Energy Audit Results for Forest City Phase I and Phase II

Prepared for the

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Hawai‘i Energy Sustainability Program

Subtask 3.5: End-use Energy Efficiency and Demand Response

Prepared by

University of Hawai‘i's
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and Hawai‘i Natural Energy Institute

Submitted by

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Project Report 2: Energy Audit Results for Forest City Phase I and Phase II

Provided to the Hawaiʻi Natural Energy Institute

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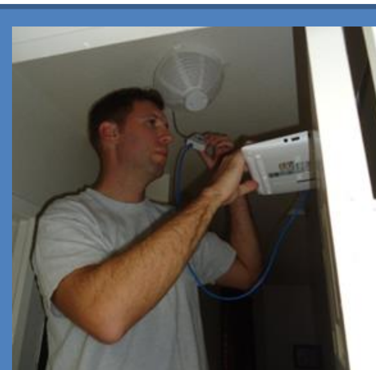

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HNEI FUNDING

This overall project has been funded by two consecutive agreements between the Hawaiʻi Natural Energy Institute (HNEI) and the School of Architecture (SOA). These have been account #6660925 (dates: 7/15/10 to 8/31/12) for $119,111 and account #6662338 (dates: 1/1/11 to present) for $264,721.

OVERAL PROJECT OBJECTIVES

The intent of the relationship between the Hawaiʻi Natural Energy Institute and the School of Architecture's Environmental Research and Design Laboratory (ERDL) is to change the current approach to architectural design and energy use in the State of Hawaiʻi. The overall objectives of this project were:

1. Expand technical capacity of the interdisciplinary ERDL Team; ensure knowledge transfer and institutional program stability:
    a. Expand core team of staff; and
    b. Obtain training opportunities for staff and students.
2. Leverage local projects as learning opportunities for team members in order to build capacity, publish research, and enhance the team's value to the community.
3. Leverage outside public and private sector resources to expand scope and assist program sustainability.
4. The long-term goal is to build a strong research team that conducts innovative research, provides extension services to influence the design and energy consumption of buildings in our climate zone, and provides education and field experience for university students.

PROJECT SHORT-TERM GOALS

The short-term goals of this project were to develop technical skills for the ERDL team in the following disciplines:

1. Residential energy auditing;
2. Monitoring equipment deployment;
3. Residential energy analytics;
4. Data capturing, management and reporting;
5. Building simulation;
6. Energy modeling; and
7. Experimental techniques for testing building design strategies and studying energy utilization.

PROJECT STAFF

This project was managed by Arthur James Maskrey and Eileen Peppard. Part-time undergraduate engineering student assistants who worked on this project were: Trevor Wilkey, Jason Epperson, Christian Damo, Adam Oberbeck. An urban planning graduate student worked on this project: Justin Witty.

FOREST CITY STAFF AND RESIDENT VOLUNTEERS

This project would not have been possible without the dedication of Forest City Vice President of Development, Will Boudra, the determination of Project Manager, Brent Arakaki, and the collaborative efforts of many staff members and electricians.

Military residents who participated in these studies volunteered to allow access and monitoring of their homes. The Watt Watcher Team expresses their sincere appreciation for the residents' cooperation. Without their consent, these studies would not have been possible.

ENERGY AUDITS RESULTS: FOREST CITY PHASE I

Datasets

The Watt Watcher Team instrumented 32 homes. Energy data were successfully captured on 28 homes; four yielded little or no data due to equipment malfunction. Of the 28 homes, 22 yielded useful information for all four pairs of current transducer (CT) instrumentation: total energy, domestic hot water, air conditioner and clothes dryer (Table 1). The refrigerator was monitored using a plug-in Kill-A- Watt® meter. The first two sets of houses measured in this study were instrumented with the TED energy monitor device and did not yield consistent data. A few of those data sets were for only 2 or 9 days instead of 30 days. Table 2 shows intended data collection periods.

Table 1. Descriptive statistics of available energy datasets.

