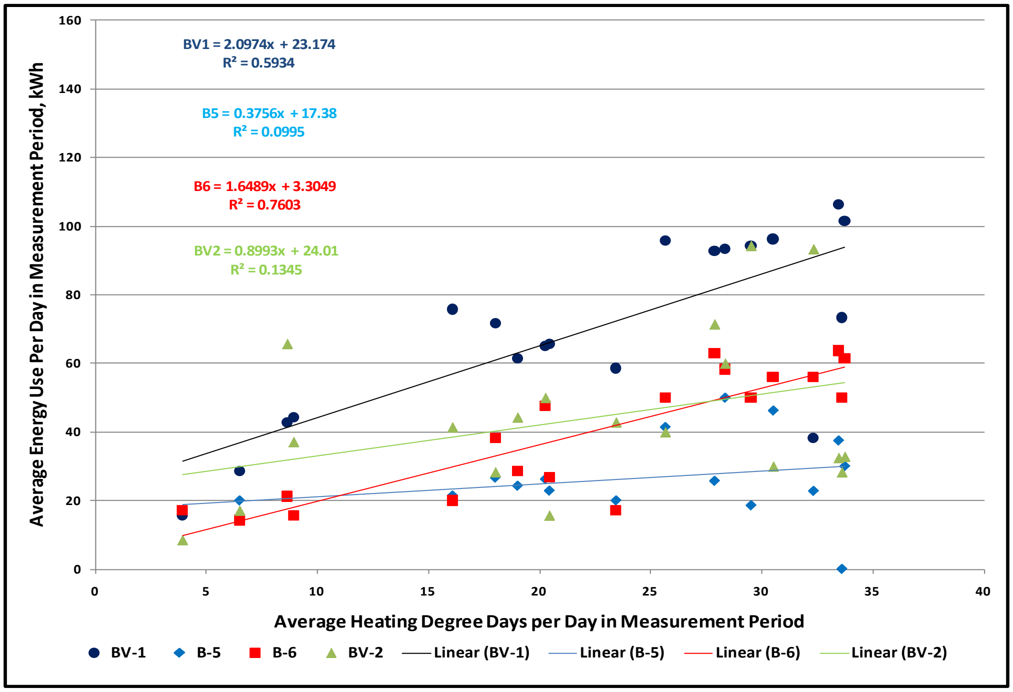

Figure 24. BV-1, B-5, B-6 and BV-2 average daily usage and HDD for the heating period.

8.2 Block Vinyl-Sided Units BV-3 through BV-6

Temperature sensors were installed in each unit of the masonry block vinyl-sided building for part of the heating season (February through April 2011). Energy use data was obtained via periodic utility meter readings, as energy transducers were installed in May 2011; after the heating season ended. The average indoor temperatures in these units were closest of any of the buildings to those used in the energy simulations—69°F, 64°F, 70°F, and 66°F. Figure 25 charts the electricity used during utility meter measurement period normalized to the number of HDDs in that period.

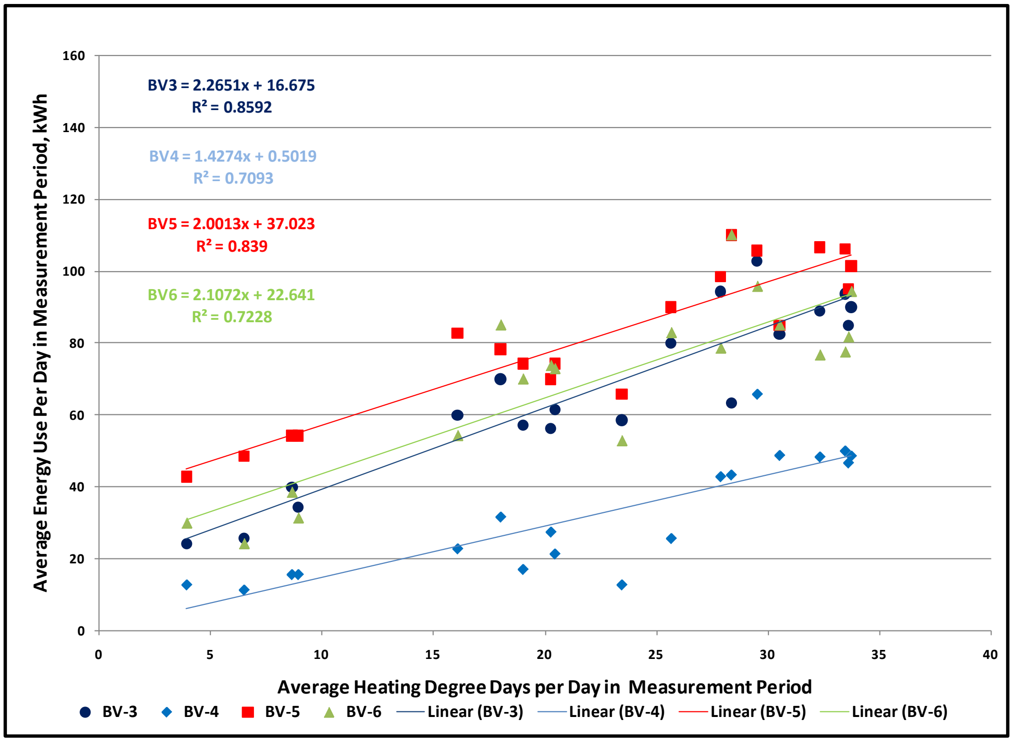

Figure 25. BV-3 through BV-6 average daily usage and HDD for the heating period.

8.3 Wood Frame Brick Units FB-1 through FB-4

Temperature sensors were installed in each unit of this wood frame brick-veneered building for part of the heating season (February through April 2011). Energy use data was obtained via periodic utility meter readings, as energy transducers were installed in May 2011; after the end of the heating season. The average indoor temperatures vary considerably—70°F, 65°F, 66°F and 58°F. Each of the homes in this building contains the same conditioned area, 1,080 ft^2. Figure 26 charts the electricity used during each utility meter measurement period normalized to the number of HDDs in that period. The FB-4 unit appears to be an anomaly both as an exterior unit and lower slope of energy use with reference to the weather severity.

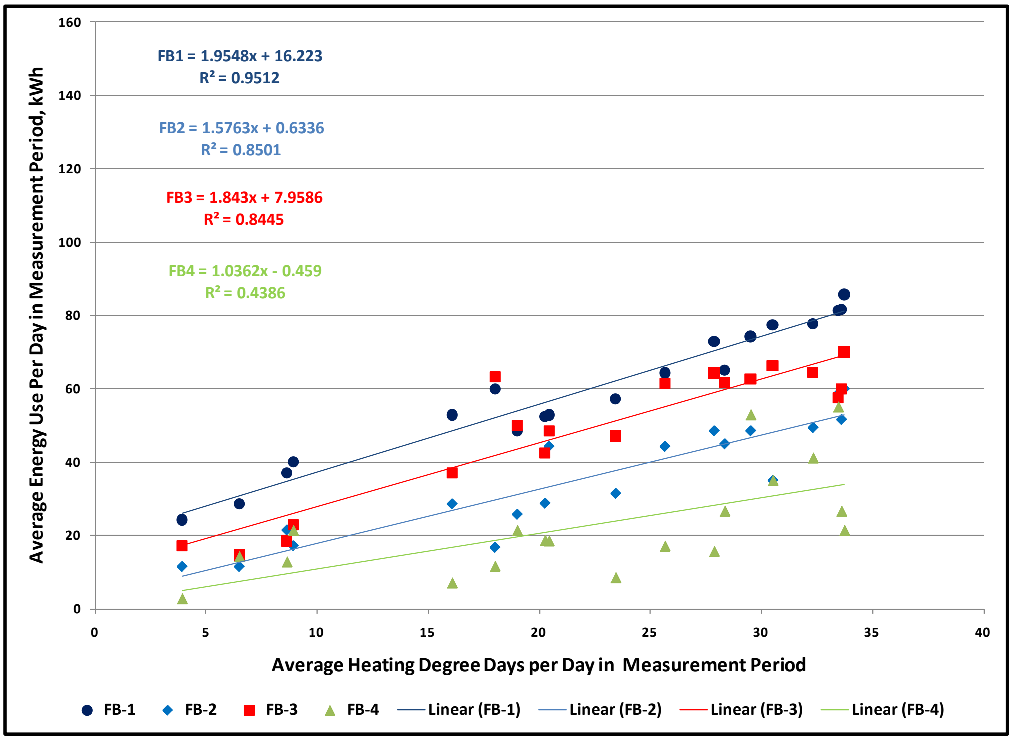

Figure 26. FB-1 through FB-4 average daily usage and HDD during the period.

8.4 Wood Frame Vinyl Units FV-1 through FV-4

Temperature sensors were installed in each unit of this wood frame vinyl-sided building for part of the heating season (February through April 2011). Energy use data was obtained via periodic utility meter readings, as energy transducers were not installed until May 2011 after the end of the heating season. Average indoor temperatures were 63°F, 69°F, 68°F, and 68°F. Whole house energy use is plotted against the HDDs in the period in Figure 27.

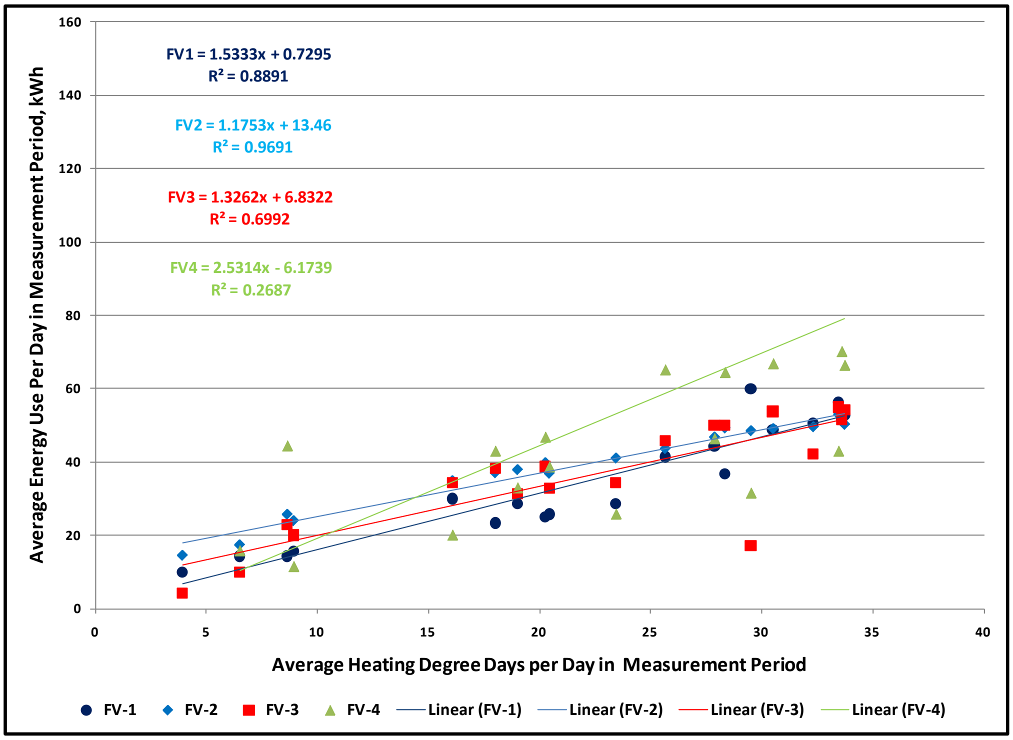

Figure 27. FV-1 through FV-4 average daily usage and HDD for the heating period.

9 Indoor Relative Humidity

One interest for the research in the pilot home program is to document the indoor conditions that represent comfort of the homeowners. Anecdotal evidence from homeowner interviews has identified lower than typical indoor temperature settings due in large part to energy use. Commensurate with the lower indoor temperatures, there is a concern that many homes have higher than acceptable RH that result in condensation and other indoor air quality problems. Using comfort as the criteria, 2001 ASHRAE Fundamentals (8.12) sets 25%–60% RH as the range acceptable to 80% of the population. This is the range where few people can detect humidity in the air. Below 25%, dry nose, throat, and skin are noticeable, while above 60% people detect a stickiness, or clammy feeling, on their skin. The Air Conditioning Contractors of America (ACCA) generally supports this humidity range at which various air contaminants grow.[9] More recently, building science experts suggest that heat season RH should be less than 40% to prevent condensation on cold surfaces.[10]

[9] ACCA Consumer Education Series, *Manage Your Humidity*, 2003, http://www.superior-air.com/Humiweb.pdf
[10] Krigger & Dorsi, *Residential Energy*, 2009, Saturn Resource Management, Inc.

Homes in the pilot study tended to show average indoor RH within the ASHRAE recommendation range, however, a majority of the units showed average household RH higher than the more recently recommended limit of 40%; 14 of 26 homes recorded in Table 11 showed average heat season RH above 40%. Two of the block houses had RH levels over 60% (B-3 and B-5) for some duration of the heat season. Both of these units indicate significantly cooler indoor average temperatures than the pilot group of homes—62ºF and 64°F. The GHI Report 1, Phase 1[11] proposed exhaust fans with timers as a method of diluting the humid indoor air by exhaust ventilation. (RH sensors in units B-1 and B-2 were not available for this measurement period.) Figure 28 through Figure 38 show the available RH data for each home.

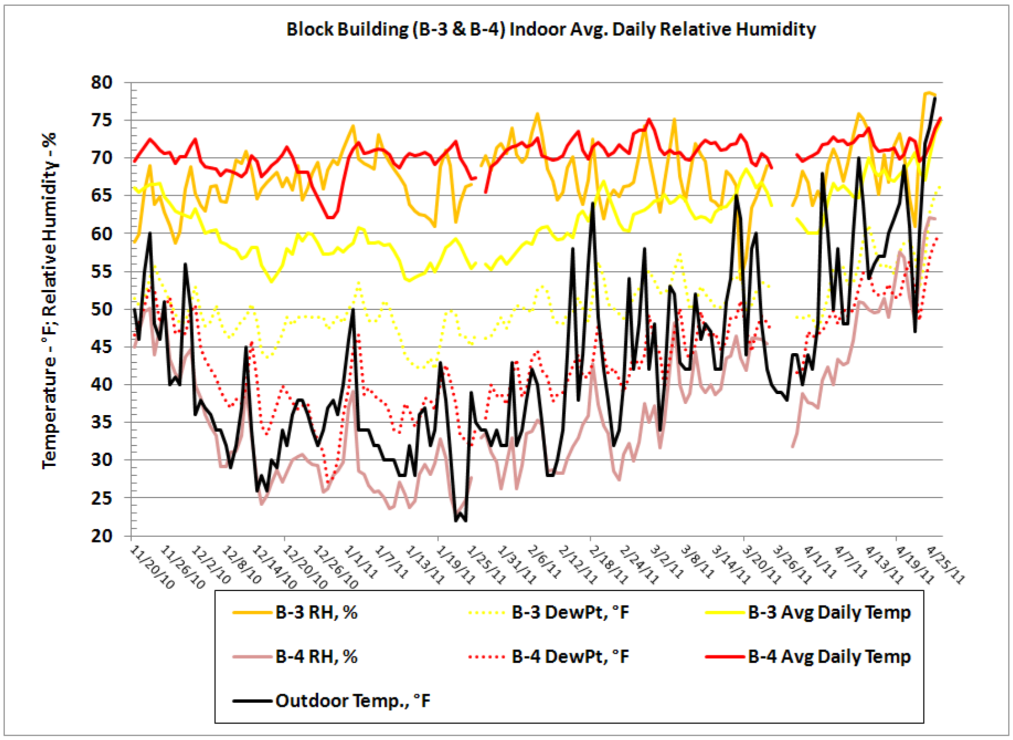

Figure 28. Indoor relative humidity B-3 and B-4.

[11] NAHB Research Center report to the Board of Directors of Greenbelt Homes, Inc. April 2011

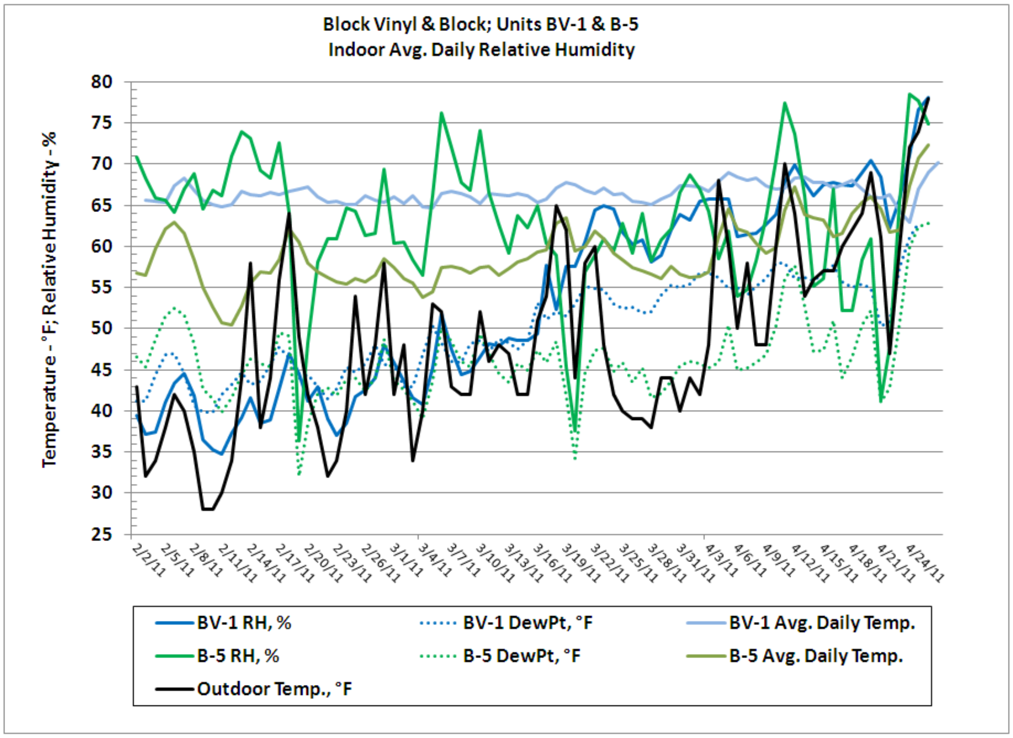

Figure 29. Indoor relative humidity BV-1 and B-5.

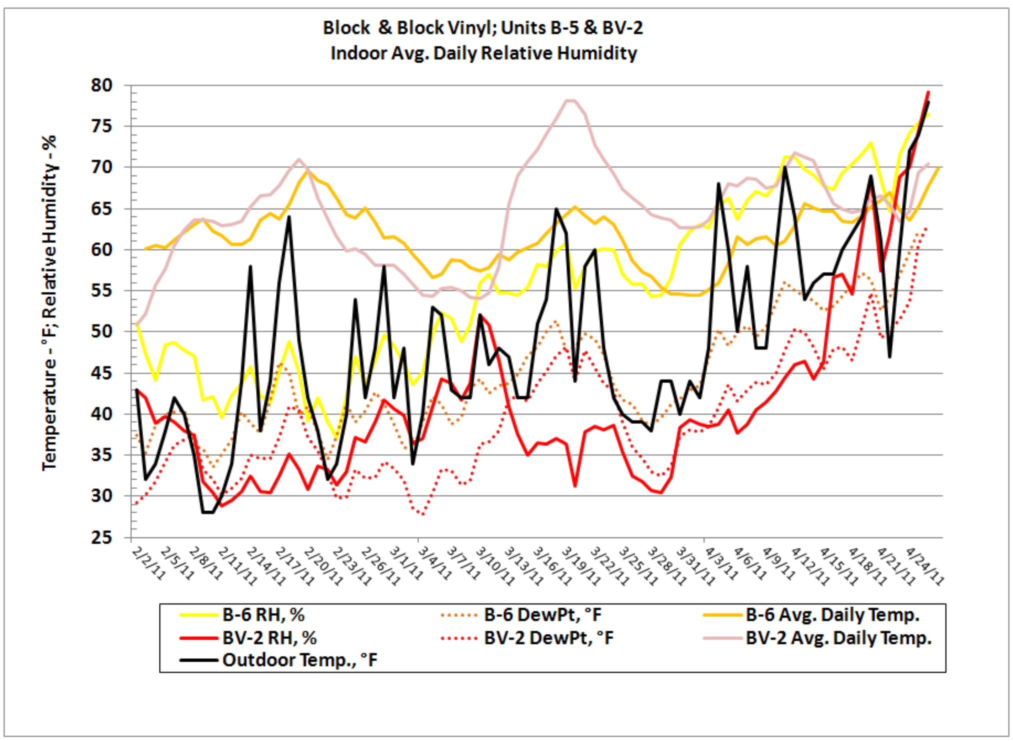

Figure 30. Indoor relative humidity B-6 and BV-2.

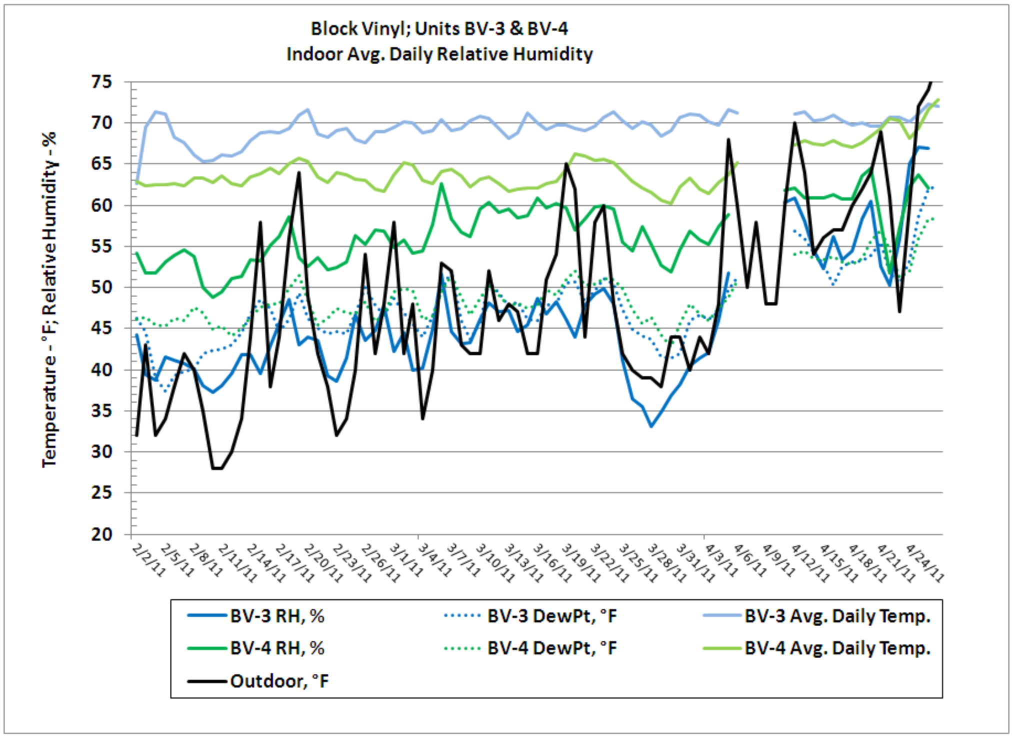

Figure 31. Indoor relative humidity BV-3 and BV-4.

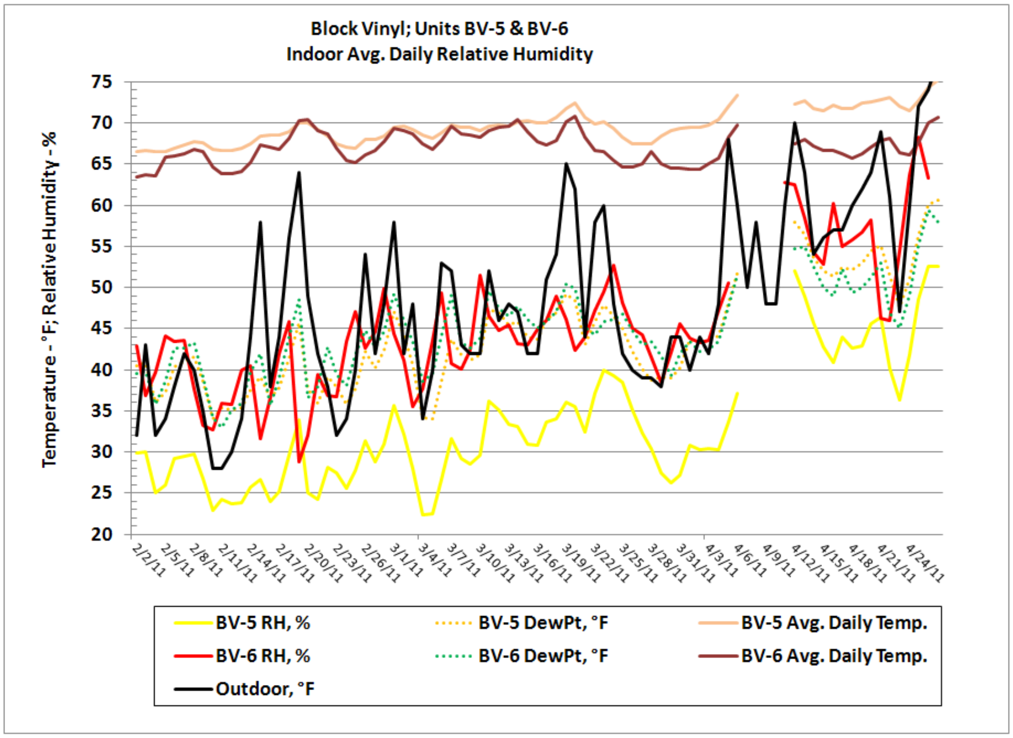

Figure 32. Indoor relative humidity BV-5 and BV-6.

The indoor RH of the wood frame brick and wood frame vinyl buildings for the heating period are detailed in Figure 33 through Figure 38.

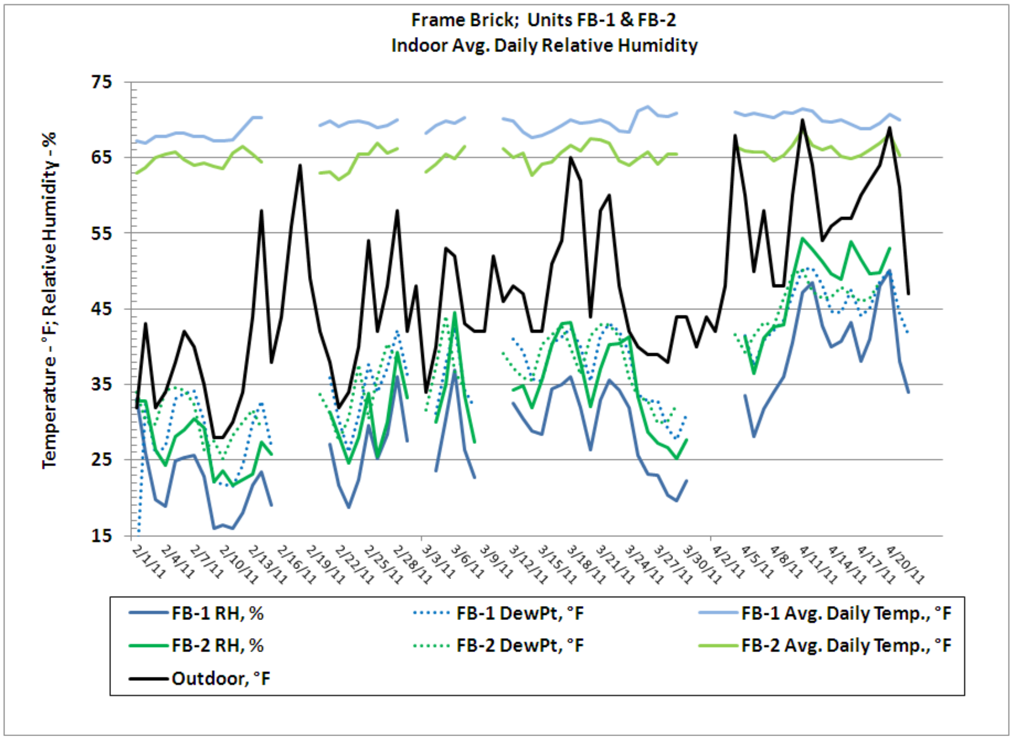

Figure 33. Indoor relative humidity FB-1 and FB-2.

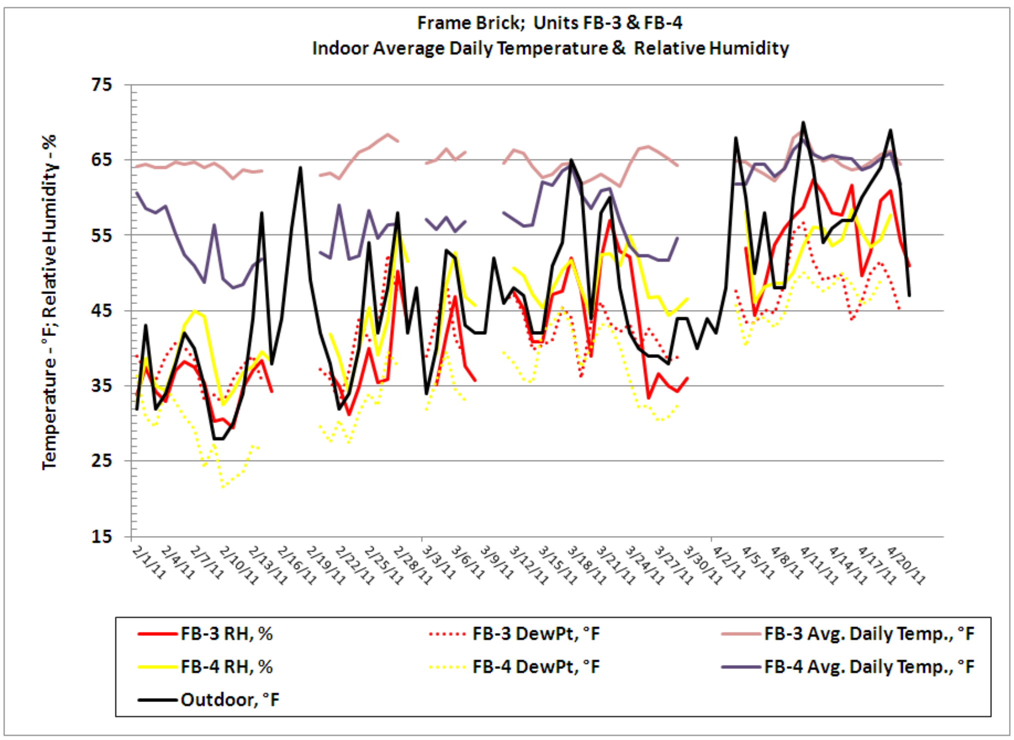

Figure 34. Indoor relative humidity FB-3 and FB-4.

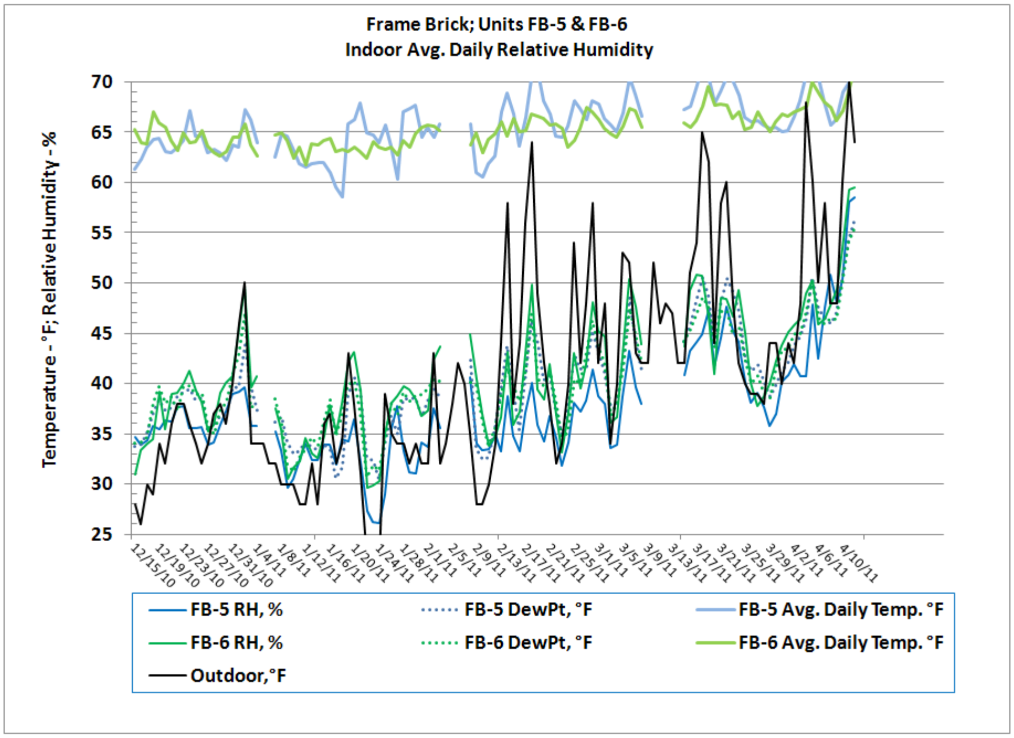

Figure 35. Indoor relative humidity FB-5 and FB-6.

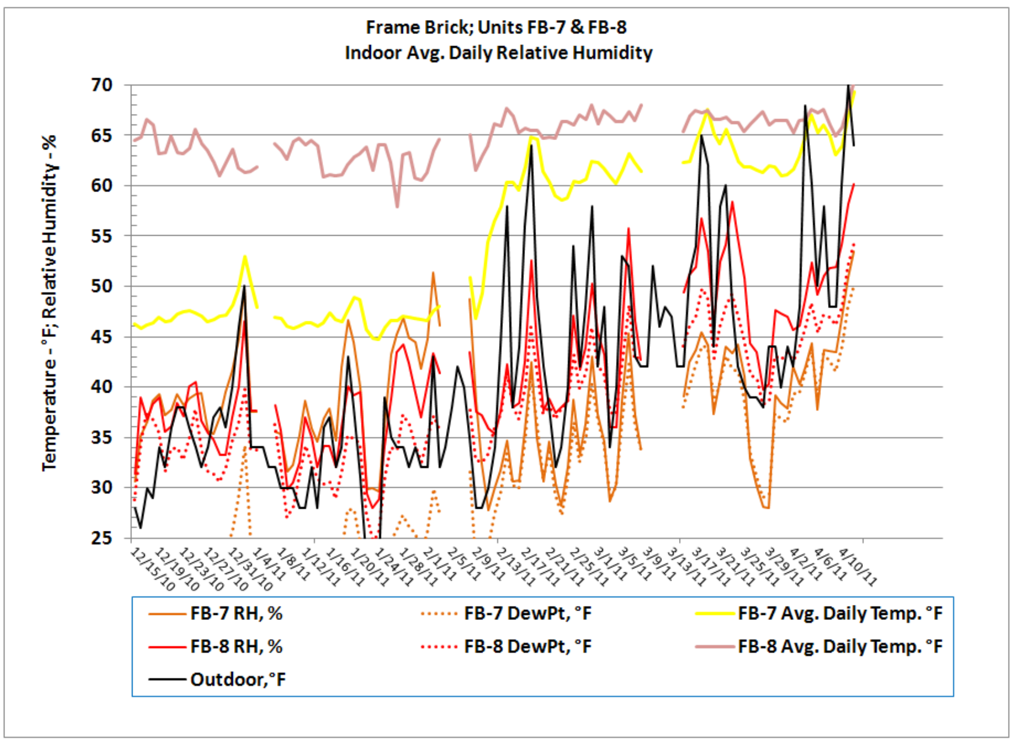

Figure 36. Indoor relative humidity FB-7 and FB-8.

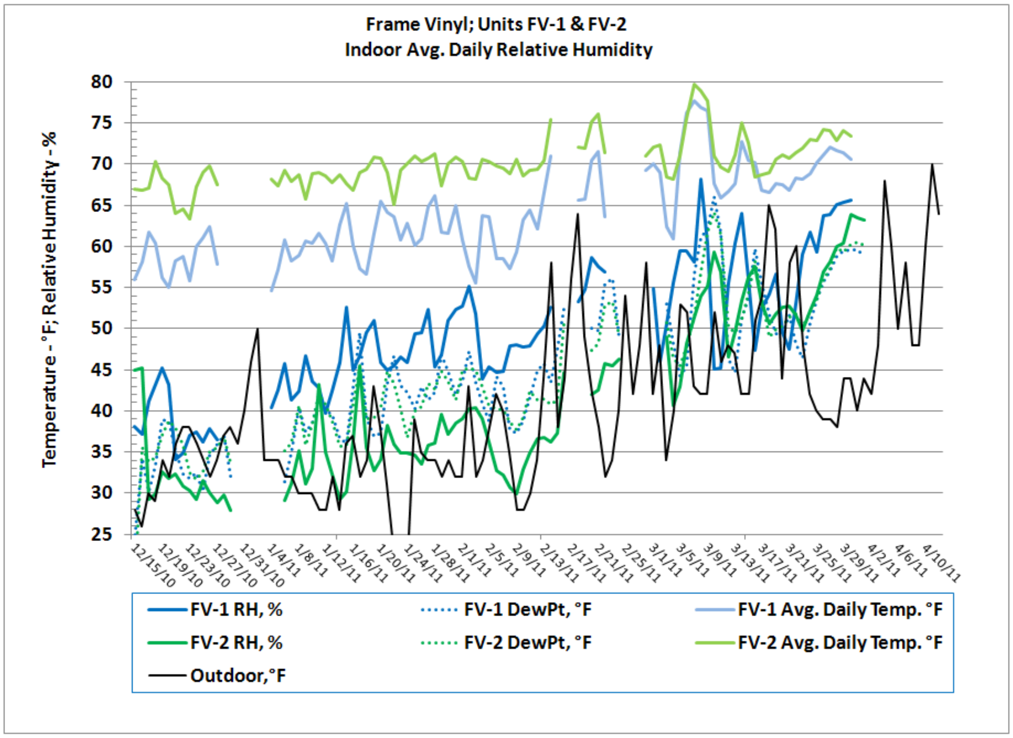

Figure 37. Indoor relative humidity FV-1 and FV-2.

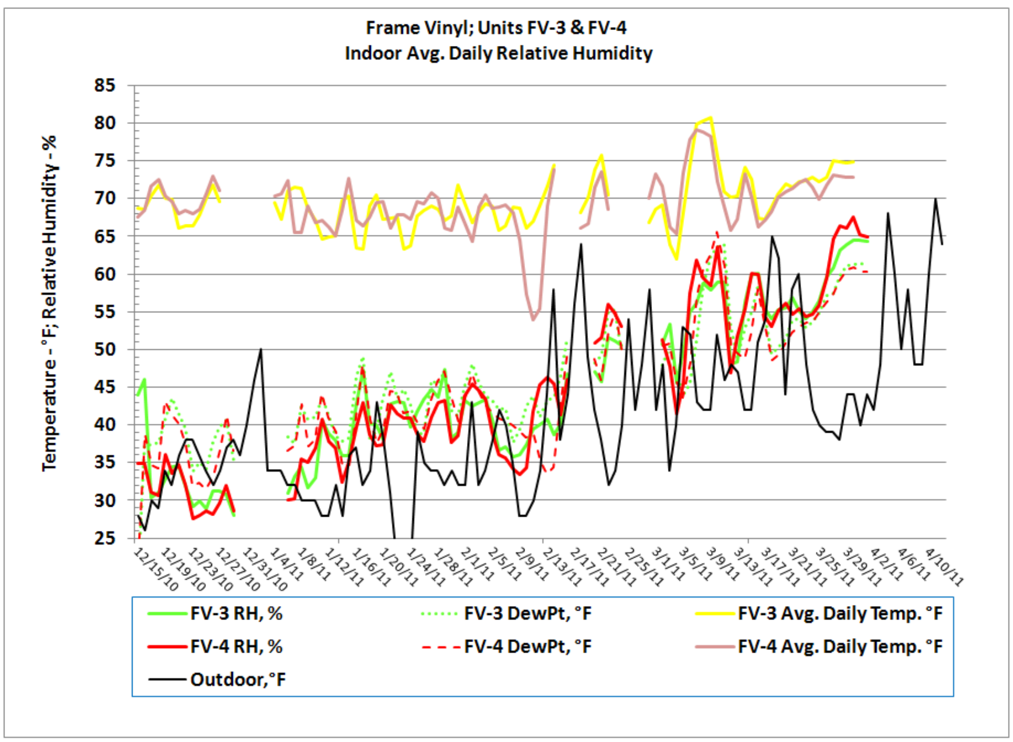

Figure 38. Indoor relative humidity FV-3 and FV-4.

10 Building Crawlspaces

Figure 39 through Figure 45 chart the RH in the crawlspaces of the buildings in the pilot study. An acceptable range would be similar to the range identified for indoor conditions. Dehumidifiers have been recommended for the block (B) and wood frame brick (FB) building crawlspaces, as these are currently closed crawlspace foundations without mechanical ventilation or a heat source. Air dilution via ventilation grills was recommended for the wood frame vinyl (FV) buildings. The buildings are outfitted with the grills, but these have been blocked by deck band boards and built-up grade. A full vapor barrier to cover the entire crawlspace floor was added in the fall of 2011 to all buildings.

The data indicates that the dew point in the crawlspaces remains below the temperature in the crawlspaces, generally resulting in little condensation potential on surfaces. One group of block building, units BV-1 through BV-2, did not report the RH due to a sensor malfunction. Average daily temperatures for the crawlspace are reported.

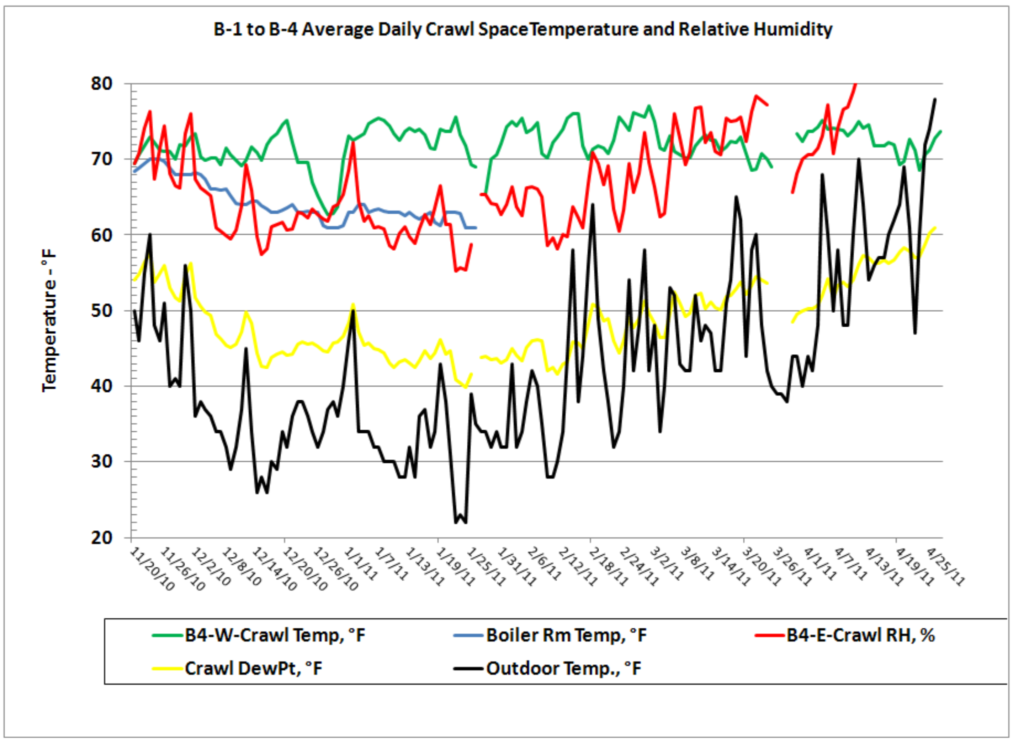

Figure 39. Crawlspace relative humidity; Units B-1 through B-4.

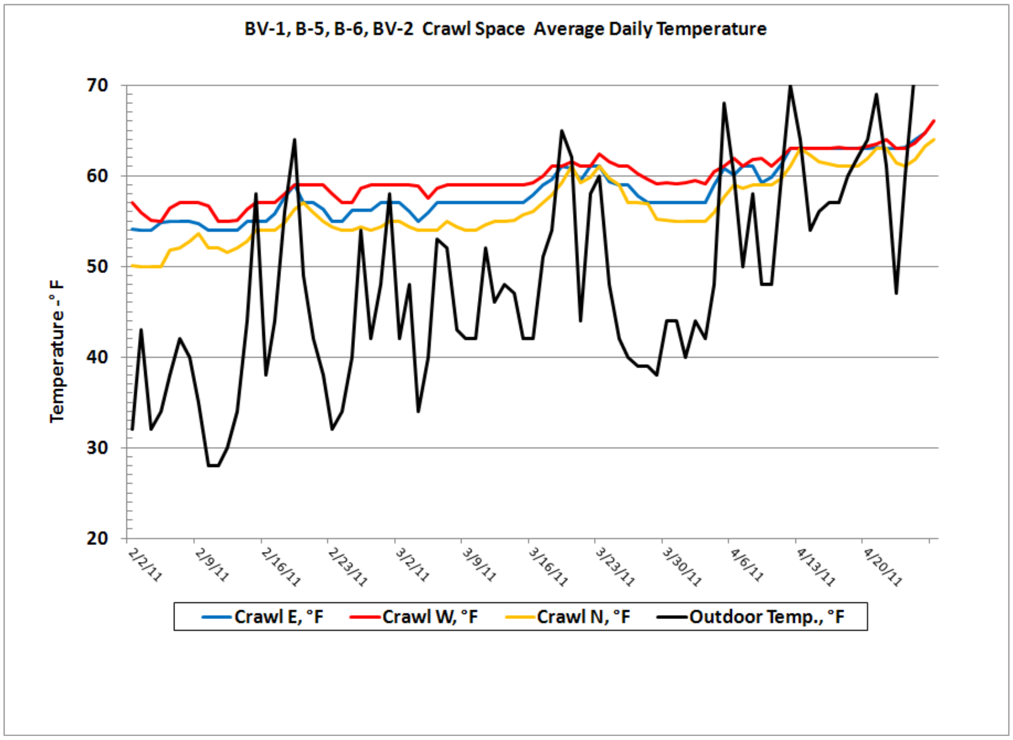

Figure 40. Crawlspace temperature; BV-1, B-5, B-6 and BV-2.

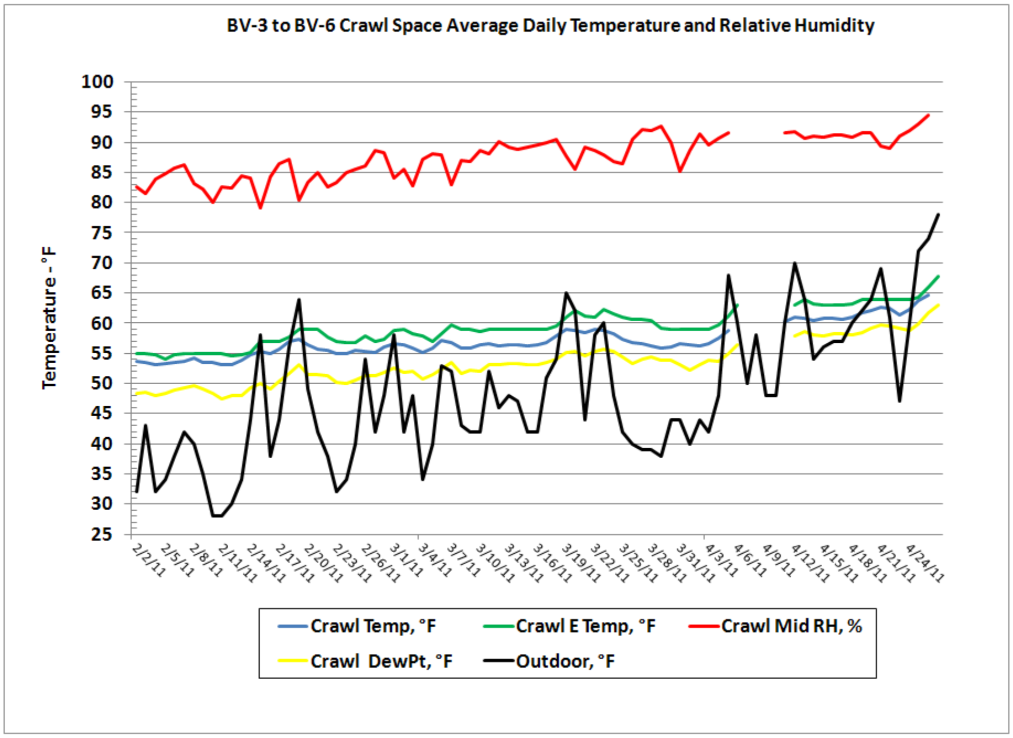

Figure 41. Crawlspace temperature and relative humidity BV-3 through BV-6s.

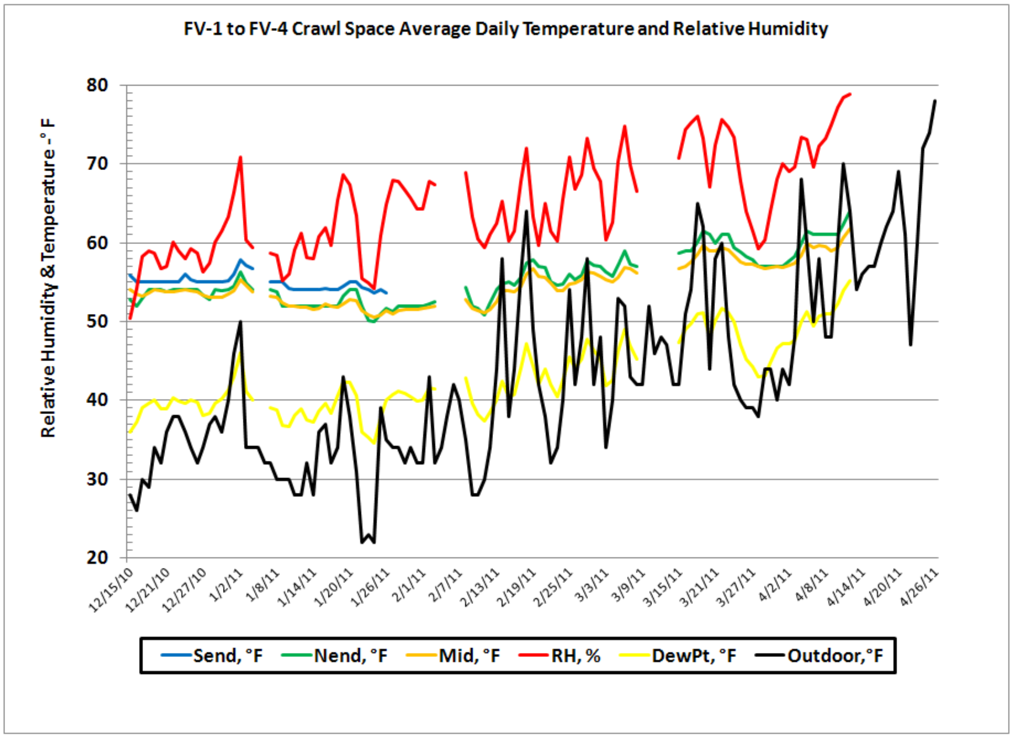

Figure 42. Crawlspace temperature and relative humidity FB-1 through FB-4.

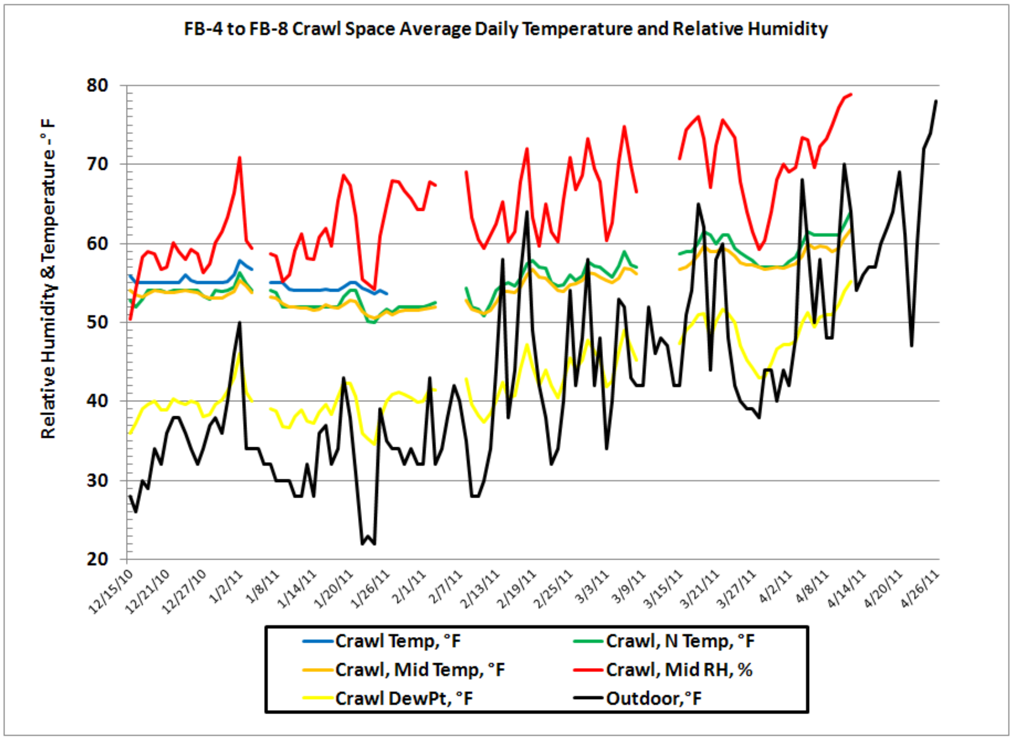

Figure 43. Crawlspace temperature and relative humidity FB-5 through FB-8.

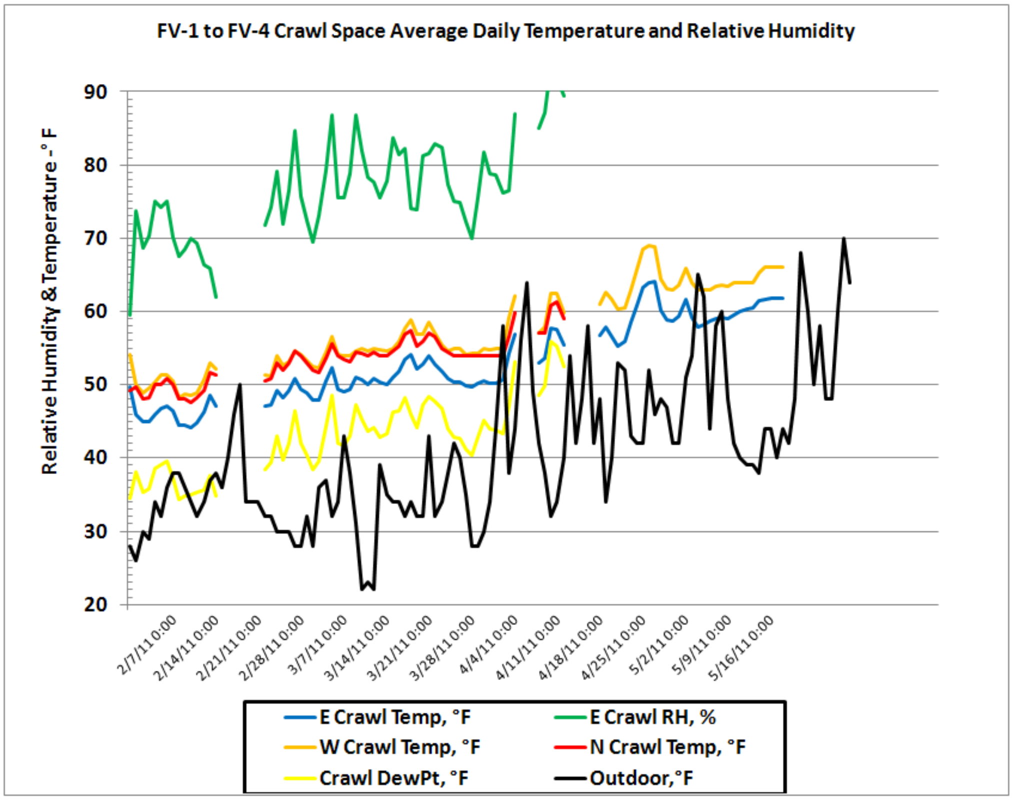

Figure 44. Crawlspace temperature and relative humidity FV-1 through FV-4.

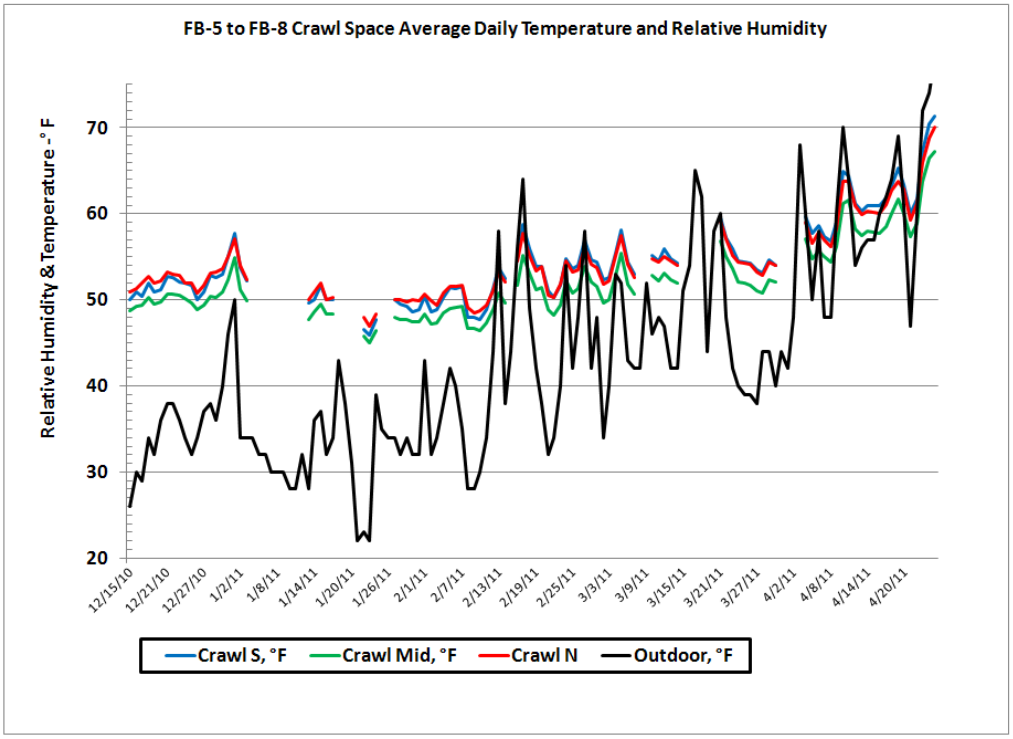

Figure 45. Crawlspace temperature and relative humidity FV-5 through FV-8.