Circuit	Number of Datasets per Circuit
Whole house	28
AC	28
Water heater	25
Dryer	27
Number of Circuits with Data per House	**Number of Houses with This Many Datasets**
4	22
3	6
2	1
0	3

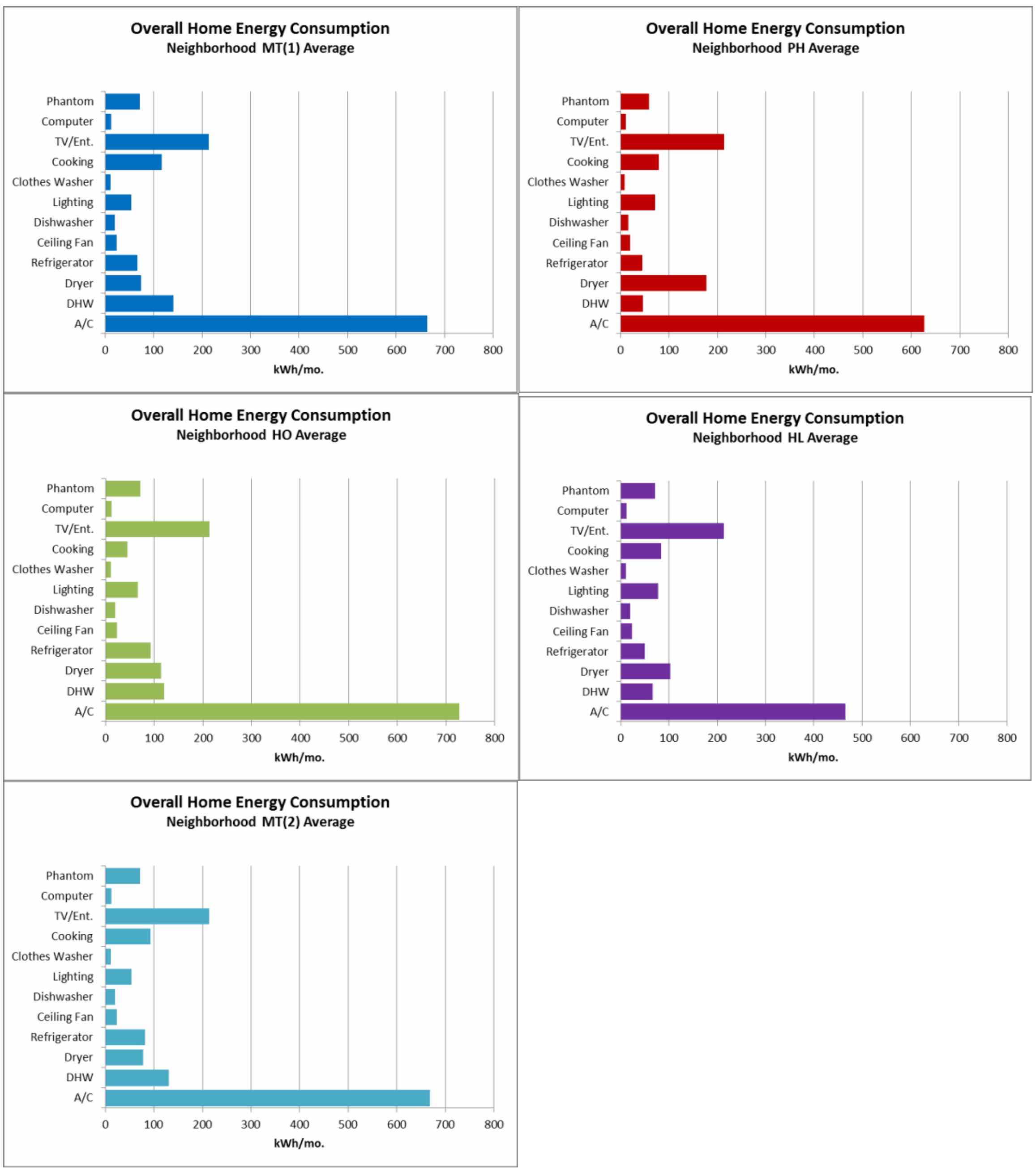
Table 2. Data collection periods.

Neighborhood	Data Collection Period
MT (1)	October 23 to Nov 17, 2010
PH	November 19 to Dec 12, 2010
HO	December 22, 2010 to January 18, 2011
HL	February 2 to March 8, 2011
MT (2)	March 22 to April 19, 2011

Estimated Average End-Use Disaggregation by Neighborhood

Figure 1 compares the relative energy consumption of common energy-consuming devices. While the data for the four monitored end-uses were measured (air conditioner, water heater, dryer, refrigerator), the remaining end-uses are approximations based on available research. Estimates are based on a variety of sources, including Hawaiian Electric Company, the National energy labs, and private research organizations.