11 Summary

The purpose of Phase 1 of the Greenbelt Homes Inc. (GHI) pilot program was to determine the pre-retrofit condition of older homes, develop simulation models to estimate energy and cost savings, make building envelope upgrade recommendations, and instrument the homes to determine a baseline energy use and compare with utility meter readings. The pre-retrofit condition of the 28 homes in the pilot program was established through occupant interviews, compilation of the previous years' utility bills, physical inspections, and air infiltration and water flow testing. As a result, the pre-retrofit conditions are available in detail for each of the building exterior wall types including block, wood frame with brick façade, and wood frame with vinyl siding.

The energy simulations for each wall type were completed using BEopt v1.01. Equipment specifications, dimensions, building orientation, and other apparent features were recorded by Research Center staff during site walk-through evaluations and short-term testing of the pilot project units. A minimum of one end and one interior unit was modeled in each building. Estimated savings and costs for the whole building were tallied from these outcomes. Several buildings were made up of unique homes, thus modeling more than two of the four units was warranted. The results of energy modeling were assembled in a spreadsheet to aid GHI staff in presenting the upgrade options to its membership.

The baseline monitoring included collecting energy data to establish pre-retrofit energy use. Energy use data is being recorded and analysis covering data that was captured for a period of the 2010/2011 heating season was presented herein. Ongoing data collection throughout all phases of the pilot project includes energy, temperature, and RH data. Using the collected baseline data, the Research Center compared the estimated heating energy from the simulation tins with the actual whole-house energy use monitored data. The result was a close correlation between the simulations and the data.

The baseline performance of each of the 28 homes was determined from the monitored data and the utility meter readings for each of the building types including block, wood frame with brick façade, and wood frame with vinyl siding. For the block buildings, the data shows increasing energy use as the temperature difference between outdoors and indoors increases. The energy use for heating in masonry homes such as these may be somewhat out of sync with weather patterns because the large thermal mass of the building tends to cause a lag in transferring thermal energy across the walls and floors. The energy used in the wood frame brick (FB) units is significantly lower than for the block (B) units due the former having wall insulation. The whole house energy used in the wood frame vinyl (FV) and FB units is similar since these units all have similar wall and ceiling insulation. For all of the units, the maximum energy for space heating is, as would be expected, higher for the exterior units than the interior-occupied unit. In addition, the utility meter data correlates well with the measured data for all the units.

Indoor temperature, RH, was also collected as part of the monitored data. The most significant finding, based on the recorded building conditions, is that 64% of the occupied units maintained average indoor winter temperatures less than 68°F; a threshold generally viewed as the minimum set point for energy simulations (and comfort) and that which was used for the GHI pilot program simulations. The indoor conditions, representing the pre-retrofit comfort of the homeowners, were also assessed based on the indoor RH. Homes in the pilot study tended to show average indoor RH within the 2001 ASHRAE Fundamentals 25%–60% recommendation range. However, 14 of 26 homes recorded showed average household RH higher than the more recently recommended limit of 40%. Two of the block houses had RH levels over 60% for some duration of the heat season.

Relative humidity was also monitored in the crawlspaces of the buildings in the pilot study. An acceptable range would be similar to the range identified for indoor conditions. As a result, dehumidifiers have been recommended for the block (B) and wood frame brick (FB) building crawlspaces and air dilution via ventilation grills was recommended for the wood frame vinyl (FV) buildings. A full vapor barrier to cover the entire crawlspace floor was added in the fall of 2011 to all buildings. The data indicates that the dew point in the crawlspaces remains below the temperature in the crawlspaces, generally resulting in little condensation potential on surfaces.

12 Next Steps

GHI has established a pilot project that will serve as a basis for decision making for the rollout of a decade-long community upgrade program that will improve the energy efficiency of the building envelope and equipment such as plumbing, mechanical equipment, and cladding. The pilot project has three phases focused on identifying the added costs and benefits of energy efficiency features, which are to be installed during a planned communitywide replacement program commencing in 2015. Phase 1 presented in this report consisted of an evaluation of the current operation, use, environmental conditions, and energy costs.

The next steps will include Phase 2 and 3 of the GHI pilot program. Phase 2 will consist of the installation of the building envelope improvements identified in Phase 1, monitoring energy consumption for the heating season following installation, and performing energy simulations supporting recommendations for HVAC and water heating upgrades to be implemented in Phase 3. The whole-house monitoring will continue throughout the project, both with the building envelope upgrades in Phase 2 and the HVAC upgrades in Phase 3.

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Hendron, R. (2006). "Building America Performance Analysis Procedures for Existing Homes". NREL/TP-550-38238: Golden, CO. National Renewable Energy Laboratory http://www.nrel.gov/buildings/pdfs/38238.pdf

Krigger, J; Dorsi, C. (2009). *Residential Energy: Cost Savings and Comfort for Existing Buildings.* 5th Edition..Helena, MT: Saturn Resource Management, Inc.

NAHB Research Center (2011). *Test Plan: Energy Use Analysis and Performance Monitoring of the GHI Remodel Pilot Program*. (internal only).

Appendix A: Typical Building Specifications

Table 12. 8 in. CMU Block, BV-1, B-5, B-6, BV-2.

Greenbelt Homes, Inc.				
Date:	11/15/2010			
	BV-2	B-6	B-5	BV-1
Unit Code	Before	Before	Before	Before
Feature/ Component				
Year Built	1941?	1941?	1941?	1941?
House Type	Town - End; C3.9	Town - Interior; C2.6	Town - Interior; C2.6	Town - End; C3.9
Structural Wall Type	8" CMU	8" CMU	8" CMU	8" CMU
Front Orientation	North	North	North	North
Finished Sq. Ft. Main	1,183	822	769	1,166
Addition Sq. Ft.	77	77		360
No. Stories	2	2	2	2
Bedrooms	2	1	1	3
Baths	1.5	1.0	1.0	2.0
Ceiling Ht.	8'2"	8'-2"	8'-2"	8'-2"
Foundation	Closed crawlspace 4'	Closed crawlspace 4'	Closed crawlspace 4'	Closed crawlspace 4'
Foundation R-value	R-5/7.5	R-5/7.5	R-5/7.5	R-5/7.5
Floor R-value	0	0	0	0
Heated	No	No	No	No
Vented	No	No	No	No
1st Floor	5" structural slab	5" structural slab	5" structural slab	5" structural slab
2nd Floor	5" structural slab	5" structural slab	5" structural slab	5" structural slab
Attic Ceiling	5" structural slab	5" structural slab	5" structural slab	5" structural slab
Attic R-value	R-26	R-26	R-26	R-26
Building Dimensions	27.83 x 20	25x20	25x20	27.83 x 20
Addition Dimensions	11x7	11x7		18x20
Roof Rafter	Flat Concrete Roof	Flat Concrete Roof	Flat Concrete Roof	Flat Concrete Roof
Structural Wall	8" CMU	8" CMU	8" CMU	8" CMU
Siding	Vinyl w/rigid foam	Painted CMU	Painted CMU	Vinyl w/ rigid foam
Windows Mat'l	vinyl slider	vinyl slider	vinyl slider	vinyl slider
Window Sq. Ft.	74/49/95/0	71/0/52/0	74/0/48/0	78/0/102/35
Window U-/SHGC	.55/.70	.55/.70	.55/.70	.55/.70
Wall Sheathing	none - CMU w/siding	none - painted CMU	none - painted CMU	none - CMU w/siding
Wall R-value	5.0	0	0	5.0
Front Door	3068 wood	3070 wood	3070 wood	3070 wood
Left Door	none	none	none	n/a
Rear Door	3068 ins.	3068 ins.	3070 wood	3070 wood
Right Door	none	none	none	n/a
Storms	Yes	Yes	Yes	Yes
Air Leakage, ACH50	4.8	8.4	4.3	7.2
Mechanical Ventilation, run time	0	0	0	0
Water Heater	50/Rheem	50/AO SMITH	50/AO SMITH	50/State Select
Model	RHEPRO52-2	EES52J20972H43	EES52J20972H43	P65220RT2
Energy Usage	5109 kW/yr	5109 kW/yr	5109 kW/yr	5109 kW/yr
Location	Boiler Room	Boiler Room	Boiler Room	Laundry Room
Cooling Type-Int.	Whirlpool	Fedders	LG	Hampton Bay
Manufacturer	24x18	24"x18"	24x12	HBQ075
Location	2nd wall	2nd wall	2nd wall	2nd wall
Removed out of season?	No	No	2nd hallway	No
Heating Type-Int.	Elec. BB	Elec. BB	Elec. BB	Elec. BB
EBB Capacity (Btu) Inf	37	24	25	37
H2O Heater Manufacturer	Rheem	AO SMITH	AO SMITH	State Select
Model	RHEPRO52-2	EES52J20972H43	EES52J20972H43	P65220RT2
Size	50	50	50	50 Gallon
Location	Bsmt boiler room	Bsmt boiler room	Bsmt boiler room	Laundry Room
Energy Usage	Installed 11/1997	Installed 09/2000	Installed 04/2000	4624 kwh/yr - EF .88
Toilet flush (gal. per)	1.6	1.6	1.6	2.4
Shower/Sink flow (gpm)	1.5/1.5	1.5/1.0		1.5/1.55

Table 13. 8 in. CMU Block, BV-3 through BV-6.

Greenbelt Homes, Inc.				
Date:	11/3/2010			
	BV-3	**BV-4**	**BV-5**	**BV-6**
Unit Code	Before	Before	Before	Before
Feature/ Component				
Year Built	1941	1941	1941	1941
House Type	Town - End, C 2.8	Town - Interior, C 2.7	Town - Interior, C 3.7	Town - End, C 3.7
Structural Wall Type	8" CMU	8" CMU	8" CMU	8" CMU
Front Orientation	Southeast	Southeast	Southeast	Southeast
Finished Sq. Ft.	1080	1080	1160	1160
Addition Sq. Ft.	32			
No. Stories	2	2	3	3
Bedrooms	2	2	3	3
Baths	1	1	1	1
Ceiling Ht.	98"	98"	98"	4
Foundation	Closed Concrete Crawl 3.5'	Closed Concrete Crawl 3.5'	Walkout Bsmt	Walkout Bsmt
Foundation R-value	R-5	R-5	No	No
Floor R-value	0	0	0	0
Vented Crawlspace	No	No	n/a	n/a
1st Floor	5" structural slab	5" structural slab	5" structural slab	5" structural slab
2nd Floor	5" structural slab	5" structural slab	5" structural slab	5" structural slab
Attic Ceiling	5" structural slab	5" structural slab	5" structural slab	5" structural slab
Attic R-value	R-26	R-26	R-26	R-26
Roof Rafter	Flat Concrete Roof	Flat Concrete Roof	Flat Concrete Roof	Flat Concrete Roof
Building Dimensions	26.67x20	26.67x20	28.67x20w/bsmt.	28.67x20w/bsmt.
Addition Dimensions	4x8			
Structural Wall	8" CMU	8" CMU	8" CMU	8" CMU
Siding	Vinyl - no insul.?	Vinyl - no insul.?	Vinyl - no insul.?	Vinyl - no insul.?
Windows Mat'l	1980 Vinyl sliders	1980 Vinyl	1980 Vinyl	1980 Vinyl
Window, Sq. Ft.	64/35/107/0	65/0/80/0	70/0/120/0	73/0/127/49
Window U-/SHGC	.55/.70	.55/.70	.55/.70	.55/.70
Wall R-value	0	0	0	0
Front Door	wood 3070 2 lt.	wood 3070 w/3lt.	wood 3070 w/ 3 lts	wood 3070 w/ 3 lts
Rear Door	3068 full glass	3070 wood 1/2 gl	3070 w/ 1/2 lt.	3070 w/ 1/2 lt.
Air Leakage, ACH50	7.5	3.5	4.3	4.0
Mech.Vent., run time	0.00%	0.00%	0.00%	0.00%
Water Heater	47/State	State	Rheem	50/State
Model	E5650DOLS	P65020LSWX	81SV52D	P6522ORTZ
Energy Factor Use	Effic. .90	5,000	5,108	
Location	Stair Closet	Low under counter	Bsmt.	Boiler Room
Cooling Type	LR - thru-wall 15Kbtu	Hall thru-wall	LR thru wall A/C	Hall thru wall GE
Cooling Manufacturer	Sears	Carrier	Fedders FE596151	Unk.
Model	15Kbtu	EER 9.2	FE596151	RS APR-1000ES 8.9EER
Removed out of season?	No	No	No	No-hall, Yes MBR
Location	Hall thru-wall	2nd wall	2nd wall	MBR portable
Heating Type	FE596151	FE596151	FE596151	FE596151
Linear feet (@250 watts/foot)	24	33	46	43
Thermostat Location	on units	on units	on units	on units
Ceiling Heat (K, Kitchen; B, Bath)	no	no	no	no
Toilet Flush (gal. per)		2.4		1.6
Shower/Sink Flow (gpm)	1.5/1.25	2.0/1.5	2.5/1.75	1.5/2.55

Table 14. Wood Frame Brick Veneer, FB-1 through FB-4.

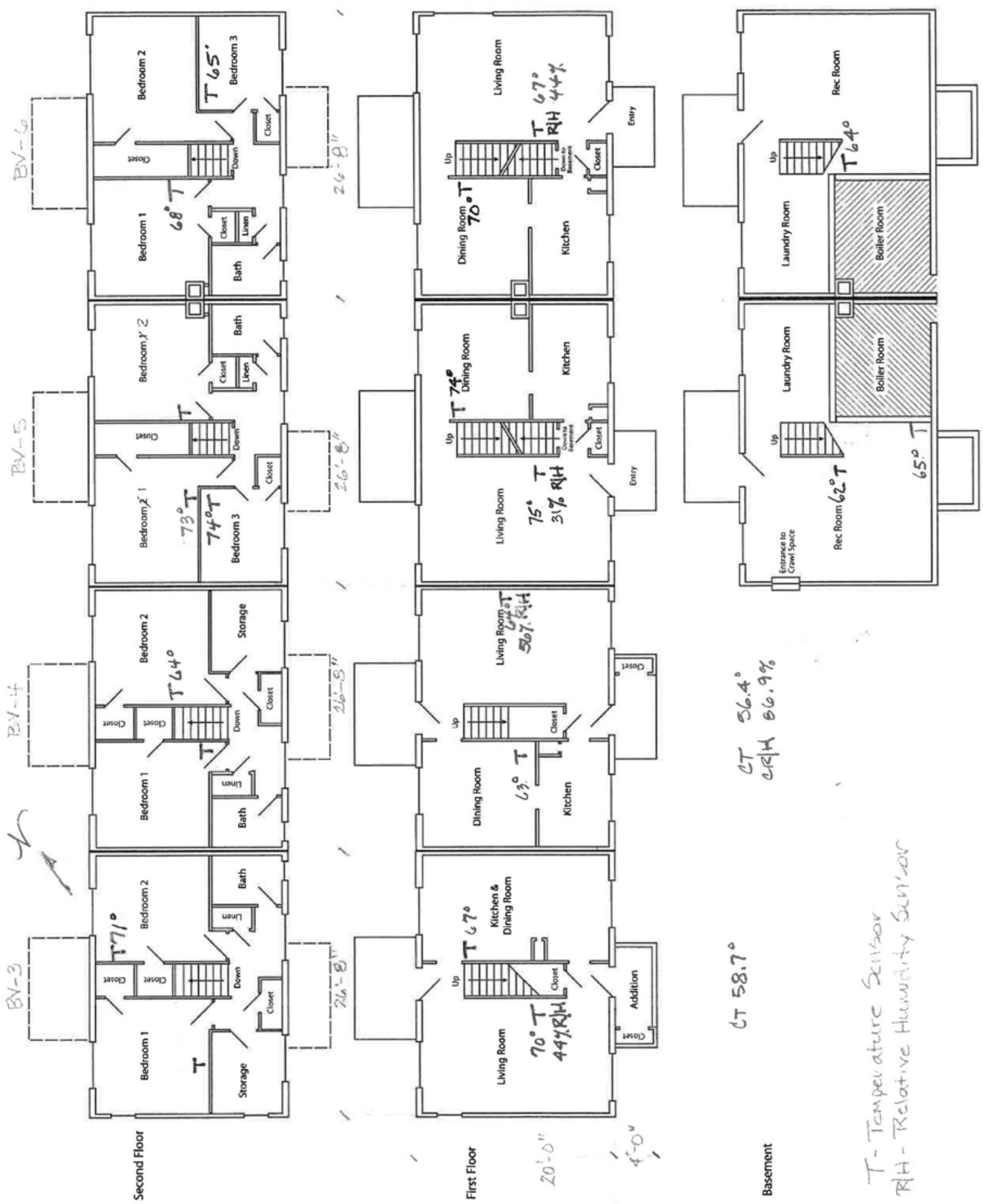
Greenbelt Homes, Inc.				
Date:	11/8/2010			
Unit Code	FB - 1	FB - 2	FB - 3	FB - 4
Feature/ Component	Before	Before	Before	Before
Year Built	1936	1936	1936	1936
House Type	Town-End, C2.7	Town-Interior, C 2.7	Town-Interior, C2.7	Town-End, C2.7
Structural Wall Type	2x4 Frame w/Brick	2x4 Frame w/Brick	2x4 Frame w/Brick	2x4 Frame w/Brick
Front	South	South	South	South
Finished Sq. Ft., Main	1080	1080	1080	1080
Addition, Sq. Ft.	0	0	0	0
No. Stories	2	2	2	2
Bedrooms	2	2	2	2
Baths	1	1	1	1
Ceiling Ht.	7'-11"	7'-11"	7'-11"	7'-11"
Foundation	Concrete Crawl 4'	Concrete Crawl 4'	Concrete Crawl 4'	Concrete Crawl 4'
Foundation R-value	R-10	R-10	R-10	R-10
Floor R-value	0	0	0	0
Vented Crawlspace	No	No	No	No
1st Floor	structural slab	structural slab	structural slab	structural slab
2nd Floor	2x8 joists at 16"	2x8 joists at 16"	2x8 joists at 16"	2x8 joists at 16"
Attic Ceiling	2x8 joists at 16"	2x8 joists at 16"	2x8 joists at 16"	2x8 joists at 16"
2nd Floor and Attic	2x8 joists at 16"	2x8 joists at 16"	2x8 joists at 16"	2x8 joists at 16"
Attic R-value	R-16	R-16	R-16	R-16
Roof Rafter	2x6 rafters at 16"	2x6 rafters at 16"	2x6 rafters at 16"	2x6 rafters at 16"
Roof Sheathing	1x6 T&G	1x6 T&G	1x6 T&G	1x6 T&G
Wall Sheathing	1x6 T&G	1x6 T&G	1x6 T&G	1x6 T&G
Structural Wall	wood frame 2x4	wood frame 2x4	wood frame 2x4	wood frame 2x4
Siding	Brick Veneer	Brick Veneer	Brick Veneer	Brick Veneer
Windows Mat'l	vinyl casement 9/16"	vinyl sliders	vinyl sliders	vinyl sliders
Building Dimensions	26.67x20	26.67x20	26.67x20	26.67x20
Addition Dimension	n/a	n/a	n/a	n/a
Window SF	66/0/96/35	67/0/88/0	71/0/85/0	66/19/96/0
Window U-/SHGC	.55/.70	.55/.70	.55/.70	.55/.70
Wall R-value	R-11	R-11	R-11	R-11
Front Door	3070 wd	3070 wd	3070 wd	3070 wd
Storm Doors	Yes	Yes	Yes	Yes
Rear Door	Wood 1/2 glass	Wood 1/2 glass	Wood 1/2 glass	Wood 1/2 glass
Air Leakage, ACH50	10.4	6.8	7.4	8.0
Mech. Vent., run time	0	0	0	0
Water Heater	50 gal. State	50 gal. State	50 gal. State	50 gal. State
Model	CD065220RTV	CD065220RTV	CD065220RTV	CD065220RTV
Energy Factor Use	5952 kwh	5952 kwh	5952 kwh	5952 kwh
Location	Boiler Room	Boiler Room	Boiler Room	Boiler Room
Cooling Type	Hall thru- wall	Hall thru-wall	Thru wall A/C	Thru wall A/C
Manufacturer	Carrier 26x18 EER9.0	GE EER9.7	Frigidaire Energy Star	Carrier 24" x 15"
Model	Carrier	GE	FAS257R24	International Series
Location	2nd floor thru-wall	2nd floor thru-wall	2nd floor thru-wall	2nd floor thru-wall
Heating Type	Electric Baseboard	Electric Baseboard	Electric Baseboard	Electric Baseboard
Linear feet (@250 watts/foot)	36	29	26	28
Ceiling Heat (K, Kitchen; B, Bath)	K	B	K,B	
Thermostat Location	on wall	on wall	on wall	on wall
Toilet flush (gper)	1.6	1.6	2.4	2.5
Shower/Sink Flow (gpm)	1.0/1.5	1.5/1.5	1.5/1.6	3.0/1.5

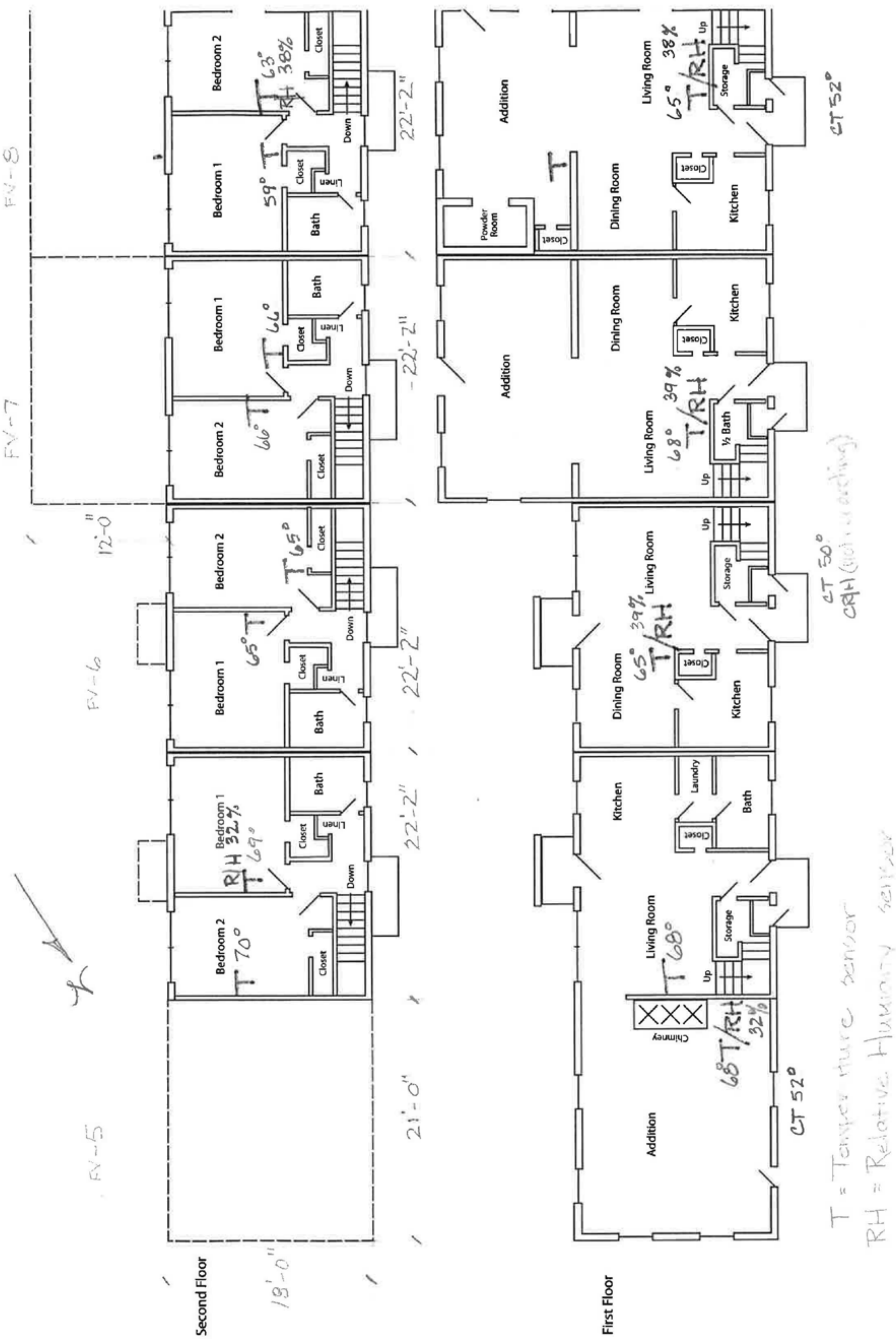
Table 15. Wood Frame Vinyl, FV-1 through FV-4.

Greenbelt Homes, Inc.				
Date:	11/19/2010			
Unit Code	FV1	FV2	FV3	FV4
Feature/ Component	Before	Before	Before	Before
Year Built	1941	1941	1941	1941
House Type	Town-End Left: F-2L	Town -Interior	Town -Interior; F-2	Town-End Right; F-2
Structural Wall Type	Frame 2x4	Frame 2x4	Frame 2x4	Frame 2x4
Front	North	North	North	North
Finished Sq. Ft. Main	782	782	782	782
Addition Sq. Ft.	154			88
No. Stories	2	2	2	2
Bedrooms	2	2	2	2
Baths	1	1	1	1
Ceiling Ht.	7-11"		7-II"	
Foundation	Block Crawlspace - 32"	Block Crawlspace - 32"	Block Crawlspace - 32"	Block Crawlspace - 32"
Floor R-value	R-11, FG Batt	R-11, FG Batt	R-11, FG Batt	R-11, FG Batt
Vented Crawlspace	8x16" vent ea. Side of unit	8x16" vent ea. Side of unit	8x16" vent ea. Side of unit	8x16" vent ea. Side of unit
1st Floor	2x8 at 16"	2x8 at 16"	2x8 at 16"	2x8 at 16"
2nd Floor	2x8 at 16"	2x8 at 16"	2x8 at 16"	2x8 at 16"
Attic Floor	2x6 at 16"	2x6 at 16"	2x6 at 16"	2x6 at 16"
Attic R-value	R-16	R-16	R-16	R-16
Roof Rafter	2x6	2x6	2x6	2x6
Roof Sheathing	1x8	1x8	1x8	1x8
Structural Wall	2x4	2x4	2x4	2x4
Siding	Vinyl siding on 2x4	Vinyl siding on 2x4	Vinyl siding on 2x4	Vinyl siding on 2x4
Windows Mat'l	Vinyl/sunroom sgl w/strms	Vinyl	Vinyl	Alum. 9/16" dbl glazed
Building Dimensions	17x23	17x23	17x23	17x23
Addition Dimensions	11x14			8x11
Windows, Sq. Ft.	74/0/86/87	58/0/55/0	40/0/48/0	40/54/41/0
Window U-/SHGC	.55/.70	.55/.70	.55/.70	.55/.70
Wall Sheathing	1x6?	1x6?	1x6?	1x6?
Wall R-value	R-11, Cellulose, settled	R-11, Cellulose, settled	R-11, Cellulose, settled	R-11, Cellulose, settled
Front Door	21068 1/2 glass w/storm	3068 1/2 glass wood	21068 w/1/2 glss	3068 insulated
Front Door	2668 wood w/storm			
Rear Door	21068 wood w/storm	2868 w/storm	3068 wood	2868 with dog door
Right Door	none	none	none	3068 insulated (faces west)
Door U-value				
Air Leakage, ACH50	9.7	13.1	9.3	14.1
Mechanical Ventilation, run time	no	no	no	no
Water heater	50/Rheem	50/State Select	50/Rheem	50/Rheem
Model	81V52DC	CD65522ORTV	RH0899F03951	RH0899F03951
Energy Factor Use	4,828		5,109	5,109
Location	Closet under stairs	Closet under stairs	Closet under stairs	Closet under stairs
Cooling Type	Thru window A/C	Thru window A/C	None	DR/ window 18x12
Manufacturer	LG (18x12)	Frigidaire (18x14)		Whirlpool
Efficiency				
Location	2nd floor bedroom	Kitchen		Haier HWF05XC5-T
Removed out of season?	yes	no		yes
Heating Type	Elec. Baseboard	Elec. Baseboard	Elec. Baseboard	Elec. Baseboard
Linear feet (@250 watts/foot)	24	18	14	23
Ceiling Heat (K, Kitchen; B, Bath)	K,B	K,B	K,B	B
Thermostat Location	Interior walls	Interior walls/unit	Units	
Toilet flush (gal. per)	2.4	1.6	2.4	1.6
Shower/Sink Flow (gpm)	1.0/1.4	1.3/1.5	1.8/1.2	1.1/

Appendix B: Temperature and RH Sensor Locations

These drawings show example of floor plans and location of temperature/humidity sensors.




Second Floor
First Floor
FV-5
FV-6
FV-7
FV-8
Bedroom 1
Bedroom 2
Bath
Closet
Linen
Down
Up
Addition
Living Room
Dining Room
Kitchen
Storage
Laundry
Chimney
½ Bath
Powder Room
T = Temperature sensor
RH = Relative Humidity sensor

Appendix C: Phase 1 Energy Simulations

Before and After Energy Features
Energy Usage Simulation Results
Per Building and Per Unit (4 per Building)

Block Building – B-1, B-2, B-3, B-4

Table 16. Block Building – B-1, B-2, B-3, B-4.

Bldg/Unit	15A		15B		15C		15D	
Unit Code	B1	B1	B2	B2	B3	B3	B4	B4
Feature/ Component	Before	After	Before	After	Before	After	Before	After
House Type	Town - End: C 3.9		Town - Interior C2.6		Town - Interior C 2.6		Town - End C 3.9 w/11x7 add	
Structural Wall Type	8" CMU		8" CMU		8" CMU		8" CMU w/frame add	
Front Orientation	South		South		South		South	
Finished Sq. Ft., Main	1,168		844		787		1,168	
Sq. Ft. Addition							77	
No. Stories	2		2		2		2	
Bedrooms	3		2		2		3	
Baths	1		1		1		2	
Foundation	Concrete Crawl - 4'		Concrete Crawl - 4'		Concrete Crawl - 4'		Concrete Crawl - 4'	
Foundation R-value	R-5	R-10	R-5	R-10	R-5	R-10	R-5	R-10
Floor R-value	0		0		0		0	
Vented Crawlspace	No		No		No		No	
1st Floor	5" structural slab		5" structural slab		5" structural slab		5" structural slab	
Attic R-value	26		26		26		26	
Building Dimensions	25x20; 9x12		16x20; 9x12		16x20; 9x8		25x20; 9x10	
Addition Dimensions							11x7	
Square Ft Windows	54/36/85/0		63/0/55/0		72/0/68/0		37/7/100/36	
Window U-/SHGC	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30
Wall R-value	0	R-12	0	R-12	0	R-12	10	R-12
Front Door	070 wood w/storm	U=.23	3070 1/3 gls w/st	U=.23	3070 3lt w/storm	U=.23	3070 wood w/sto	U=.23
Rear Door	70 Wood 1/2 gls s	U=.23	3070 Wood 1/2 gl	U=.23	3070 Wood 1/2 gl	U=.23	3070 Wood 1/2 gl	U=.23
Right Door							28x68 insulated	
Air Leakage, ACH50	4.7	4.2	3.3	3.0	2.4	2.2	4.8	4.3
Mechanical Ventilation, run time	no	Exh.&timer-100%	no	Exh.&timer-100%	no	Exh.&timer-100%	yes-unused	Exh.&timer-100%
	Energy Costs (excl. Fan/Pump)							
Hot Water Energy	$429	$429	$353	$353	Use B2 Modeled Output		Use B1 Modeled Output	
Heating Energy	$1,466	$602	$917	$413				
Lights	$184	$184	$148	$148				
Appliances	$296	$296	$252	$252				
Misc. Loads	$444	$444	$378	$378				
Ventilation Fan		$15		$13				
Total Annual Energy Use	$2,819	$1,970	$2,048	$1,557				
% Whole House Energy Savings		30.12%		23.97%				
% Heating Energy Savings		58.94%		54.96%				
Energy Cost Savings		$849		$491		$491		$849
Cost Savings for 4-unit Block Building		$2,680						

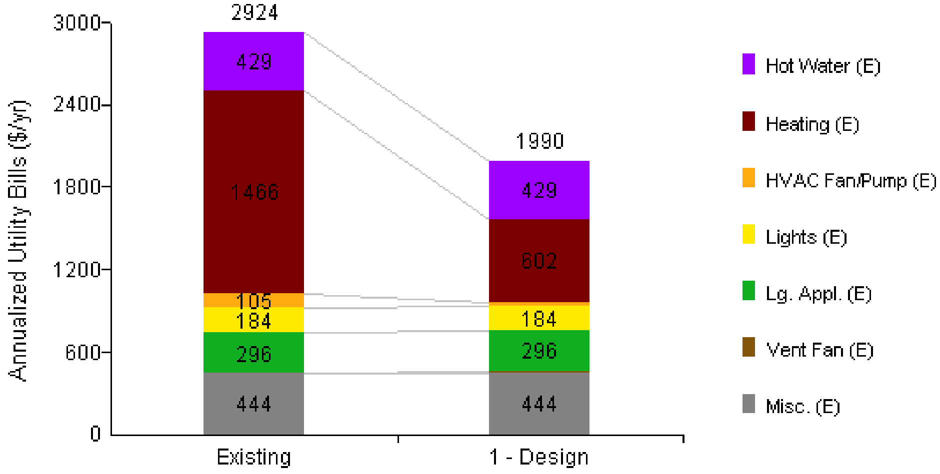


Figure 46. Modeled energy use B-1.

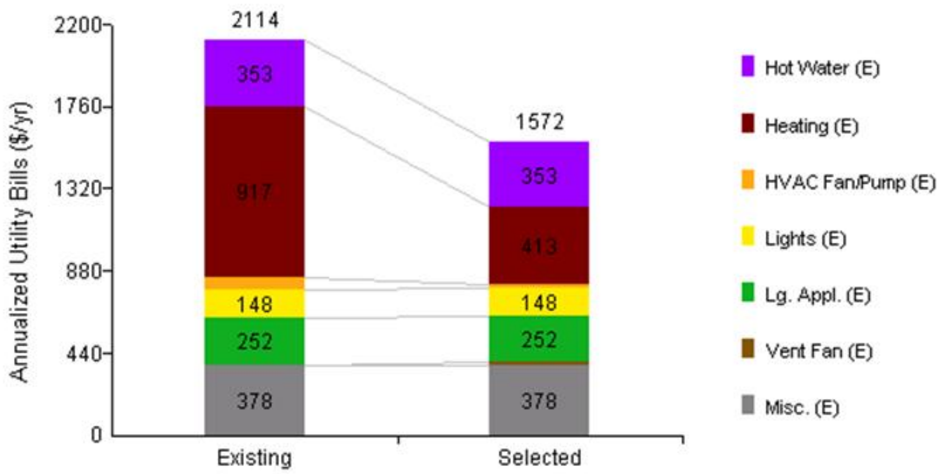


Figure 47. Modeled energy use B-2.

Block Vinyl-Sided Buildings – BV-3, BV-4, BV-5, BV-6

Table 17. Block Vinyl-Sided Buildings – BV-3, BV-4, BV-5, BV-6.

Unit Code Feature/ Component	BV3 Before	BV3 After	BV4 Before	BV4 After	BV5 Before	BV5 After	BV6 Before	BV6 After
House Type	Town - End, C 2.8		Town - Interior, C 2.7		Town - Interior, C 3.7		Town - End, C 3.7	
Structural Wall Type	8" CMU		8" CMU		8" CMU		8" CMU	
Front Orientation	Southeast		Southeast		Southeast		Southeast	
Finished Sq. Ft.	1080		1080		1160		1160	
Addition Sq. Ft.	32							
No. Stories	2		2		3		3	
Bedrooms	2		2		3		3	
Baths	1		1		1		1	
Foundation	Concrete Crawl 3.5/4'		Concrete Crawl 3.5/4'		Walkout Bsmt		Walkout Bsmt	
Foundation R-value	R-5	R-10	R-5	R-10	No	R-13	No	R-13
Floor R-value	0	R-10 Porch Slab	0	R-10 Porch Slab	0	R-10 Porch Slab	0	R-10 Porch Slab
Vented Crawlspace	No		No		n/a		n/a	
1st Floor	5" structural slab		5" structural slab		5" structural slab		5" structural slab	
Attic R-value	R-26		R-26		R-26		R-26	
Building Dimensions	26.67x20		26.67x20		28.67x20w/bsmt.		28.67x20w/bsmt.	
Addition Dimensions								
Window, Sq. Ft.	64/35/107/0		65/0/80/0		70/0/120/0		73/0/127/49	
Window U-/SHGC	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30
Wall R-value	0	R-12	0	R-12	0	R-12	0	R-12
Front Door	wood 3070 2 lt.	U=.23	wood 3070 w/3lt.	U=.23	wood 3070 w/ 3 lts	U=.23	wood 3070 w/ 3 lts	U=.23
Rear Door	3068 full glass		3070 wood 1/2 gl	U=.23	3070 w/ 1/2 lt.	U=.23	3070 w/ 1/2 lt.	U=.23
Air Leakage, ACH50	7.5	4.8	3.5	3.2	4.3	3.8	4.0	3.7
Mechanical Ventilation, run time	0.00%	Ex.&timer 100%	0.00%	Ex.&timer 100%	0.00%	Ex.&timer 100%	0.00%	Ex.&timer 100%
	Energy Costs (excluding Fan/Pump)							
Hot Water	$353	$353	$353	$353	$446	$446	$429	$429
Heating	$1,149	$568	$783	$439	$1,117	$576	$1,353	$700
Lights	$170	$170	$170	$170	$227	$227	$227	$227
Appliances	$252	$252	$252	$252	$296	$296	$296	$296
Misc. Loads	$392	$392	$392	$392	$472	$472	$472	$472
Vent Fan		$11		$13		$19		$18
Total	2,316	1,746	1,950	1,619	2,558	2,036	2,777	2,142
Percentage Energy Savings		25%		17%		20%		23%
Heating Energy Savngs		51%		44%		48%		48%
Energy Cost Savings		$570		$331		$522		$635
Annual Cost Savings for 4-Unit Block/Vinyl Building (2 with basements)				$2,058				

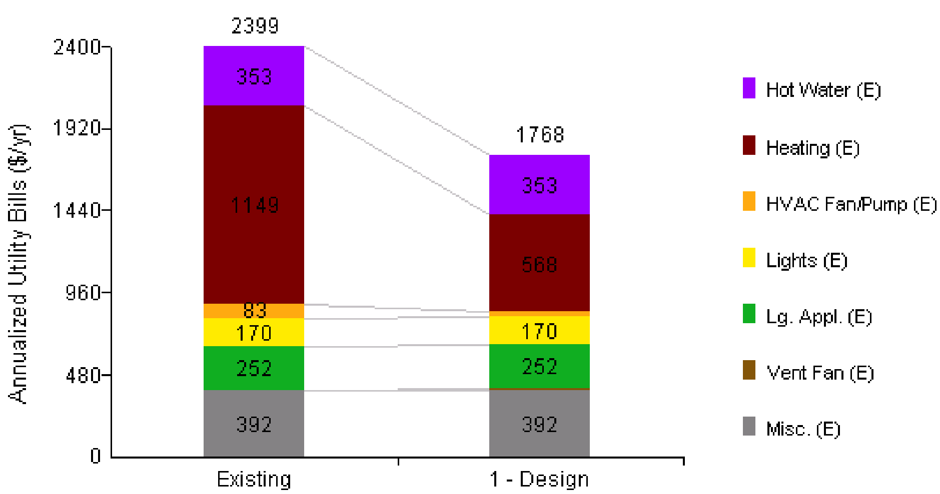


Figure 48. Modeled energy use BV-3.

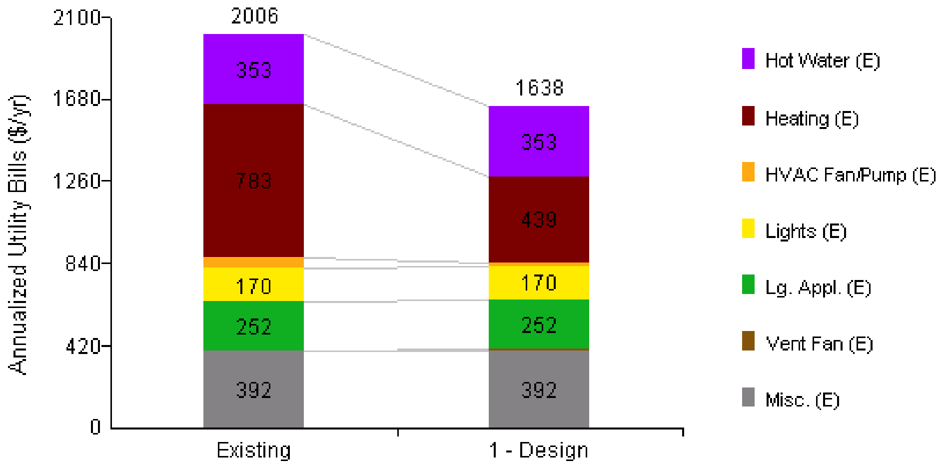


Figure 49. Modeled energy use BV-4.

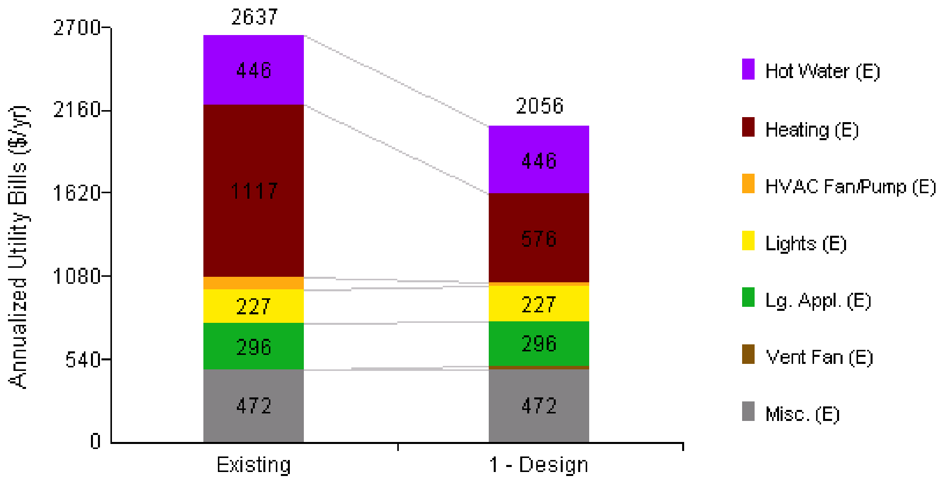


Figure 50. Modeled energy use BV-5.

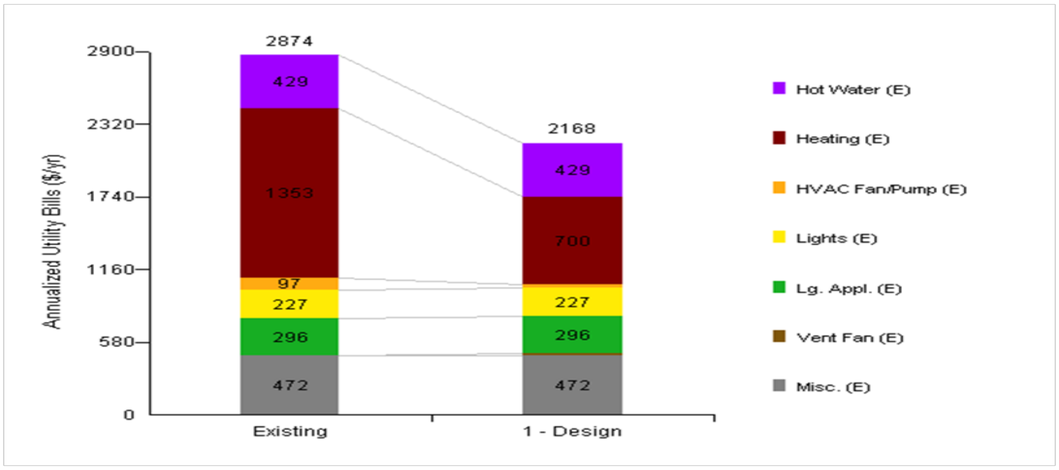


Figure 51. Modeled Energy Use BV-6.

Wood Frame Brick Building – FB-1 and FB-2

Table 18. Wood Frame Brick Building – FB-1 and FB-2.

Unit Code / Feature/ Component	FB1 Before	FB1 After	FB2 Before	FB2 After	FB3 Before	FB3 After	FB4 Before	FB4 After
House Type	Town-End, C2.7		Town-Interior, C 2.7		Town-Interior, C2.7		Town-End, C2.7	
Structural Wall Type	2x4 Frame w/Brick		2x4 Frame w/Brick		2x4 Frame w/Brick		2x4 Frame w/Brick	
Front	South		South		South		South	
Finished Sq. Ft., Main	1080		1080		1080		1080	
Addition, Sq. Ft.								
No. Stories	2		2		2		2	
Bedrooms	2		2		2		2	
Baths	1		1		1		1	
Foundation	Concrete Crawl 4'		Concrete Crawl 4'		Concrete Crawl 4'		Concrete Crawl 4'	
Foundation R-value	R-5/7.5	R-10	R-5/7.5	R-10	R-5/7.5	R-10	R-5/7.5	R-10
Floor R-value	0	R-10 porch slabs & edge	0	R-10 porch slabs & edge	0	R-10 porch slabs & edge	0	R-10 porch slabs & edge
Vented Crawlspace	No		No		No		No	
1st Floor	structural slab		structural slab		structural slab		structural slab	
Attic R-value	R-13 & R-19 batts		R-13 & R-19 batts		R-13 & R-19 batts		R-13 & R-19 batts	
Building Dimensions	26.67x20		26.67x20		26.67x20		26.67x20	
Addition Dimension								
Glass/Values	66/0/96/35		67/0/88/0		71/0/85/0		66/19/96/0	
Window U-/SHGC	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30
Wall R-value	R-11		R-11		R-11		R-11	
Front Door	3070 wd 2-lt w/storm	U=.23	3070 wd 2-lt w/storm	U=.23	3070 wd 2-lt w/storm	U=.23	3070 wd 2-lt w/storm	U=.23
Rear Door	3070 wd 1/2 gl w/storm	U=.23	3070 wd 1/2 gl w/storm	U=.23	3070 wd 1/2 gl w/storm	U=.23	3070 wd 1/2 gl w/storm	U=.23
Air Leakage, ACH50	10.4	5.6	6.8	4.8	7.4	4.8	8.0	5.6
Mechanical Ventilation, run time	0	Exh.&Timer 50%	0	Exh.&Timer 50%	0	Exh.&Timer 50%	0	Exh.&Timer 50%
	Energy Costs (excl. Fan/Pump)							
Hot Water	$353	$353	$353	$353	**Use FB2 Modeled Output**		**Use FB1 Modeled Output**	
Heating	$838	$605	$582	$451				
Lights	$170	$170	$170	$170				
Appliances	$252	$252	$252	$252				
Misc. Loads	$392	$392	$392	$392				
Ventilation Fan		$6		$7				
Total Annual Energy Use	$2,005	$1,778	$1,749	$1,625				
% Whole House Savings		11.32%		7.09%		7.09%		11.32%
% Heating Energy Savings		28%		23%		23%		28%
Energy Cost Savings		$227		$124		$124		$227
Cost Savings for 4-unit Frame/Brick Building			$702					

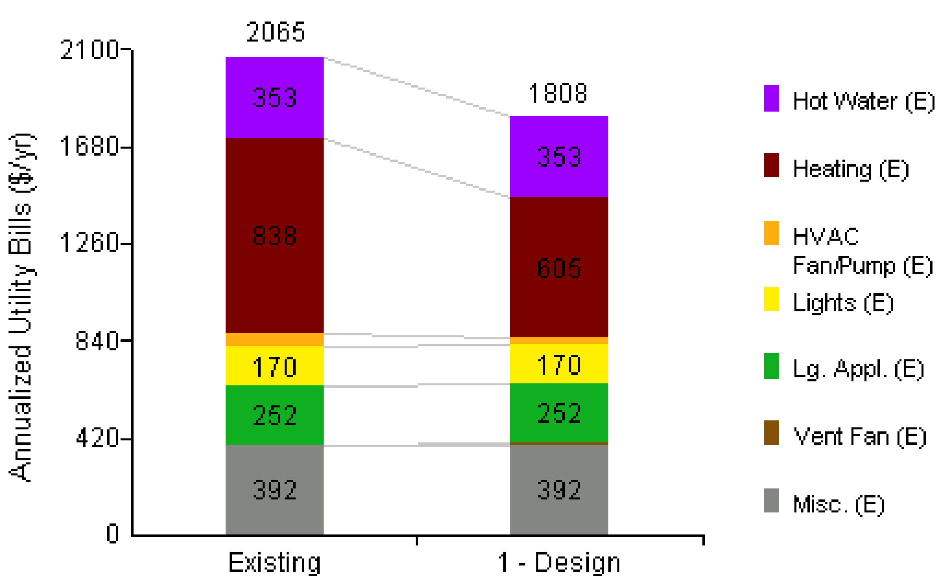


Figure 52. Modeled energy use FB-1.

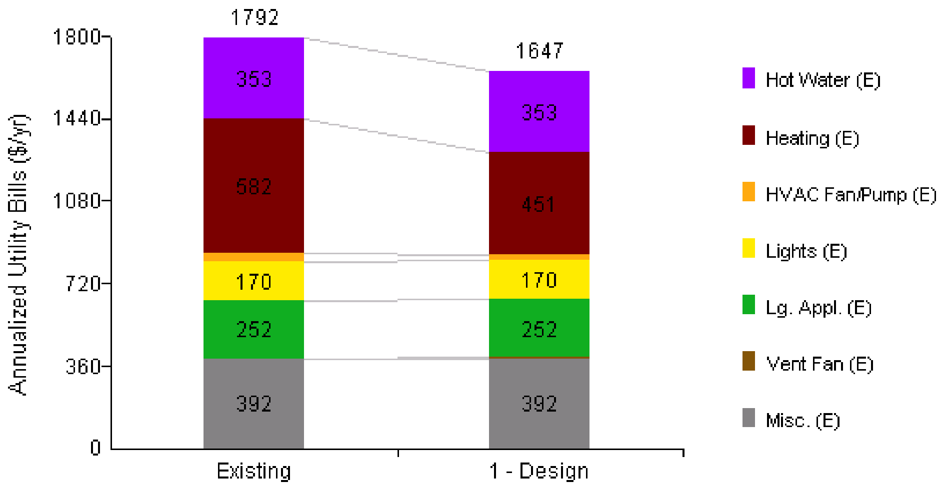


Figure 53. Modeled energy use FB-2.

Wood Frame Vinyl-Sided Building – FV-1, FV-2, FV-3, FV-4

Table 19. Wood Frame Vinyl-Sided Building – FV-1, FV-2, FV-3, FV-4.

Unit Code / Feature/ Component	FV1 Before	FV1 After	FV2 Before	FV2 After	FV3 Before	FV3 After	FV4 Before	FV4 After
House Type	Town-End Left: F-2L w/sunroom		Town -Interior		Town -Interior; F-2		Town-End Right; F-2 & fr porch add	
Structural Wall Type	Frame 2x4		Frame 2x4		Frame 2x4		Frame 2x4	
Front	North		North		North		North	
Finished Sq. Ft. Main	782		782		782		782	
Addition Sq. Ft.	154						88	
No. Stories	2		2		2		2	
Bedrooms	2		2		2		2	
Baths	1		1		1		1	
Foundation	Block Crawl - 32"		Block Crawl - 32"		Block Crawl - 32"		Block Crawl - 32"	
Floor R-value	R-11, FG Batt	R-19 SPF	R-11, FG Batt	R-19 SPF	R-11, FG Batt	R-19 SPF	R-11, FG Batt	R-19 SPF
Vented Crawlspace	8x16" vent each side, each unit		8x16" vent each side, each unit		8x16" vent each side, each unit		8x16" vent each side, each unit	
1st Floor	2x8 at 16"		2x8 at 16"		2x8 at 16"		2x8 at 16"	
Attic R-value	16	R-30/38	16	R-30/38	16	R-30/38	16	R-30/38
Building Dimensions	17x23		17x23		17x23		17x23	
Addition Dimensions	11x14						8x11	
Windows, Sq. Ft.	74/0/86/87		58/0/55/0		40/0/48/0		40/54/41/0	
Window U-/SHGC	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30	.55/.70	.30/.30
Wall R-value	R-11, Cellulose, settled		R-11, Cellulose, settled		R-11, Cellulose, settled		R-11, Cellulose, settled	
Front Door	21068 1/2 glass w/storm	U=.23	3068 1/2 glass wood	U=.23	21068 w/1/2 glss	U=.23	3068 insulated	
Front Door	2668 wood w/storm	U=.23						
Rear Door	1068 wood w/storm	U=.23	2868 w/storm	U=.23	3068 wood	U=.23	2868 with dog door	U=.23
Air Leakage, ACH50	9.7	6.4	11.5	5.6	10.4	5.6	14.1	6.4
Mechanical Ventilation, run time	no	Exhaust&Timer-10%	no	Exhaust&Timer-10%	no	Exhaust&Timer-10%	no	Exhaust&Timer-10%
	Energy Costs (excl. Fan/Pump)							
Hot Water	$353	$353	Use FV3 Modeled Output		$353	$353	$353	$353
Heating	$808	$524			$418	$191	$786	$371
Lights	$153	$153			$138	$138	$147	$147
Appliances	$252	$252			$252	$252	$252	$252
Misc. Loads	$381	$381			$370	$370	$377	$377
Ventilation Fan		$3				$3		$3
Total Annual Energy	$1,947	$1,666			$1,531	$1,307	$1,915	$1,503
% Whole House Energy Savings		14.43%				14.63%		21.51%
% Heating Energy Savings		35%				54%		53%
Energy Cost Savings		$281		$224		$224		$412
Cost Savings for 4-Unit Frame/Vinyl Building		$1,141						

FV1, FV2, FV3, FV4 with 2" polyiso under vinyl	Before	After	Use FV3 Modeled Output		Before	After	Before	After
Hot Water	$353	$353			$353	$353	$353	$353
Heating	$808	$493			$418	$165	$786	$326
Lights	$153	$153			$138	$138	$147	$147
Appliances	$252	$252			$252	$252	$252	$252
Misc. Loads	$381	$381			$370	$370	$377	$377
Ventilation Fan		$3				$3		$6
Total Annual Energy	$1,947	$1,635			$1,531	$1,281	$1,915	$1,461
% Whole House Energy Savings		16.02%				16.33%		23.71%
% Heating Energy Savings		39%				61%		59%
Energy Cost Savings		$312		$250		$250		$454
Cost Savings for 4-Unit Frame/Vinyl Building		$1,266						

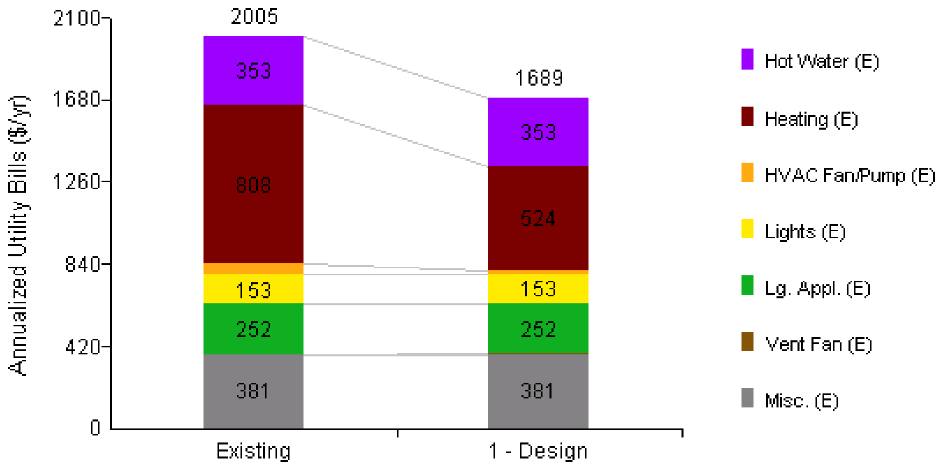


Figure 54. Modeled energy use FV-1.

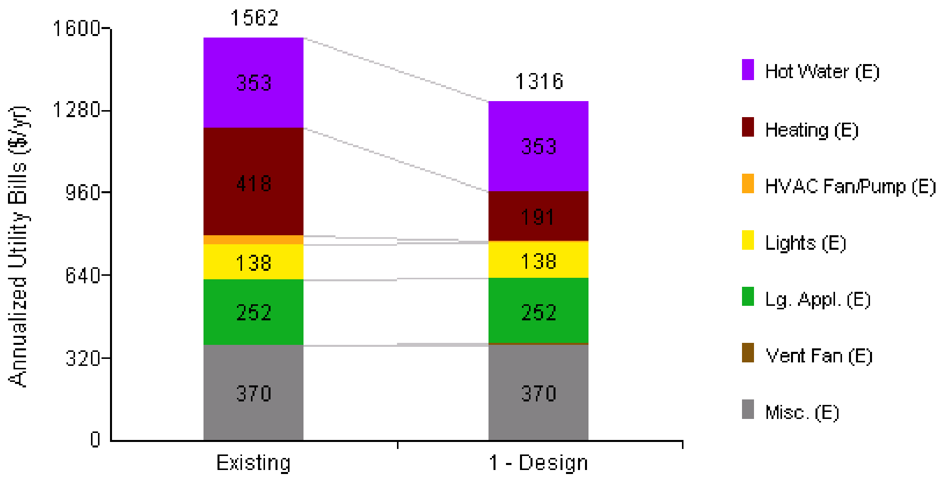


Figure 55. Modeled energy use FV-3.

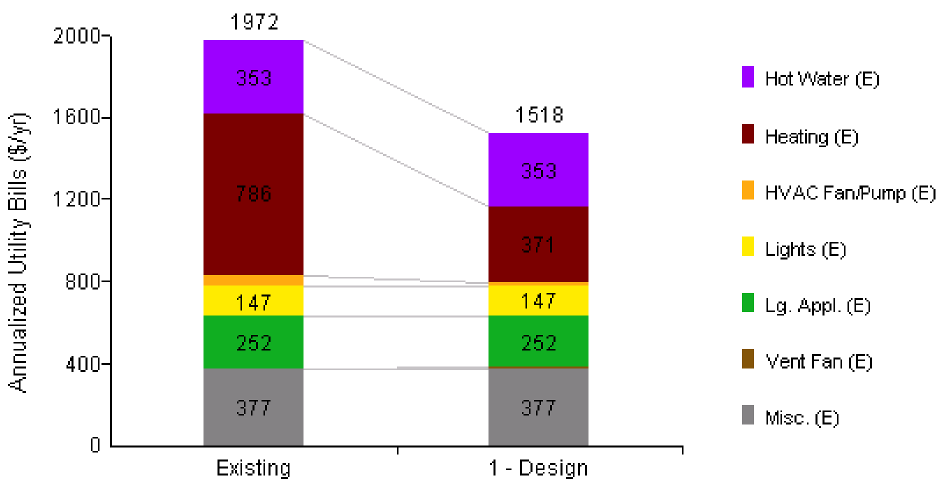


Figure 56. Modeled energy use FV-4.