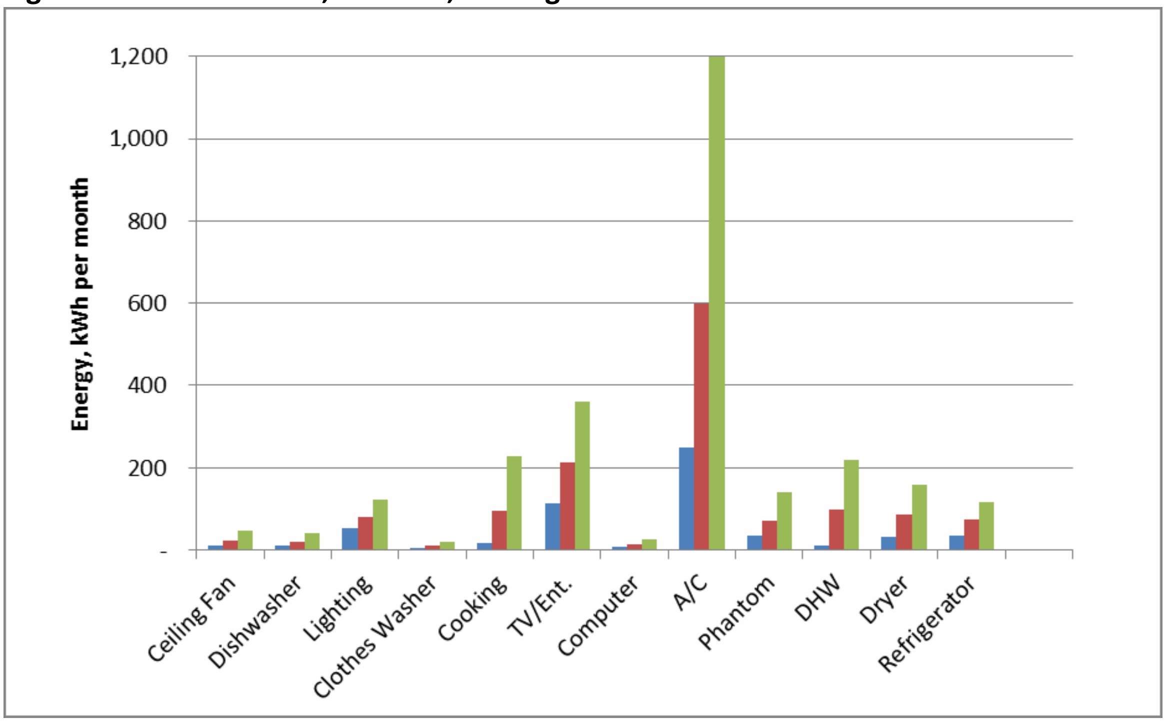
Figure 1. Disaggregation by neighborhood *using only most complete data sets*, n=3 per neighborhood.



End Use: Sensitivity to Low, Medium and High use

While several end-uses in the homes are not measured, their individual impact on overall consumption may be relatively small. Figure 2 shows the estimated relative impact of low, medium and high use of several of these end uses in Forest City neighborhoods. As indicated throughout this report, air conditioning is the major end-use. Domestic hot water, lighting, TV/entertainment are all high consumers, but pale in comparison to the AC load.

Figure 2. Estimated low, medium, and high users.



Air Conditioning Observations

Air conditioning data was collected for 28 homes with 949 to 1431 ft^2 of living area. AC energy consumption is highly variable, ranging from 0.15 to 1.2 kWh/ft^2/month (Fig. 3). This is equivalent to 150 to 1,200 kWh/month for a 1,000-ft^2 house. Air conditioning accounts for 25 to 69% of the total monthly energy use, with an average of 44% (Fig. 4). Occupants use air conditioning all or most of the time in 90% of the homes and 61% prefer a temperature setting below 74°F (Table 3).

Figure 3. Energy use for air conditioning per square foot per month.