Wood Frame Vinyl-Sided Building – FV-5, FV-6, FV-7, FV-8

Table 20. Wood Frame Vinyl-Sided Building – FV-5, FV-6, FV-7, FV-8.

Unit Code Feature/ Component	FV5 Before	FV5 After	FV6 Before	FV6 After	FV7 Before	FV7 After	FV8 Before	FV8 After
House Type	Town-End G-2R		Town -Interior, G-2L		Town -Interior, G-2R		Town-End, G-2L	
Structural Wall Type	Frame 2x4		Frame 2x4		Frame 2x4		Frame 2x4	
Front	Northwest		Northwest		Northwest		Northwest	
Finished Sq. Ft., Main	792		792		792		792	
Addition Sq. Ft.	378				264		264	
No. Stories	2		2		2		2	
Bedrooms	2		2		2		2	
Baths	1.5		1		1.5		1.5	
Foundation	Crawl/Bsmt (add'n)		Crawl		Crawl		Crawl	
Insulated	Floor R-13	R-19 SPF	Floor R-13	R-19 SPF	Floor R-13	R-19 SPF	Floor R-13	R-19 SPF
Vented	8x16 vents (1 each side)		8x16 vents (1 each side)		8x16 vents (1 each side)		8x16 vents (1 each side)	
1st Floor	2x8 joists		2x8 joists		2x8 joists		2x8 joists	
Attic R-value	16	R-30/38	16	R-30/38	16	R-30/38	16	R-30/38
Building Dimensions	22x18		22x18		22x18		22x18	
Addition Dimensions	21x18				22x12			
Windows, Sq. Ft.	45/26/117/0		34/0/95/0		33/0/90/0		33/0/67/40	
Window U-/SHGC	.55/.75/.29/.21	.30/.30	.55/.75	.30/.30	.55/.75	.30/.30	.55/.75	.30/.30
Wall R-value	R-11; cellulose	R-11/R-7 cont.	R-11; cellulose	R-11/R-7 cont.	R-11; cellulose	R-11/R-7 cont.	R-11; cellulose	R-11/R-7 cont.
Front Door	3070 wd 1/2glass/storm	U=.23	3070 wd 1/2glass/storm	U=.23	3070 wd 1/2glass/storm	U=.23	3070 wd 1/2glass/storm	U=.23
~~Left~~ Front Door	Ins. 3068 w/storm							
Rear Door	Ins. 21068/storm		3068 Vinyl/storm	U=.23	3068 wood	U=.23		
Right Door							Ins. 21068	
Air Leakage, ACH50	14.0	6.4	14.8	5.6	10.1	5.6	11.2	6.4
Mechanical Ventilation, run time	no	Exhaust&Timer-10%	no	Exhaust&Timer-10%	no	Exhaust&Timer-10%	no	Exhaust&Timer-10%
	Energy Savings (excl. Fan/Pump)							
Hot Water	**Use F8 Modeled Output**		**Use F7 Modeled Output**		$429	$429	$429	$429
Heating					$714	$363	$902	$484
Lights					$167	$167	$167	$167
Appliances					$297	$297	$297	$297
Misc. Loads					$433	$433	$433	$433
Ventilation Fan					$0	$4	$0	$4
Total Annual Energy Use					$2,040	$1,693	$2,228	$1,814
% Whole House Energy Savings						17%		19%
% Heating Energy Savings						49%		46%
Energy Cost Savings		$414		$347		$347		$414
Cost Savings for 4-Unit Frame/Vinyl Building		$1,521						

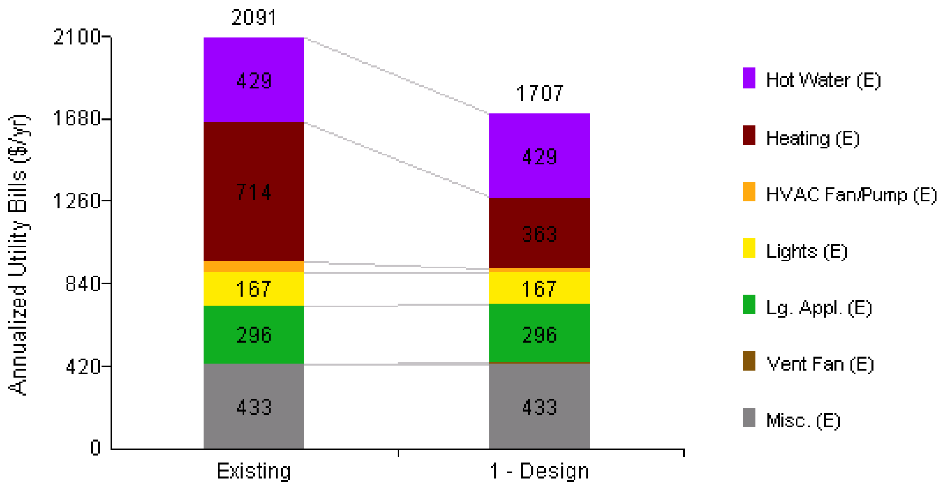


Figure 57. Modeled energy use FV-7.

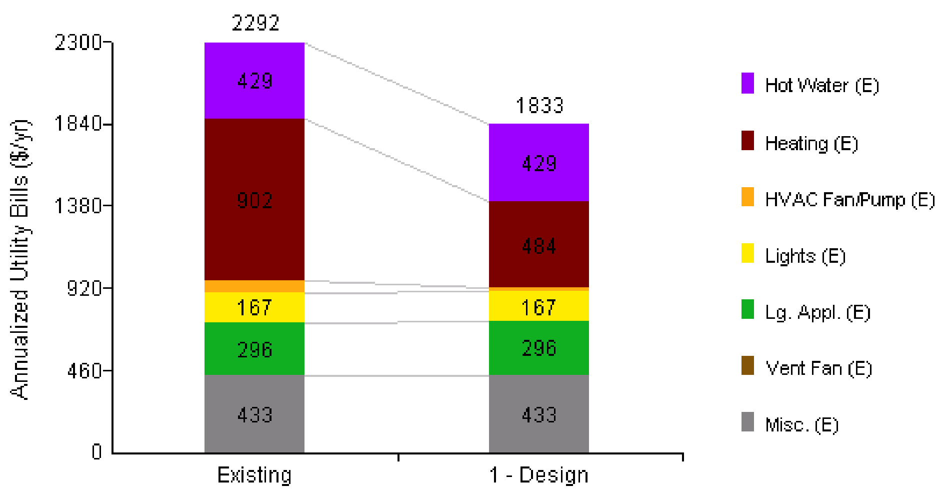


Figure 58. Modeled energy use FV-8.

Appendix D: Average Hourly Indoor Temperatures

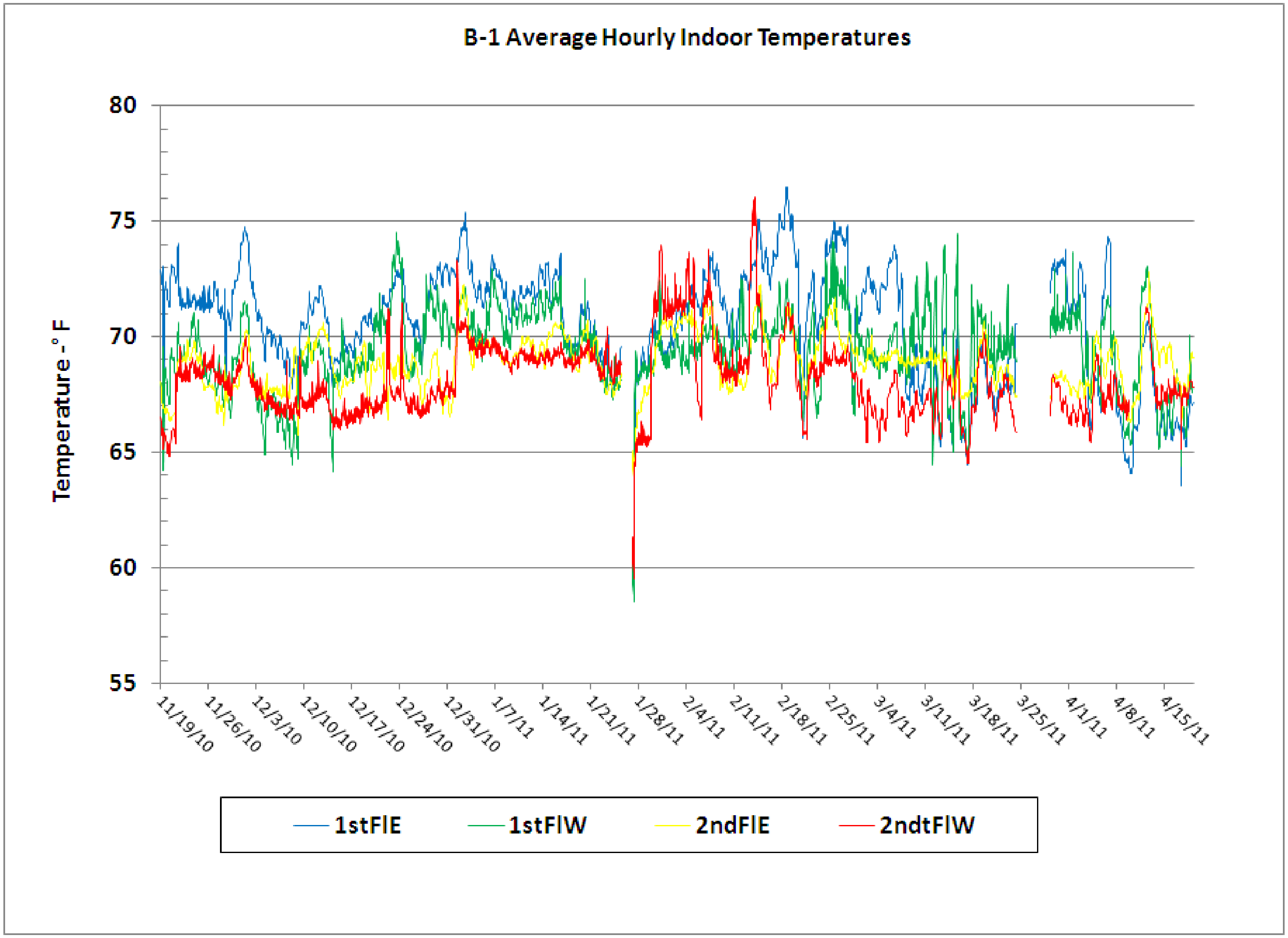


Figure 59. B-1 Average Hourly Indoor Temperature – November 2010 through April 2011.

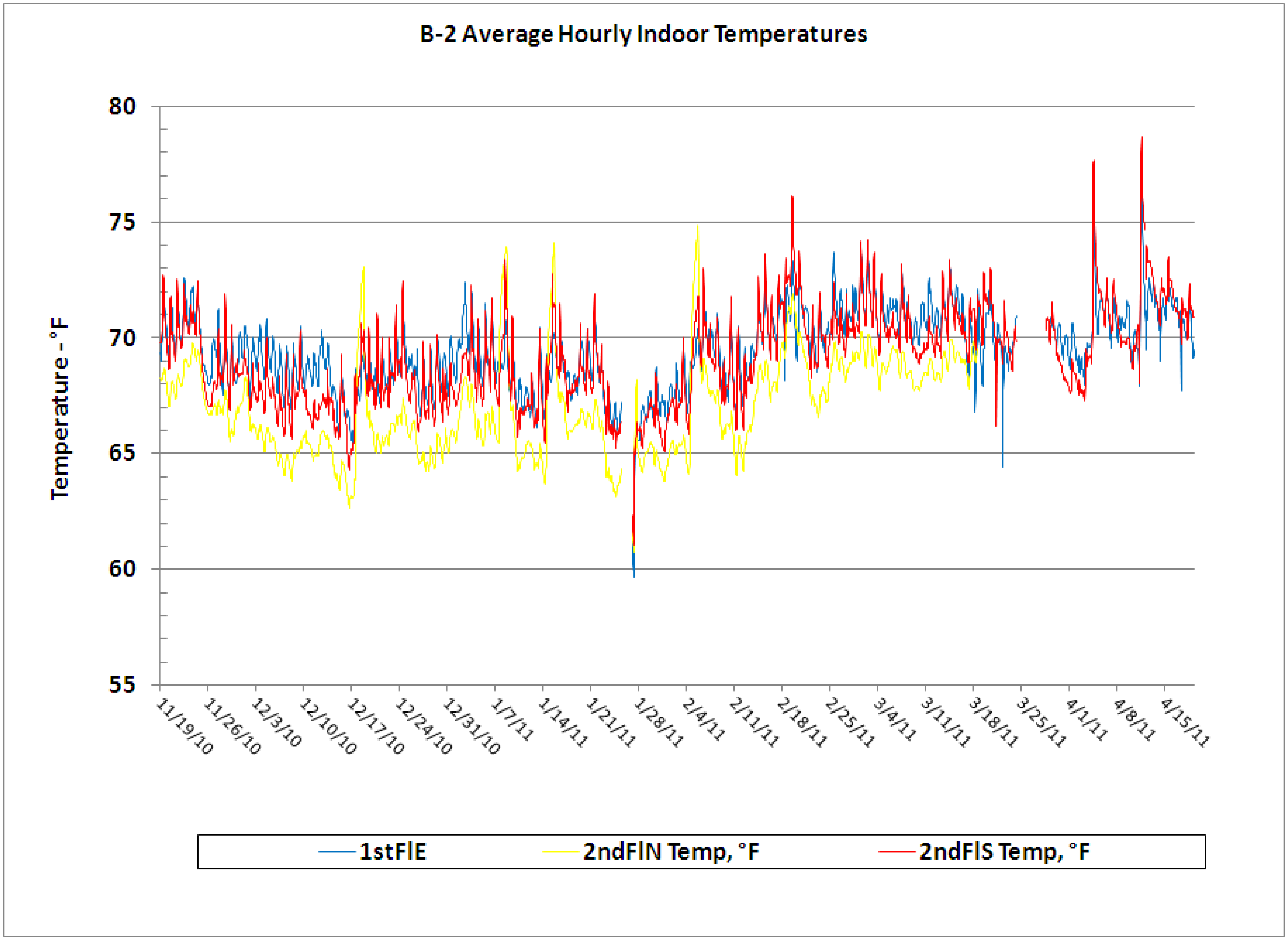


Figure 60. B-2 Average Hourly Temperature – November 2010 through April 2011.

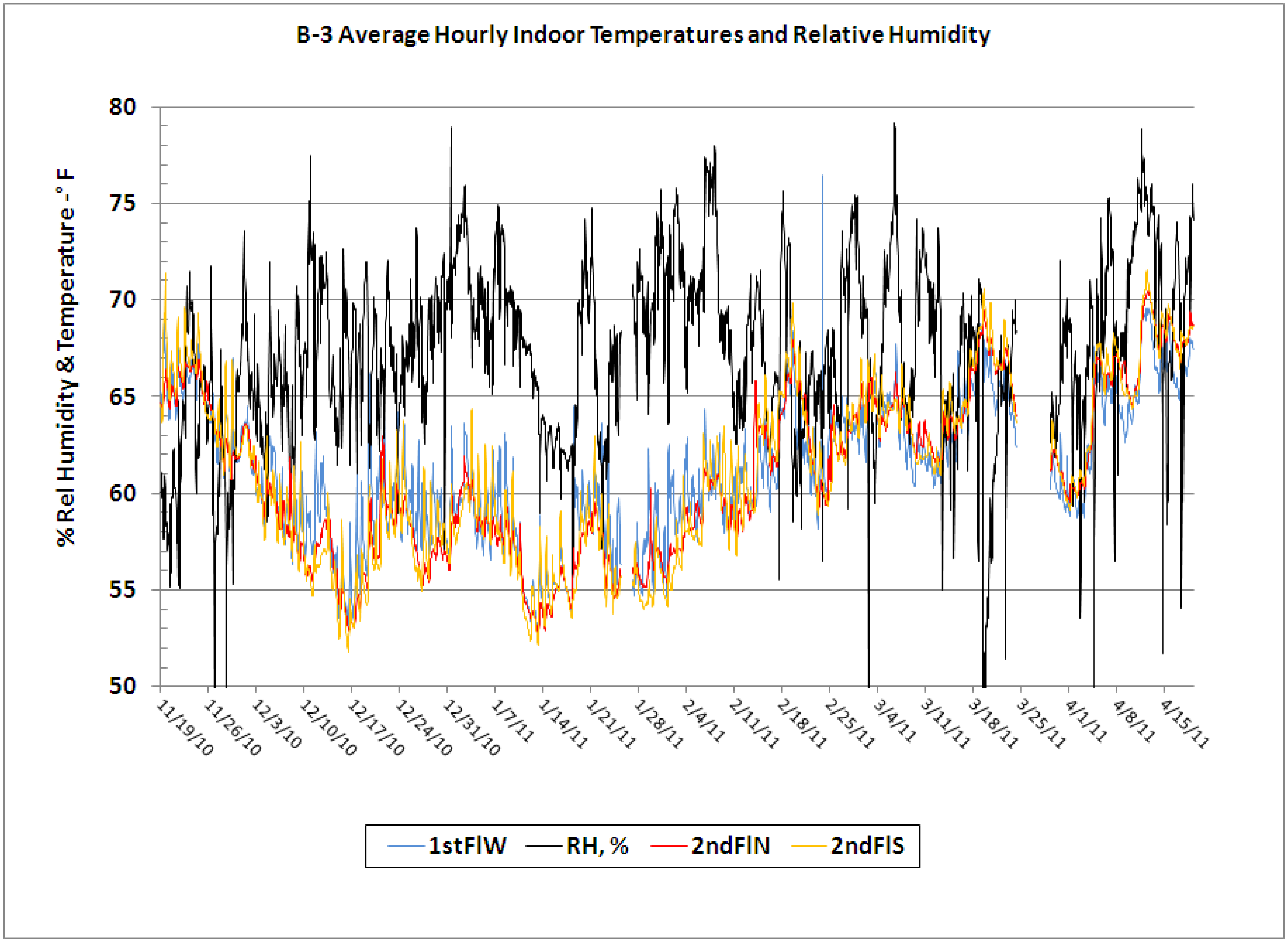


Figure 61. B-3 Average Hourly Temperature – November 2010 through April 2011.

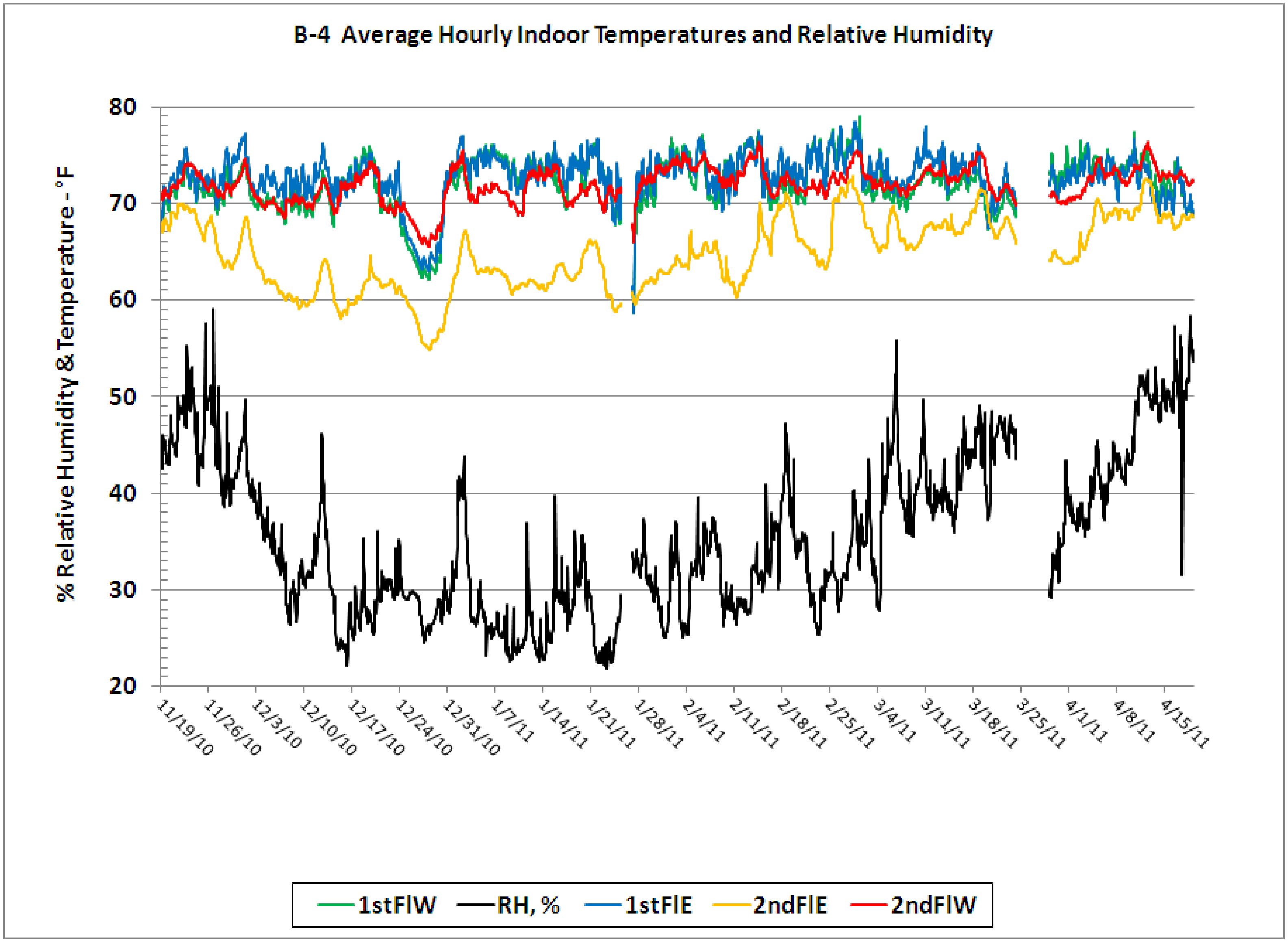


Figure 62. B-4 Average Hourly Temperature – November 2010 through April 2011.

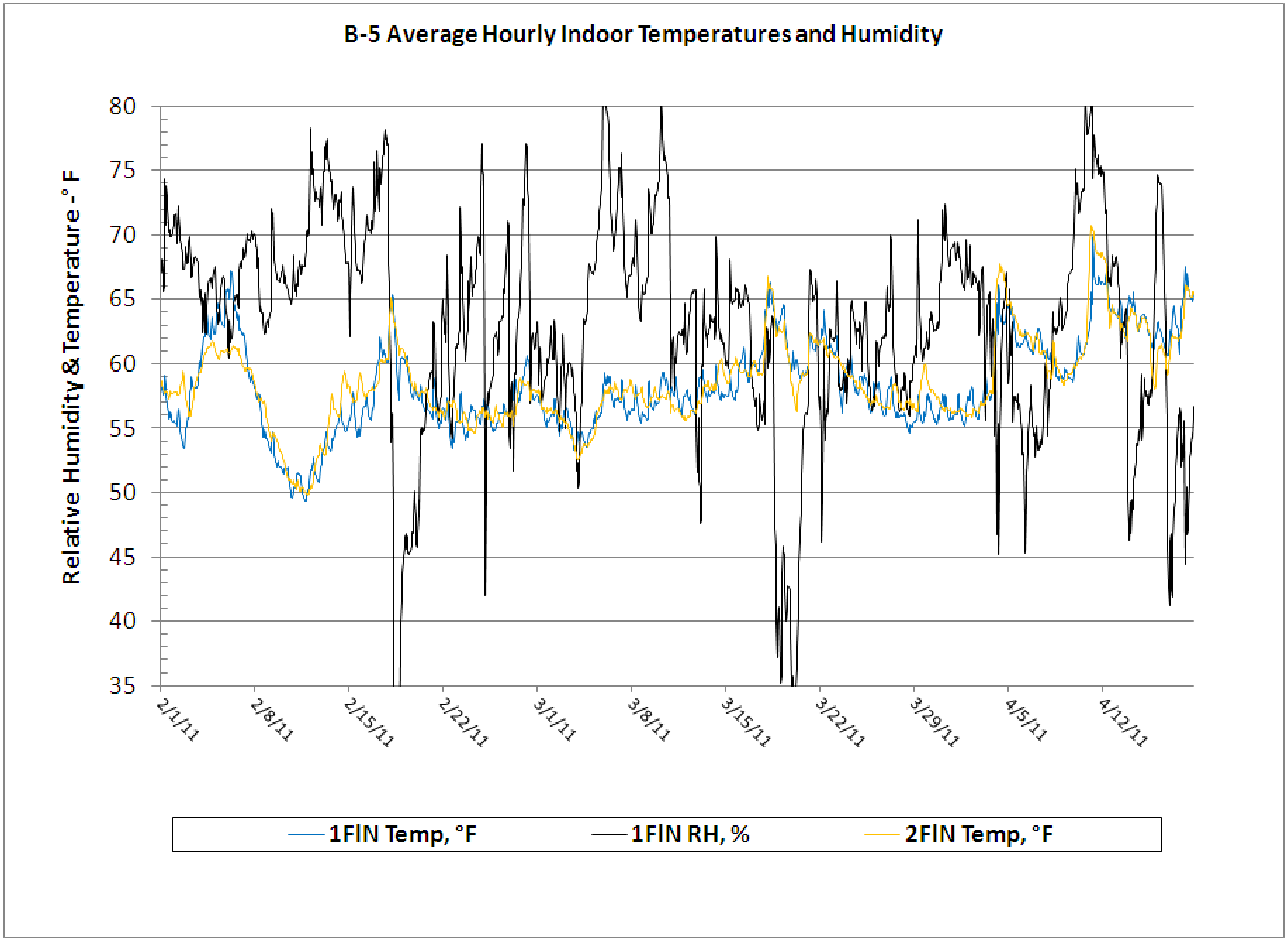


Figure 63. B-5 Average Hourly Temperature – February 2011 through April 2011.

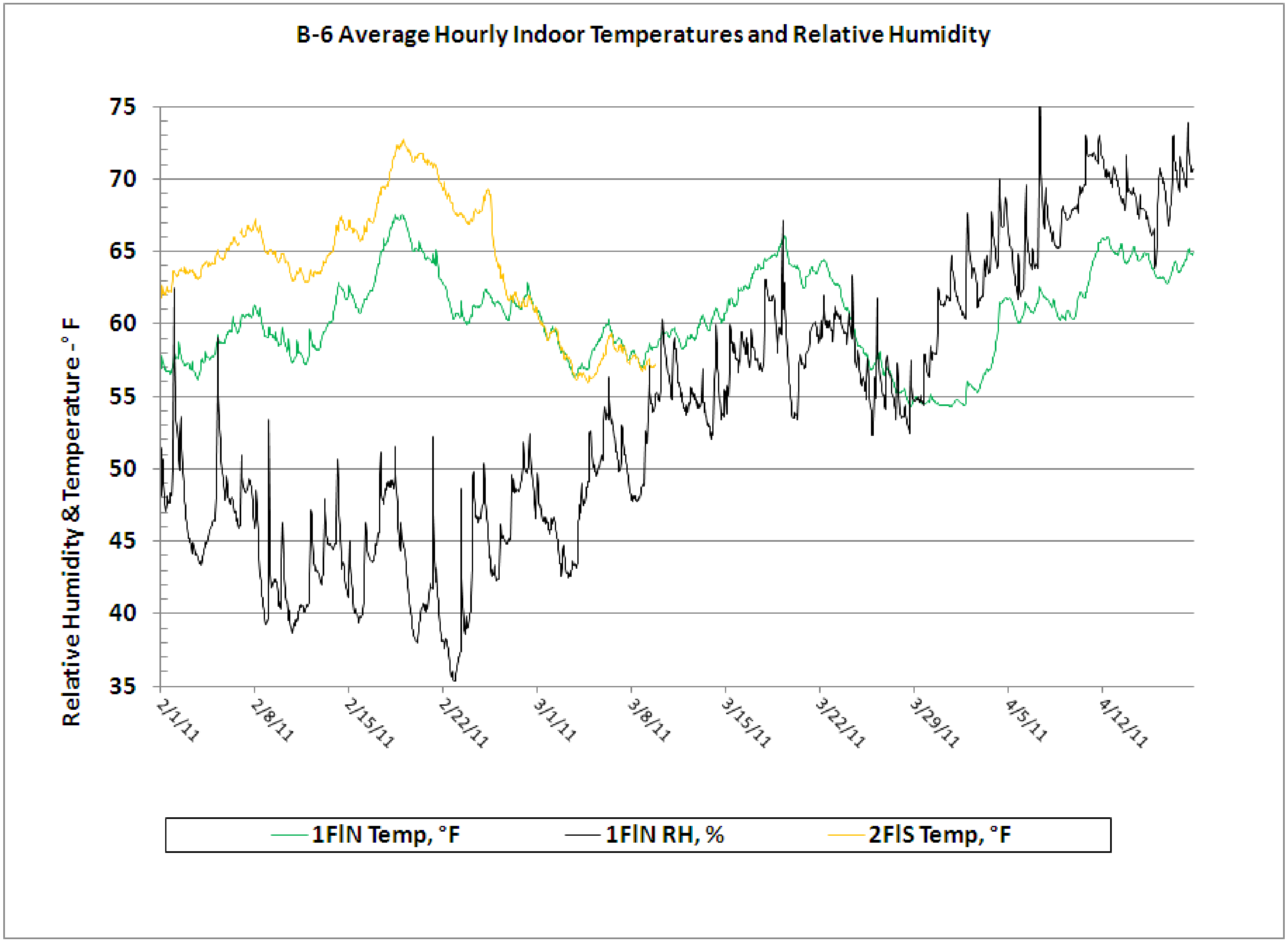


Figure 64. B-6 Average Hourly Temperature – February 2011 through April 2011.

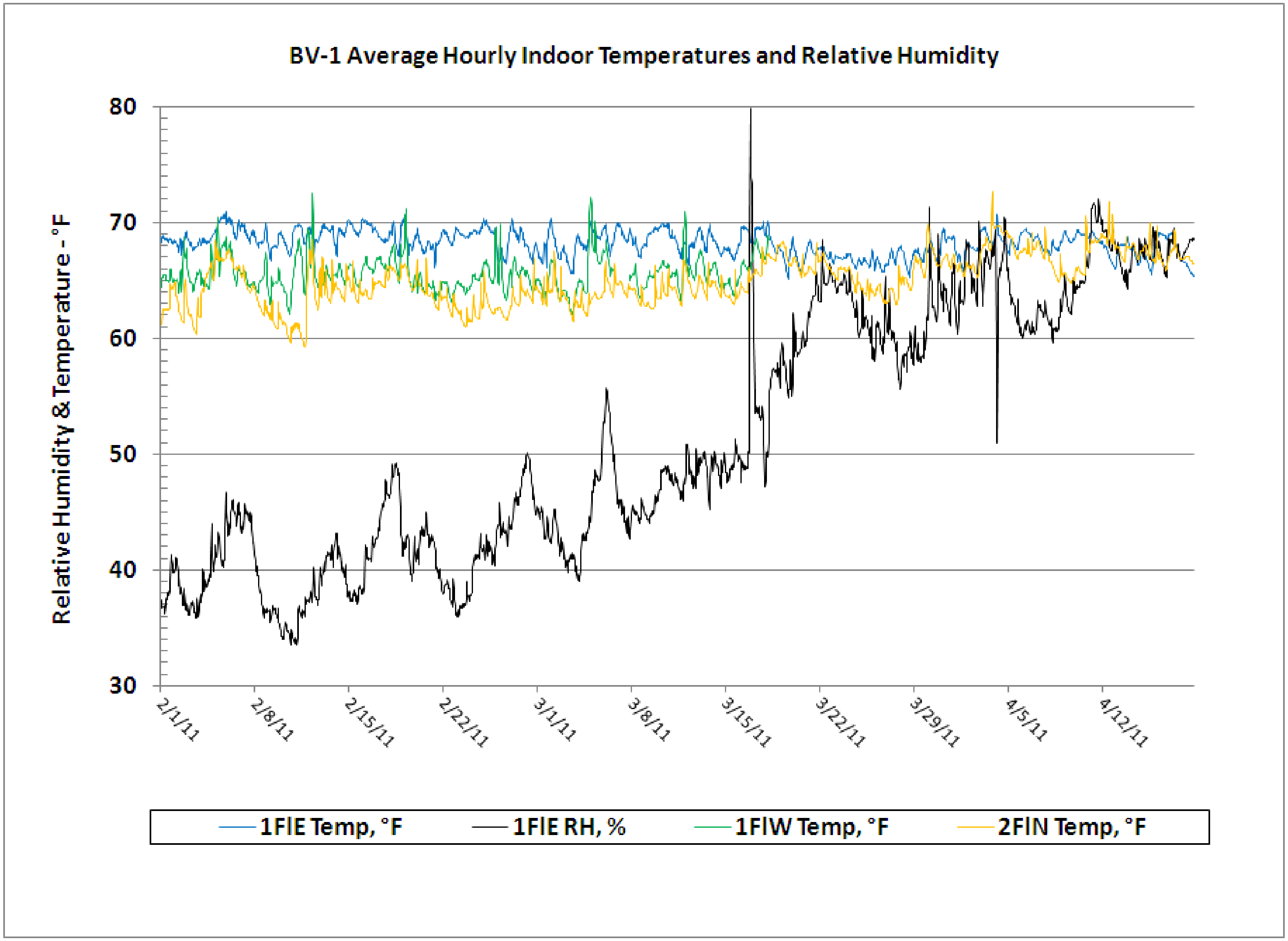


Figure 65. BV-1 Average Hourly Temperature – February 2011 through April 2011.

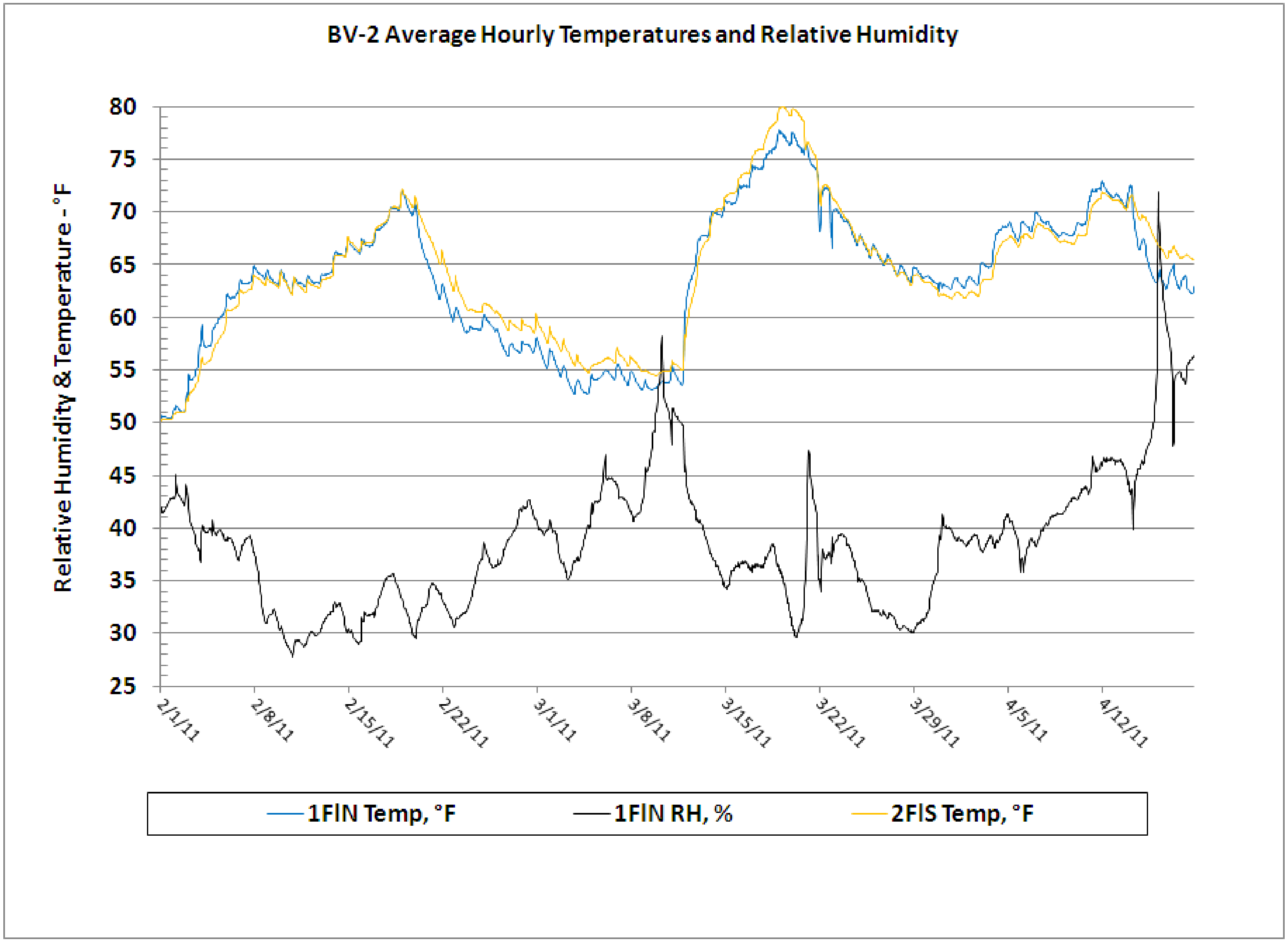


Figure 66. BV-2 Average Hourly Temperature – February 2011 through April 2011.

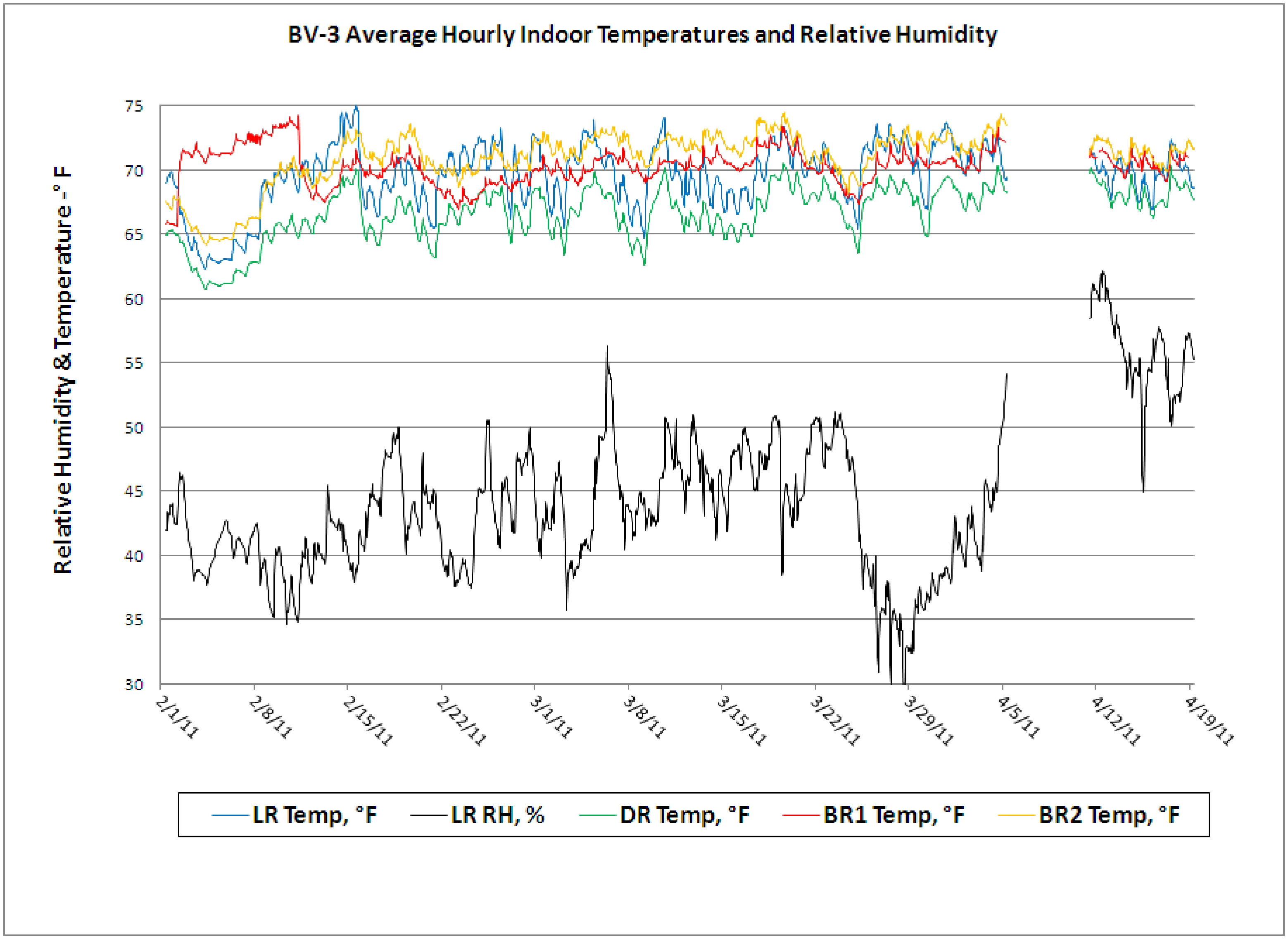


Figure 67. BV-3 Average Hourly Temperature – February 2011 through April 2011.

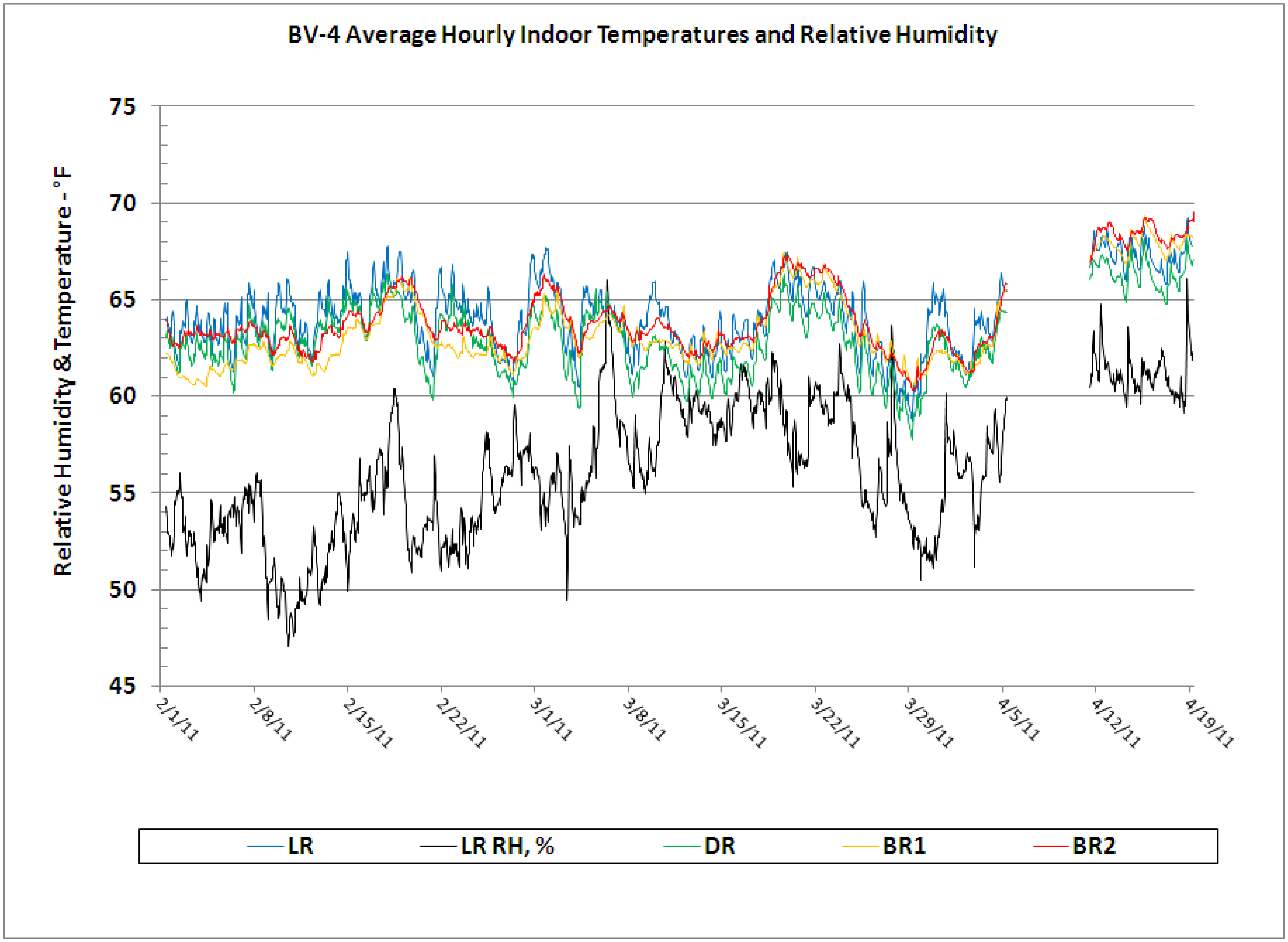


Figure 68. BV-4 Average Hourly Temperature – February 2011 through April 2011.

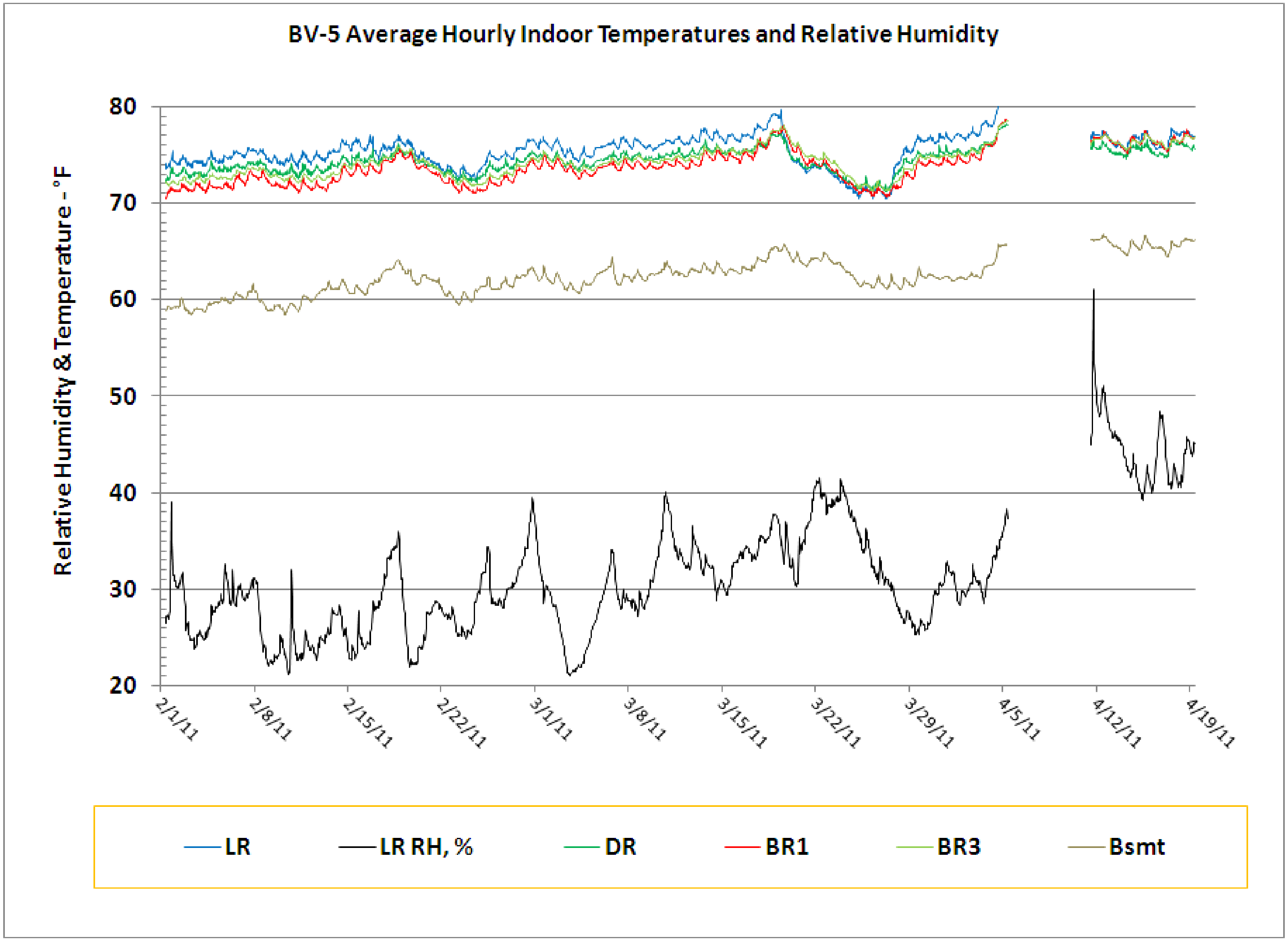


Figure 69. BV-5 Average Hourly Temperature – February 2011 to April 2011.

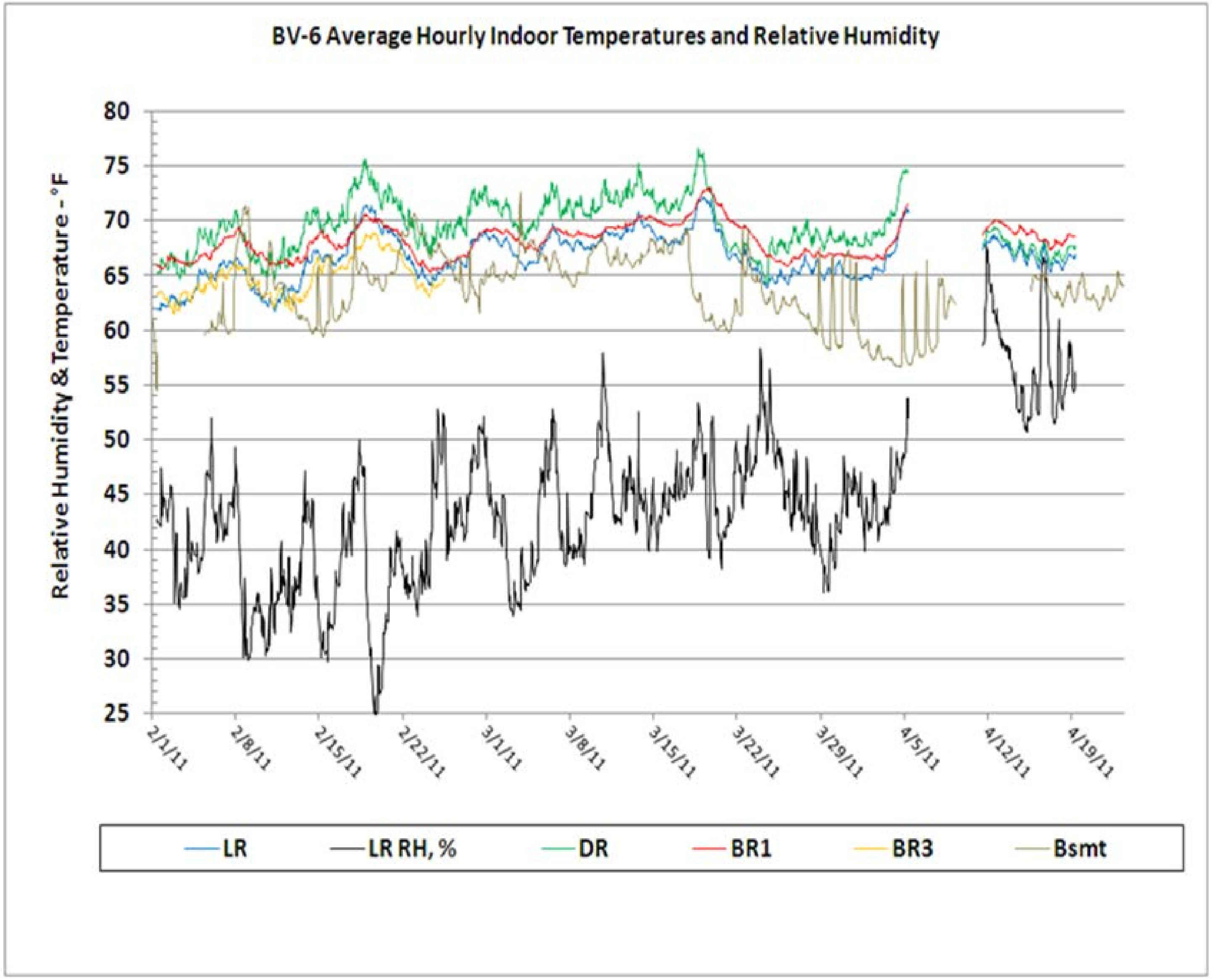


Figure 70. BV-6 Average Hourly Temperature – February 2011 to April 2011.

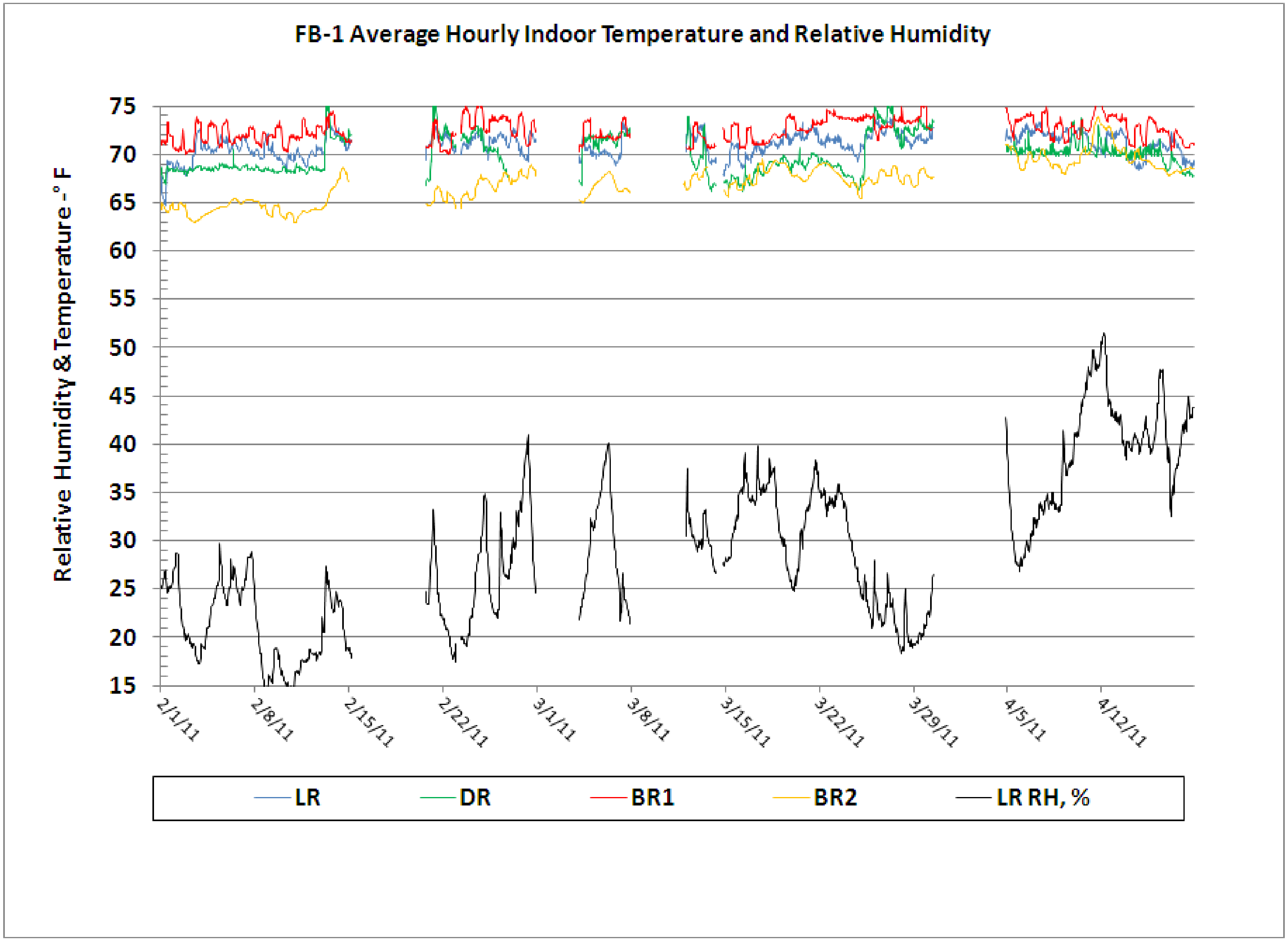


Figure 71. FB-1 Average Hourly Temperature – February 2011 to April 2011.

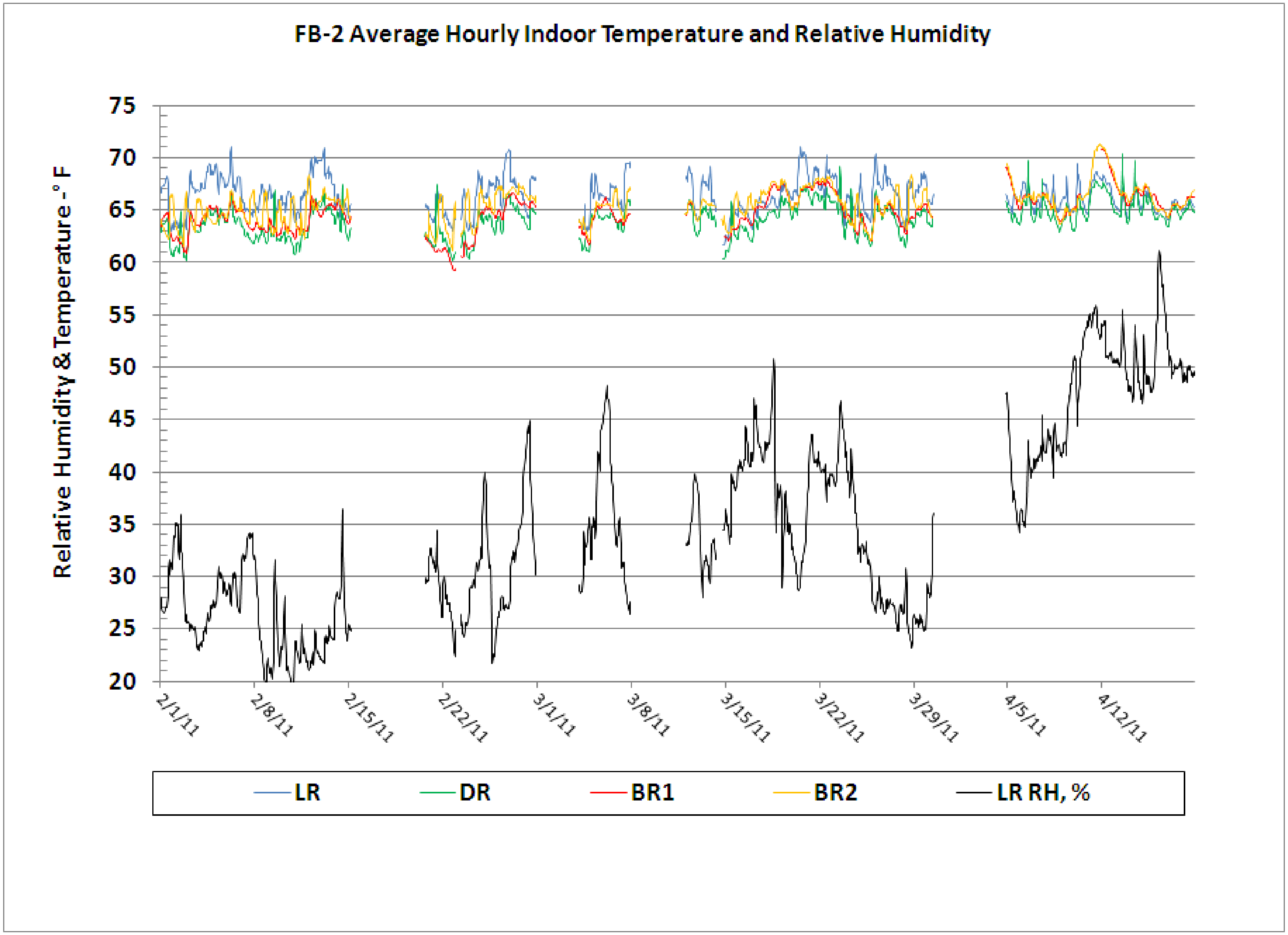


Figure 72. FB-2 Average Hourly Temperature – February 2011 to April 2011.

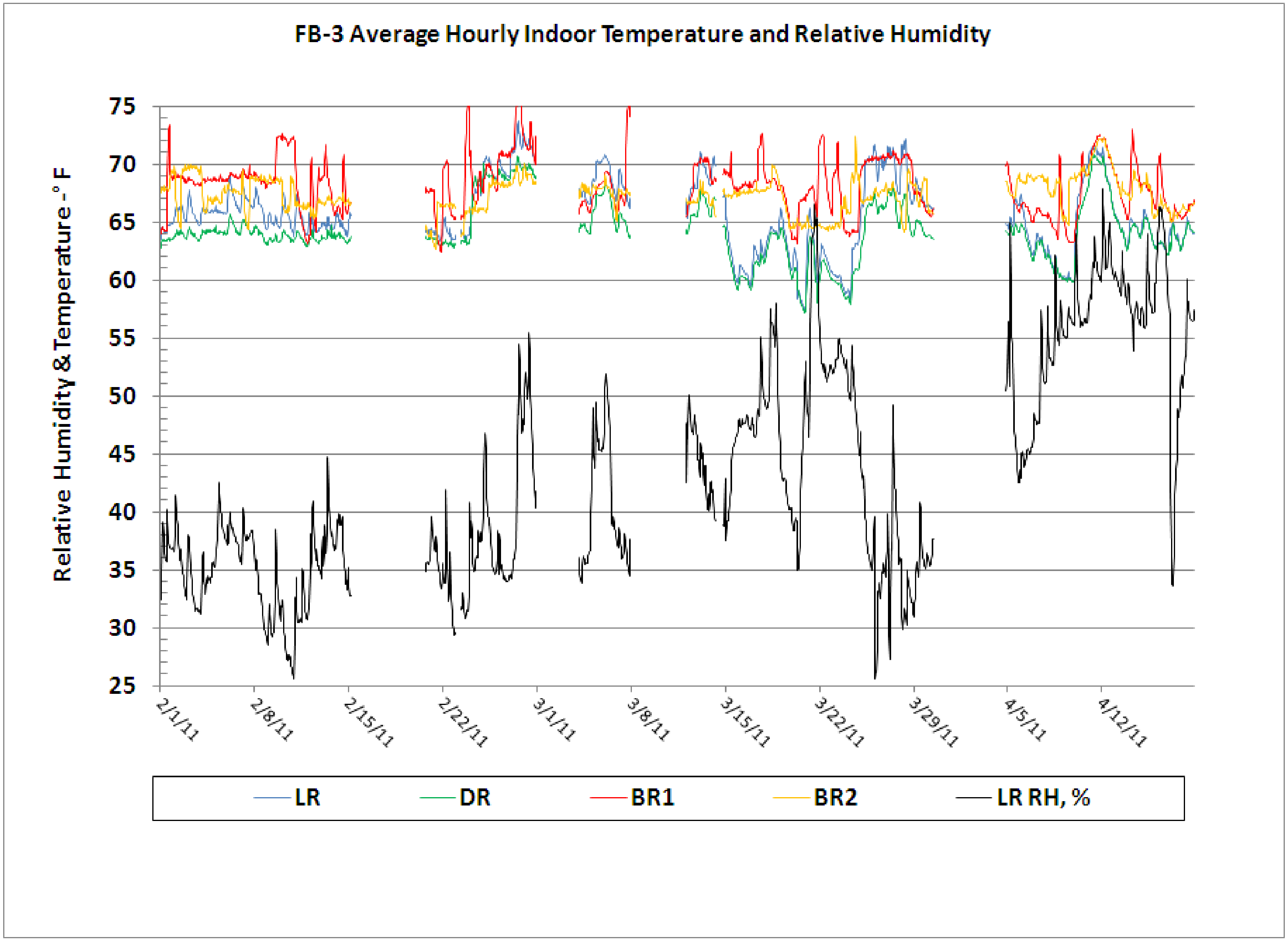


Figure 73. FB-3 Average Hourly Temperature – February 2011 to April 2011.

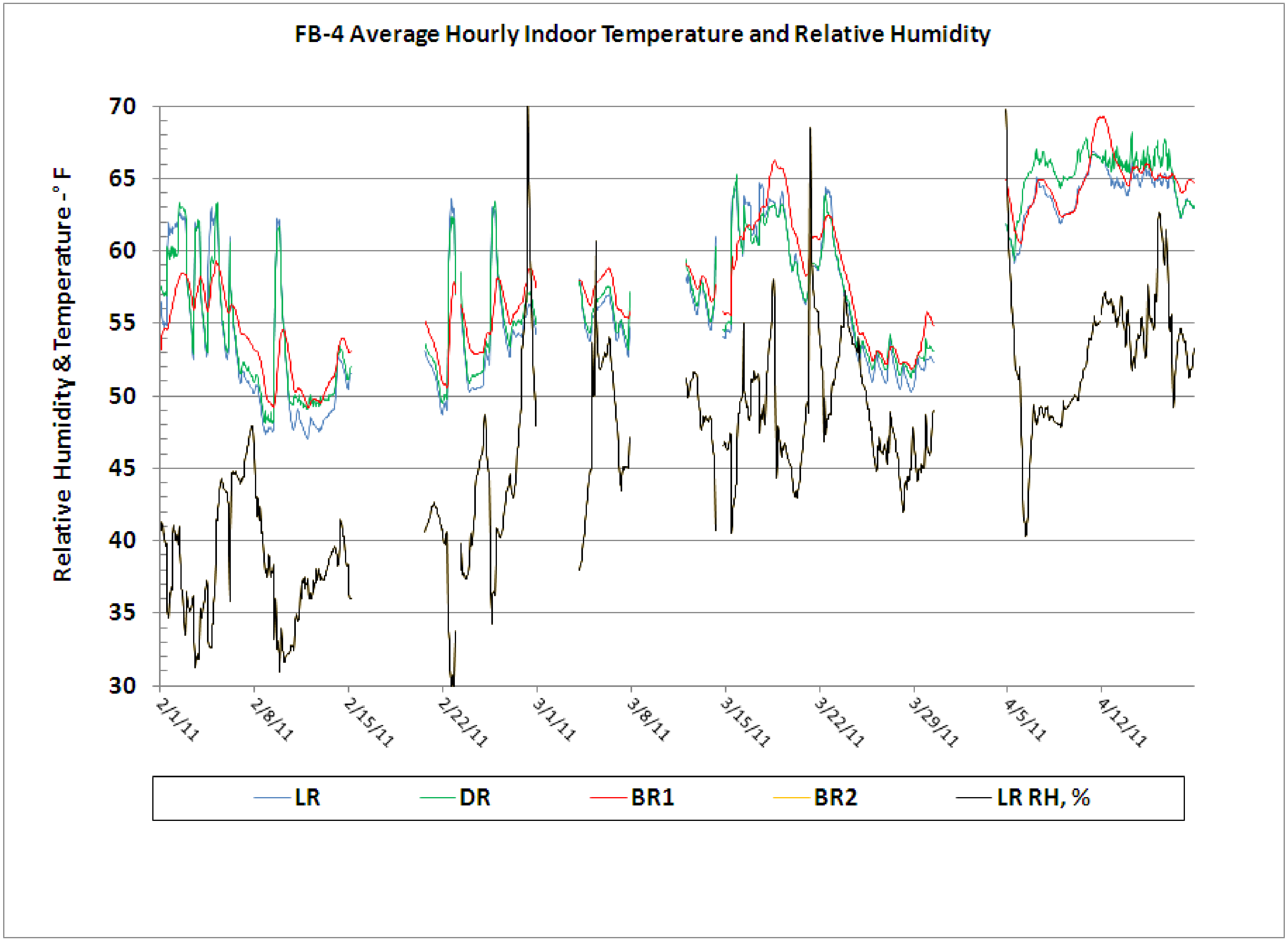


Figure 74. FB-4 Average Hourly Temperature – February 2011 to April 2011.

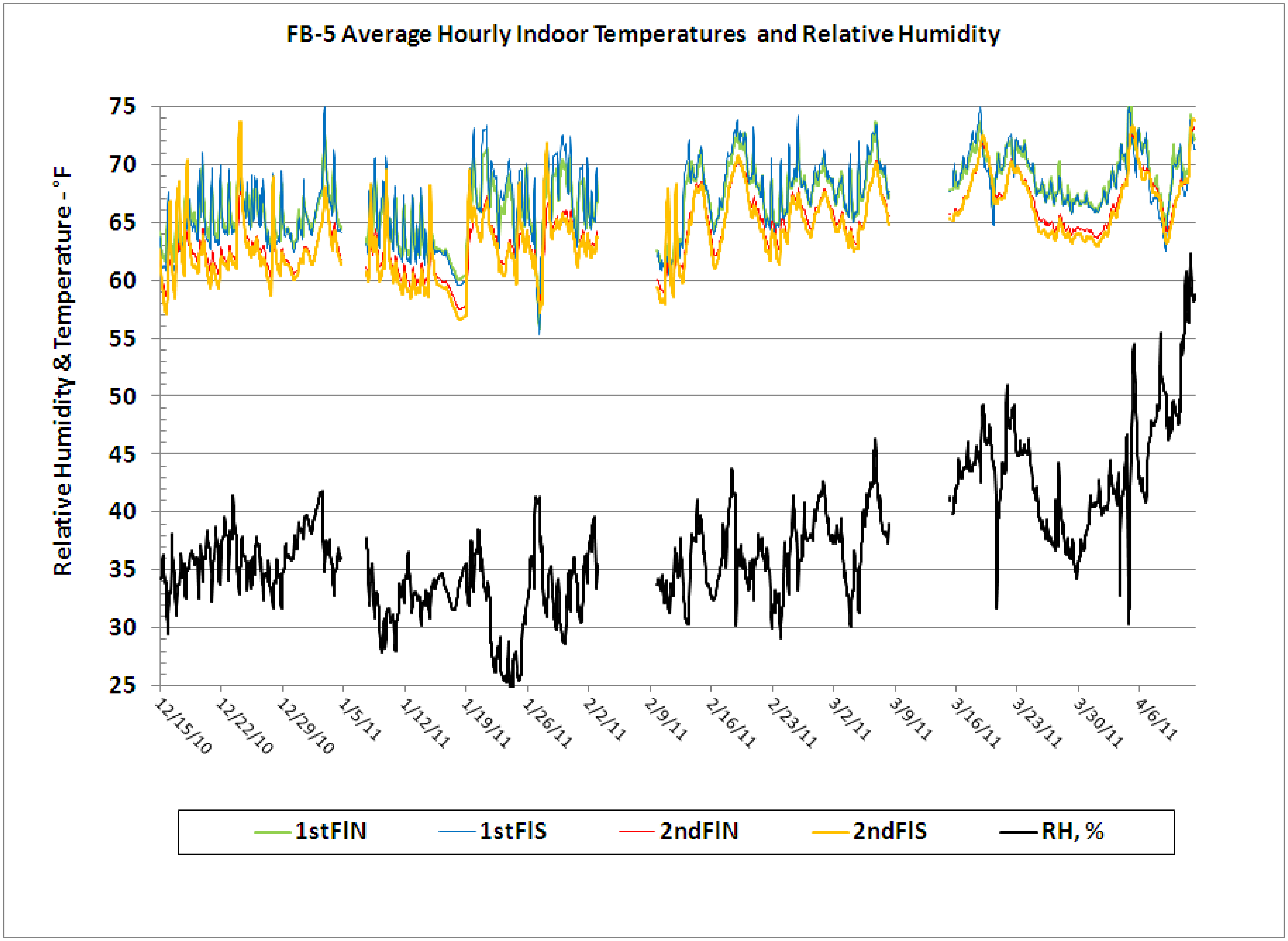


Figure 75. FB-5 Average Hourly Temperature – December 2010 to April 2011.

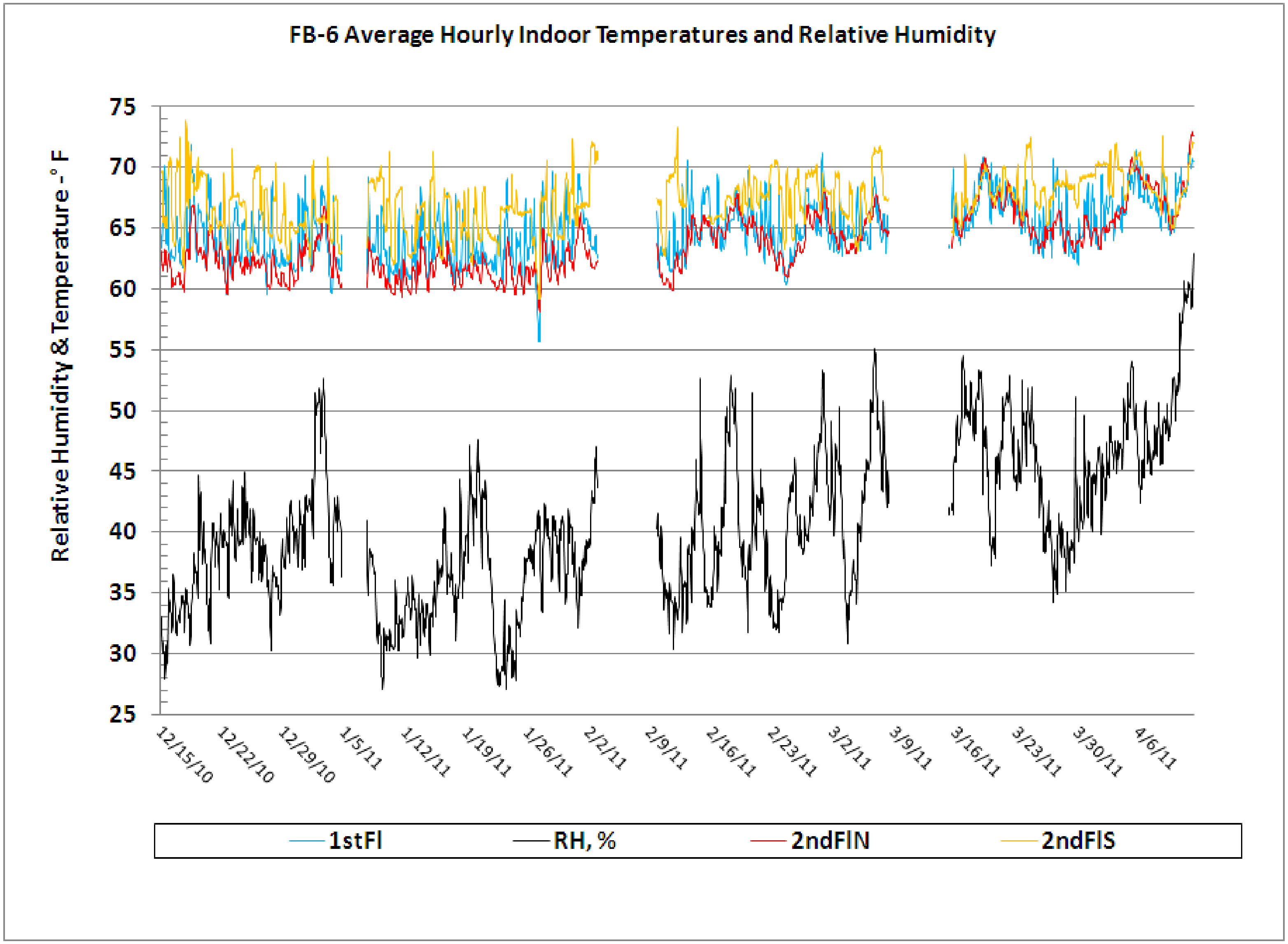


Figure 76. FB-6 Average Hourly Temperature – December 2010 to April 2011.

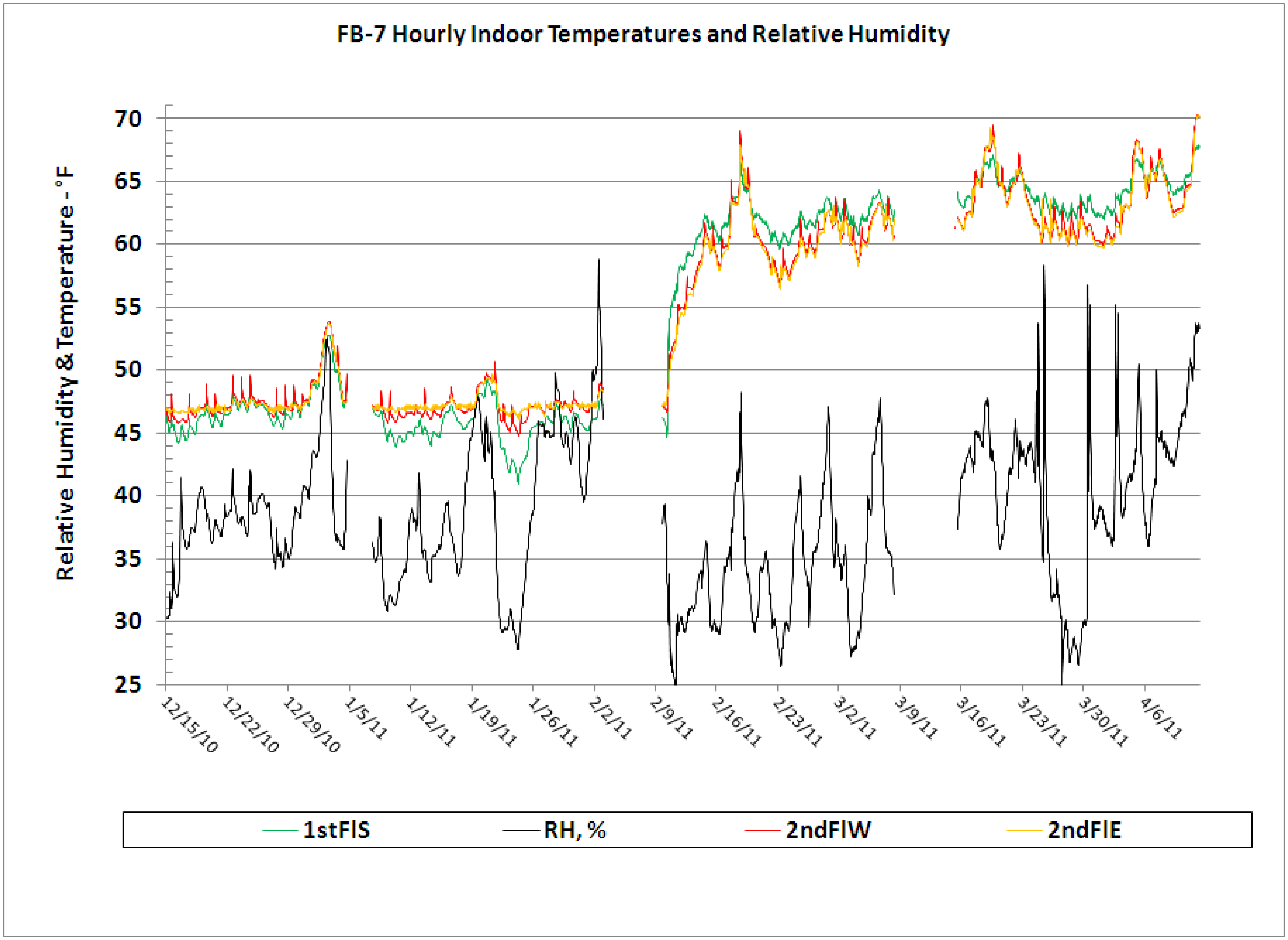


Figure 77. FB-7 Average Hourly Temperature – December 2010 to April 2011.

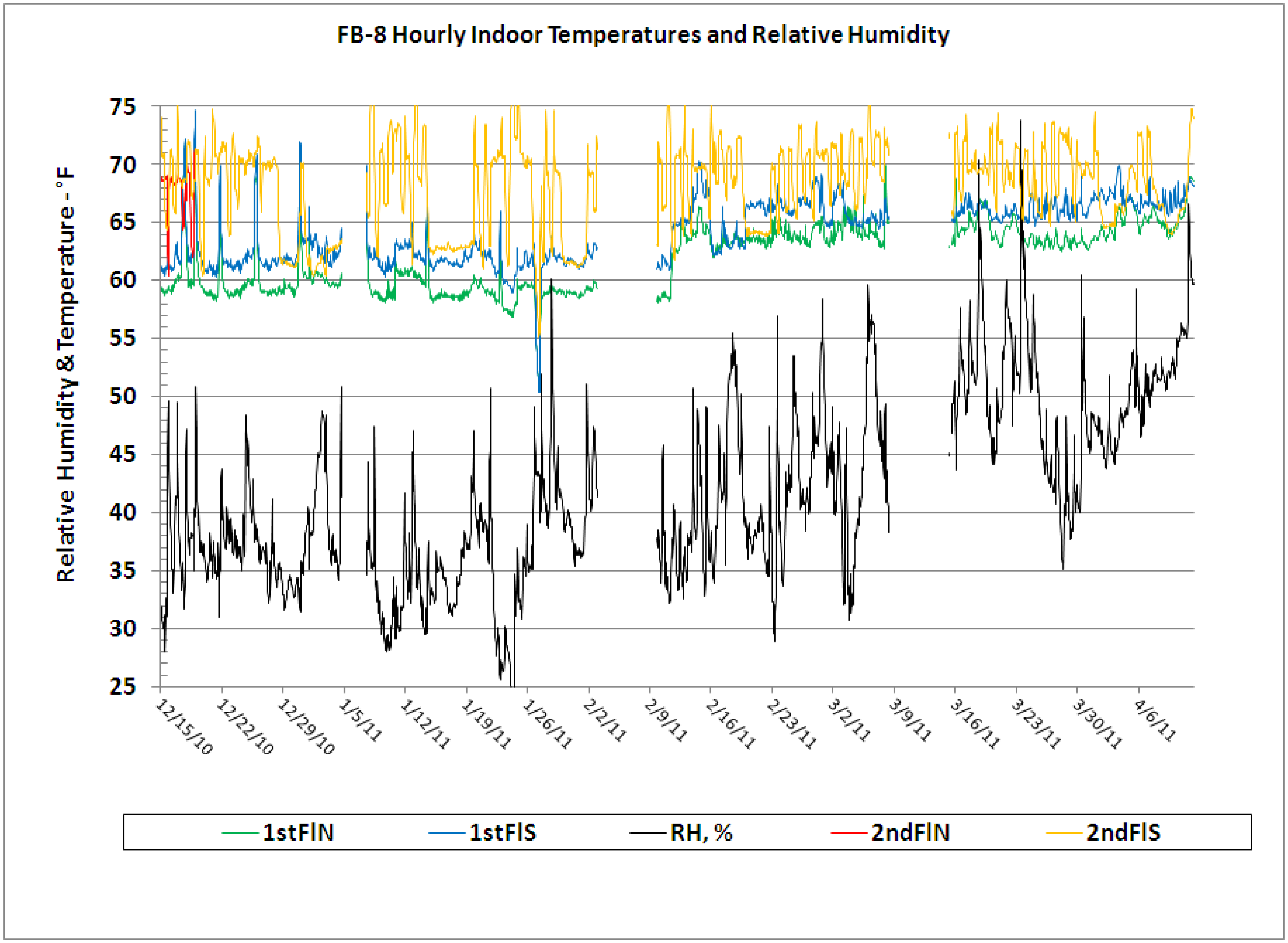


Figure 78. FB-8 Average Hourly Temperature – December 2010 to April 2011.

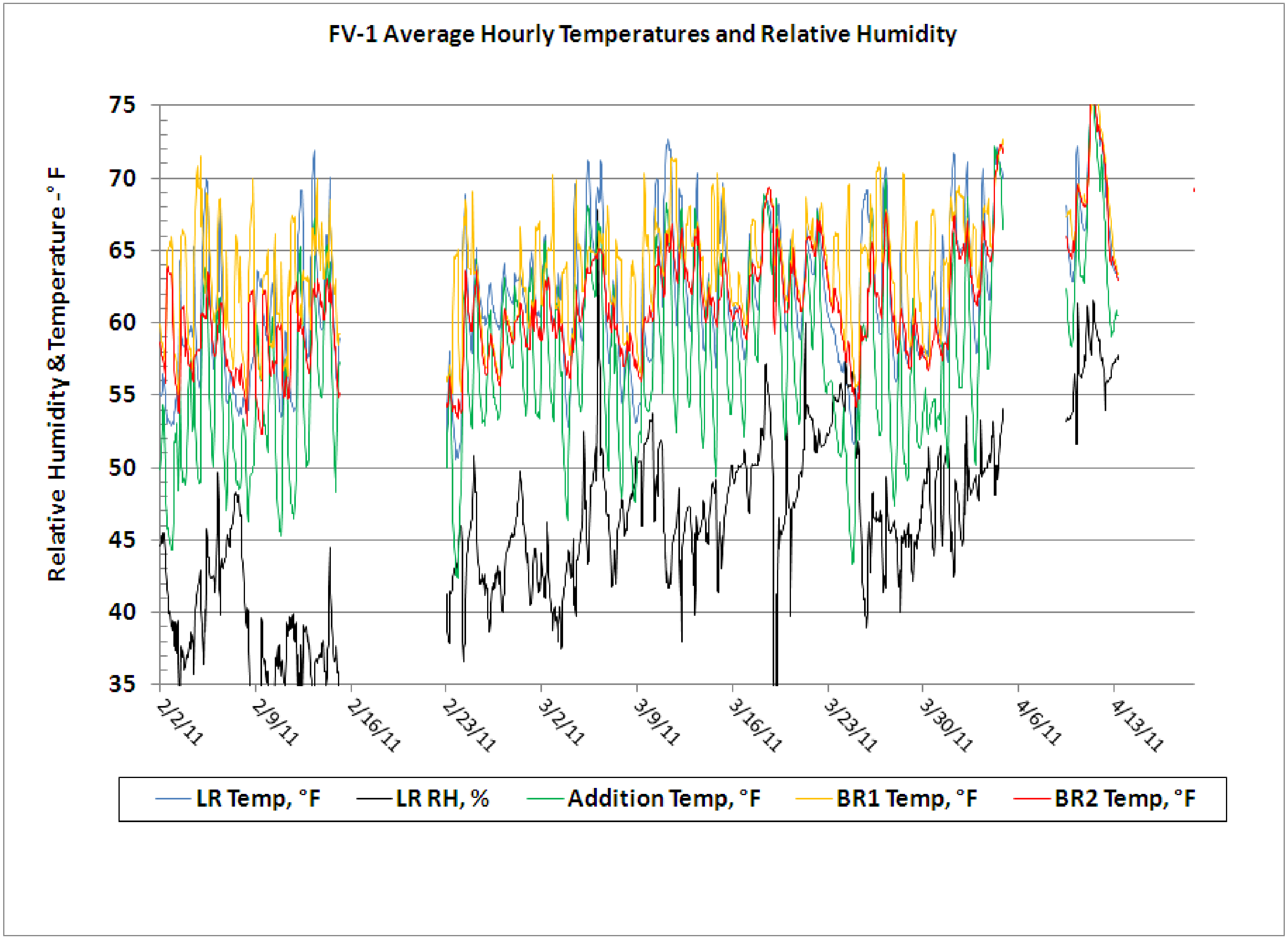


Figure 79. FV-1 Average Hourly Temperature – February 2011 to April 2011.

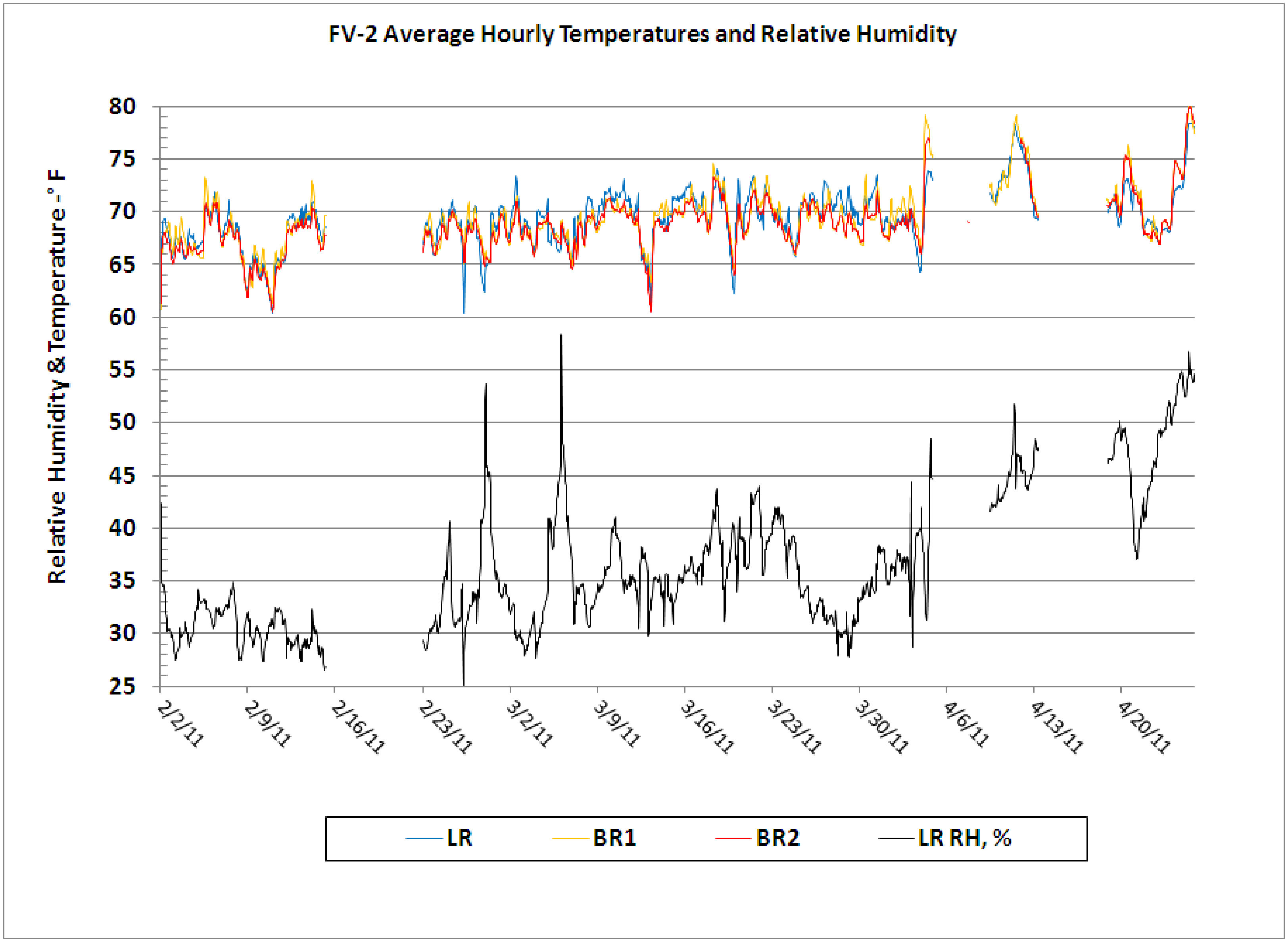


Figure 80. FV-2 Average Hourly Temperature – February 2011 to April 2011.

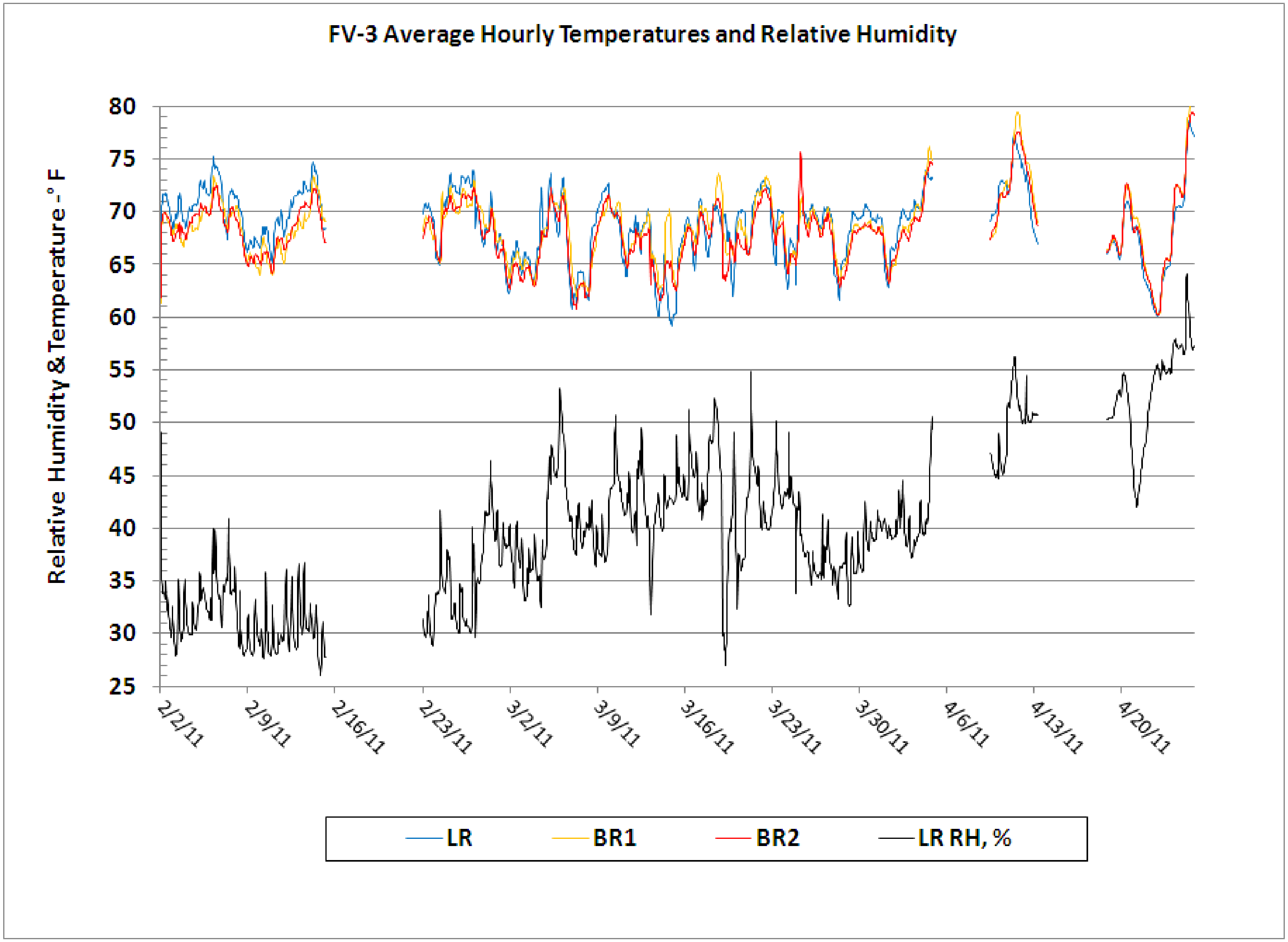


Figure 81. FV-3 Average Hourly Temperature – February 2011 to April 2011.

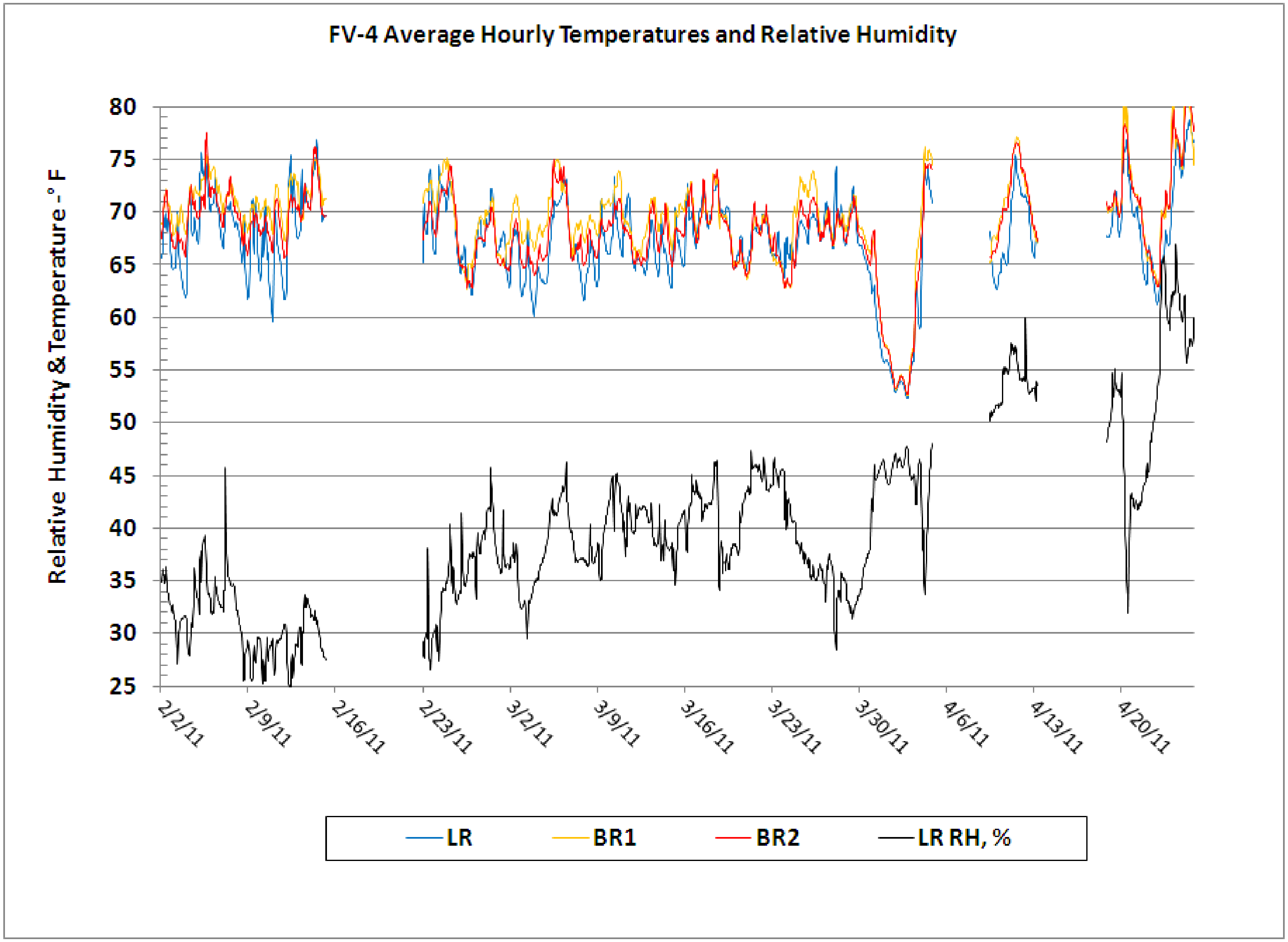


Figure 82. FV-4 Average Hourly Temperature – February 2011 to April 2011.

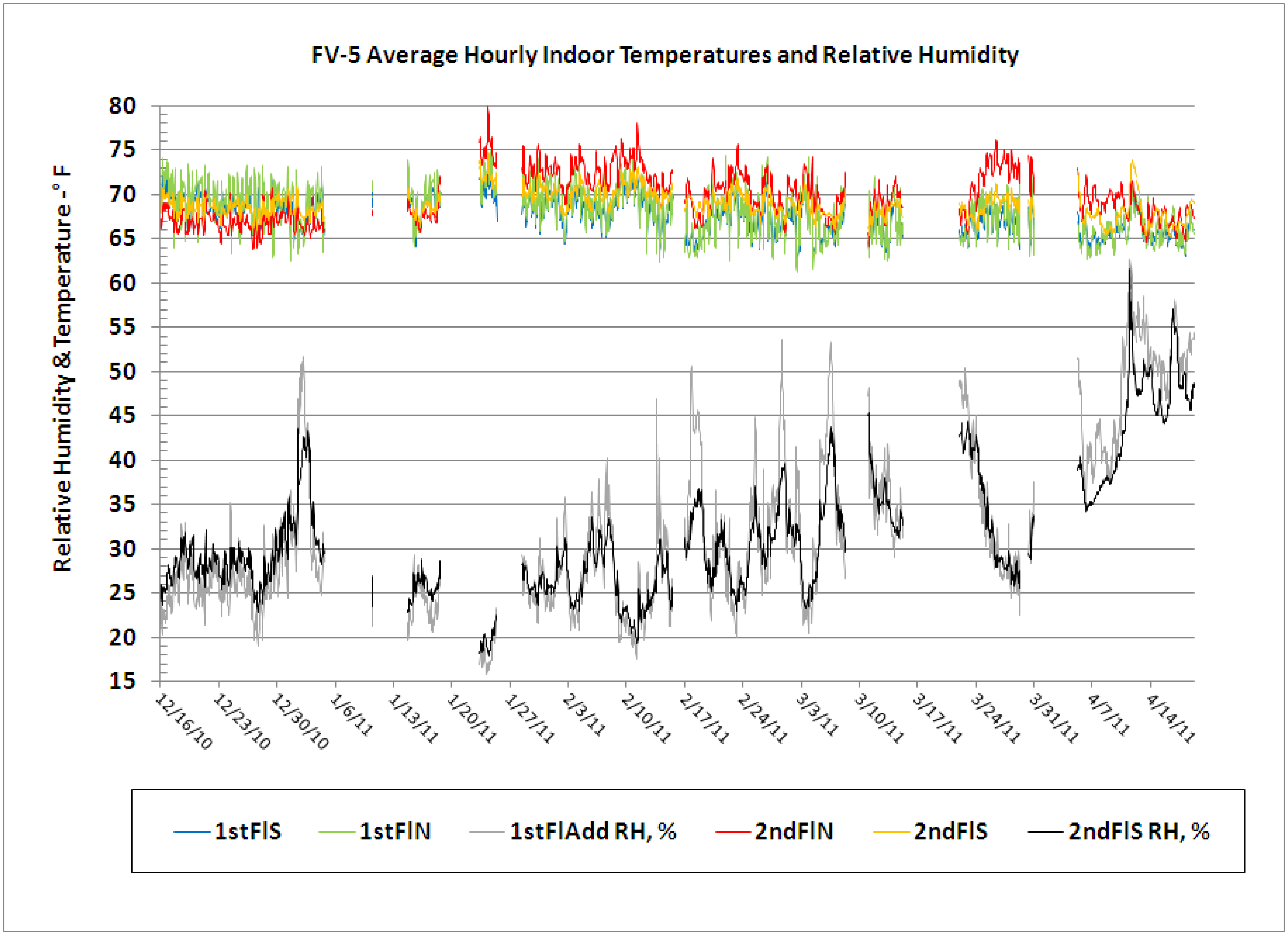


Figure 83. FV-5 Average Hourly Temperature – December 2010 to April 2011.

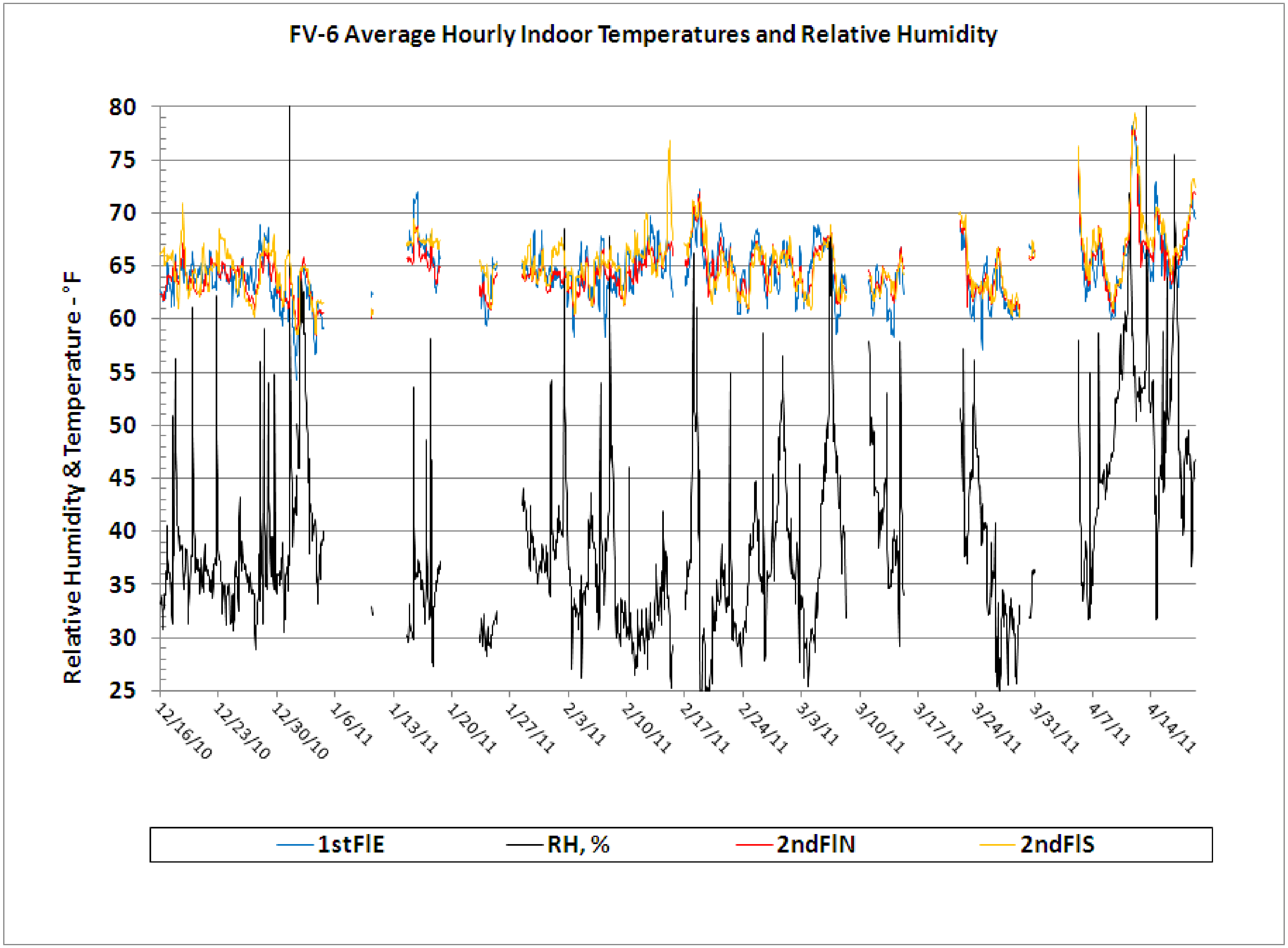


Figure 84. FV-6 Average Hourly Temperature – December 2010 to April 2011.

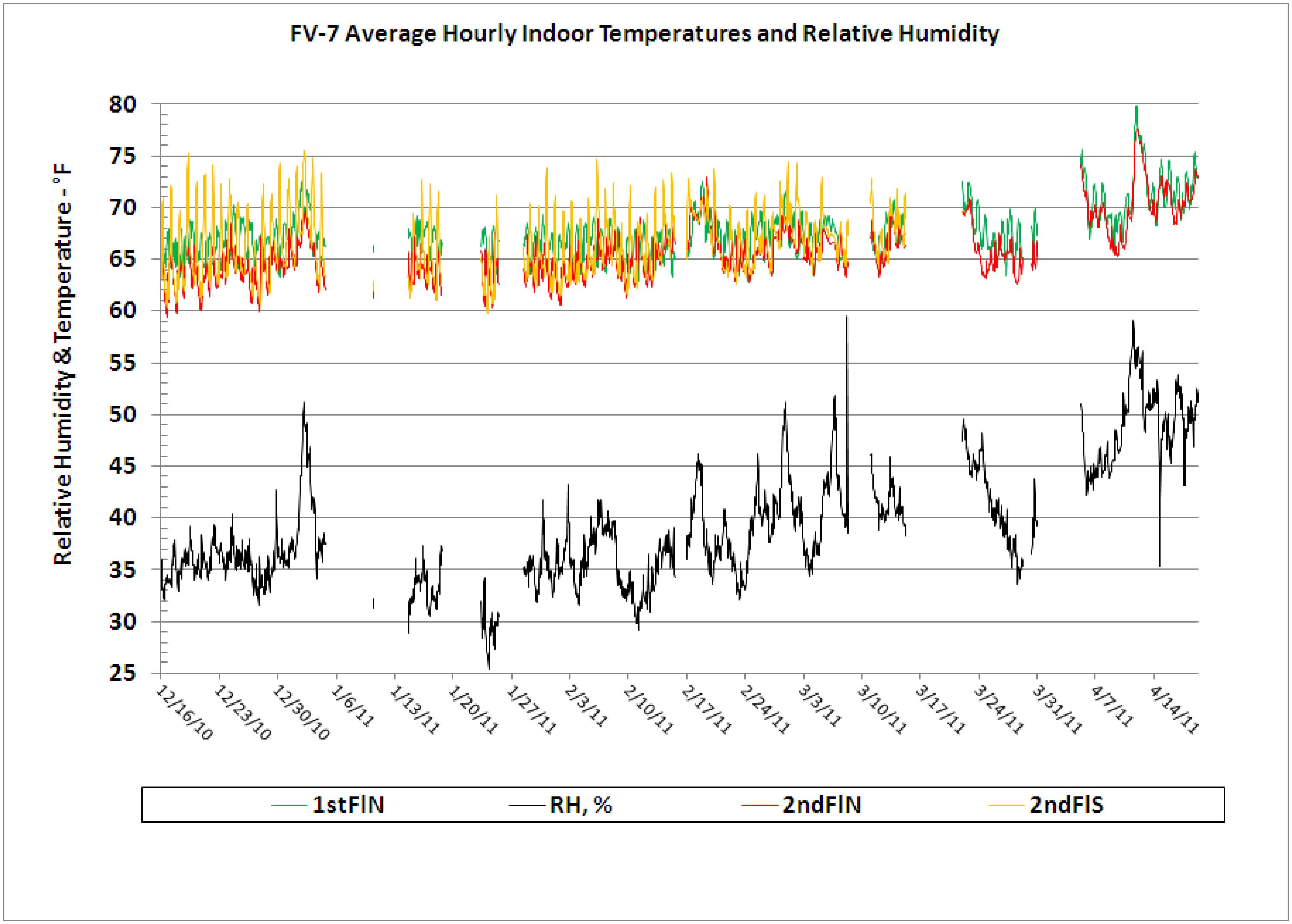


Figure 85. FV-7 Average Hourly Temperature – December 2010 to April 2011.

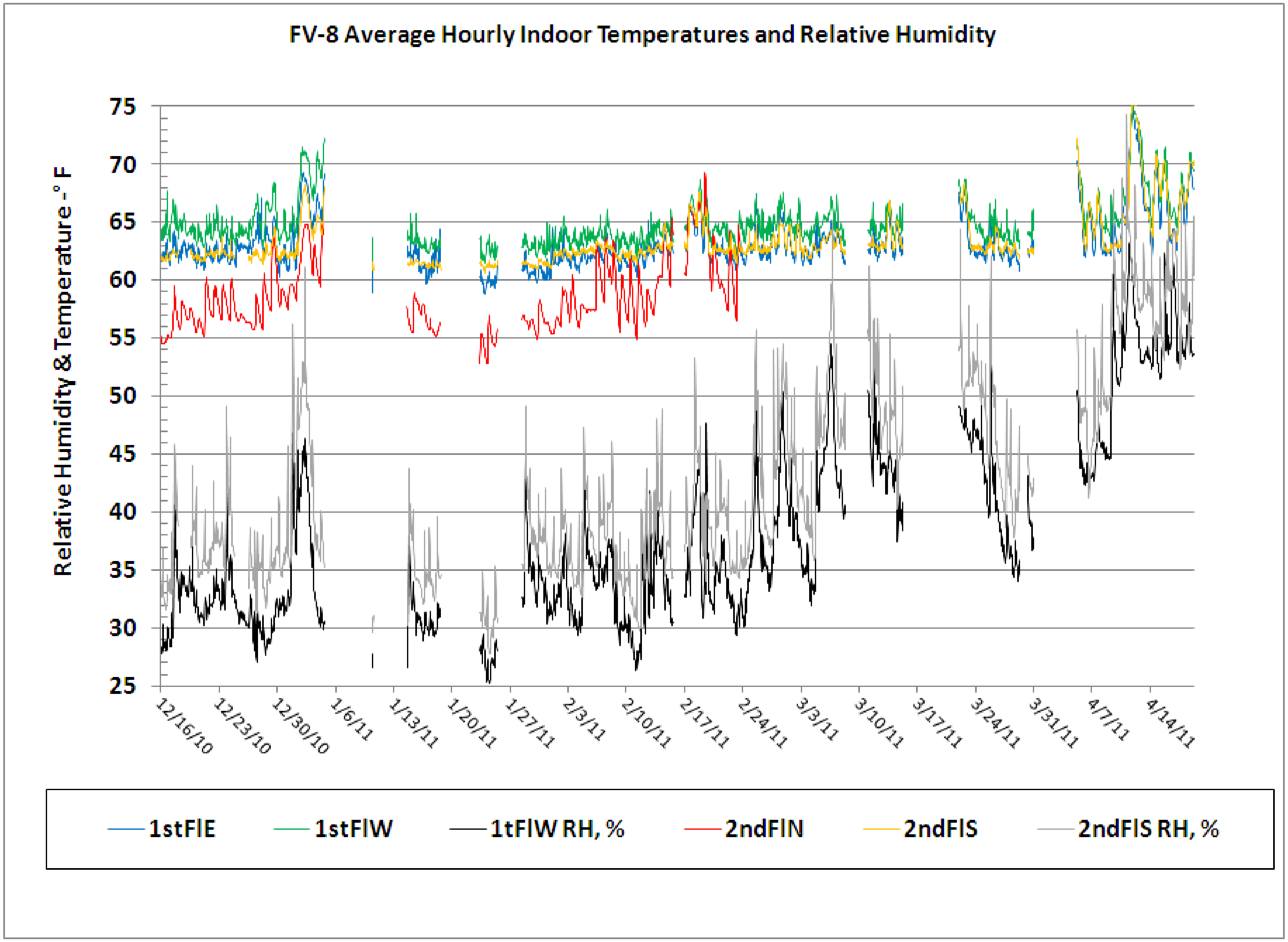


Figure 86. FV-8 Average Hourly Temperature – December 2010 to April 2011.

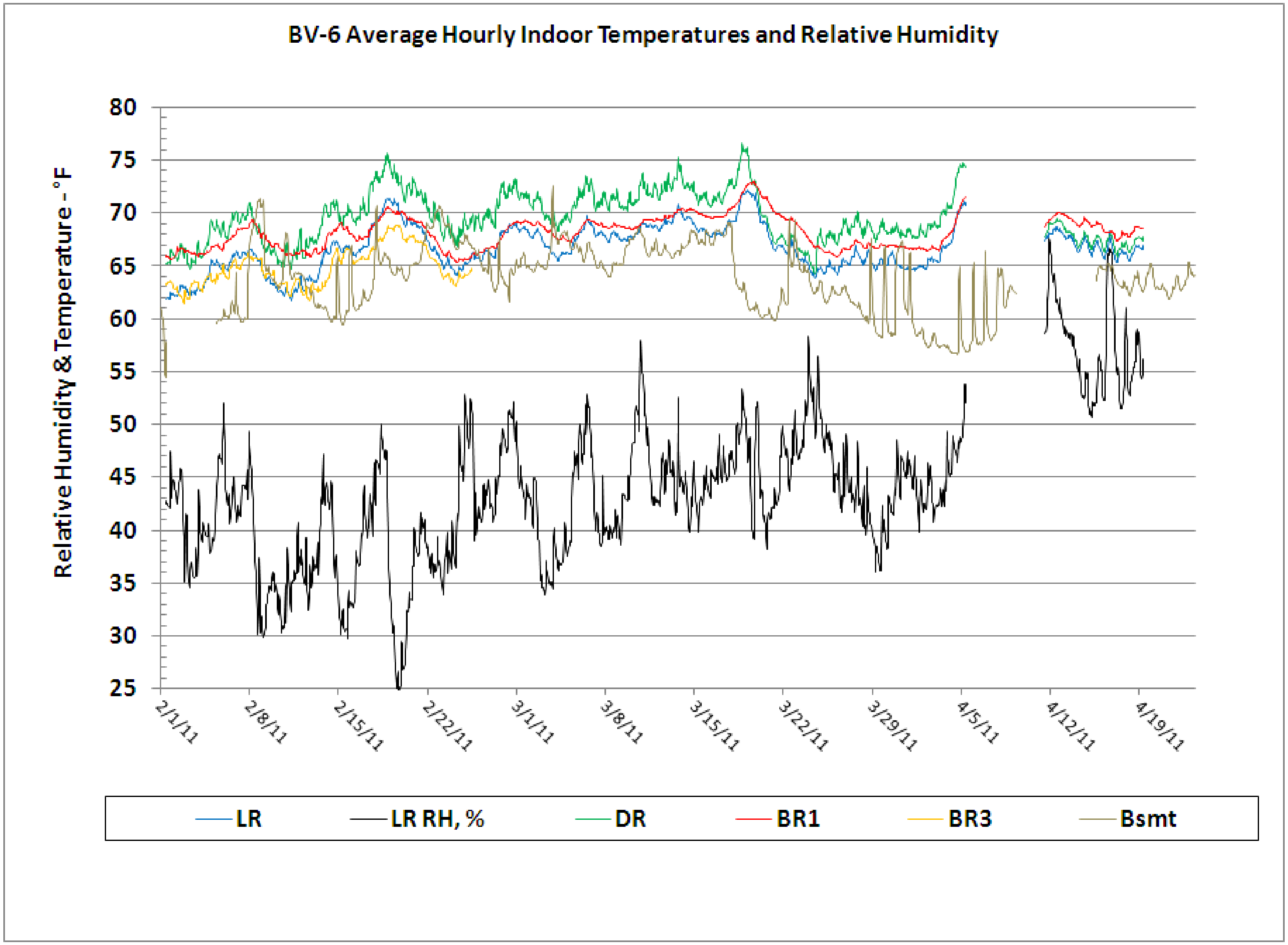


Figure 87. BV-6 Average Hourly Temperature – February 2011 to April 2011.

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