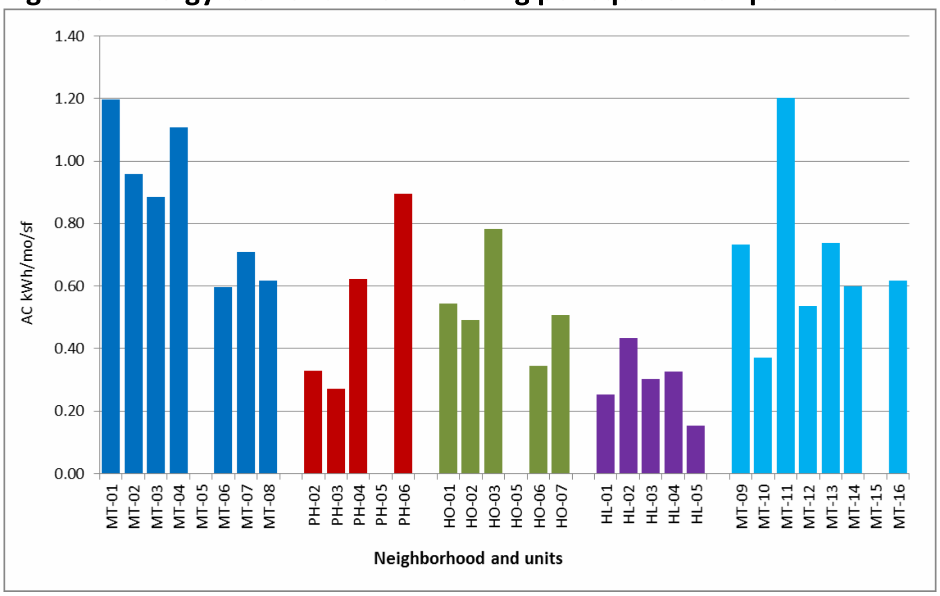


Figure 4. Portion (%) of monthly energy consumption that is attributed to air conditioning.

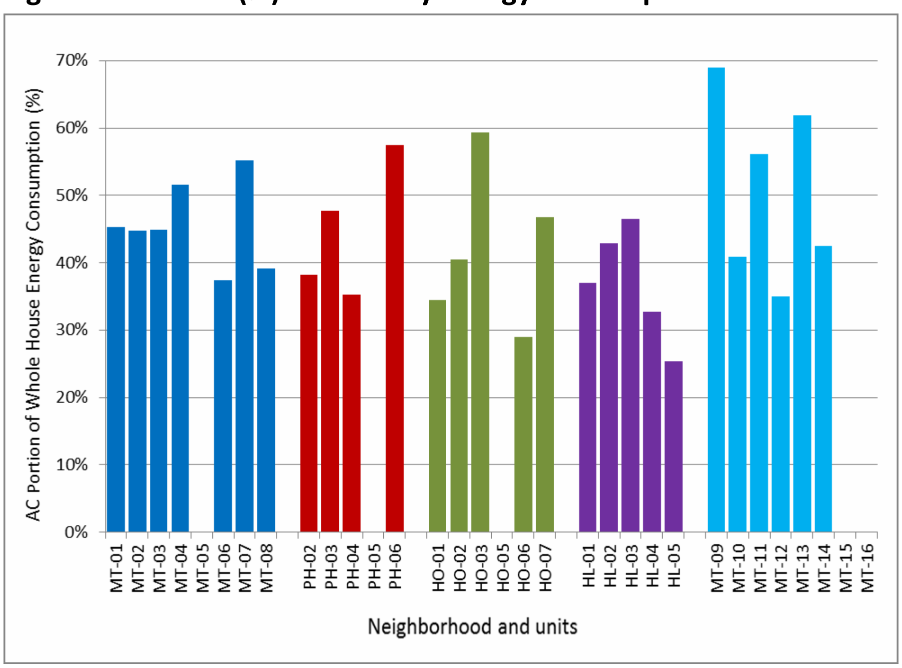


Table 3. Occupant survey responses to air conditioning habits (N = sample size).

Air conditioning condition	N	Response
AC is on all time	31	51.6%
AC is on most of the time	31	38.7%
AC is on sometimes	31	9.7%
Occupant says they set thermostat to less than 74^{o}F.	31	61%
Never open windows	32	31.3%
Of those who open windows, how many do that with AC on	23	21.7%

Relationship between Temperature and Air Conditioning

There is a relationship between air conditioning energy consumption and indoor temperature, however, the relationship is complex and requires further analysis. Table 4 lists the highest energy user to lowest energy user for air conditioning (per sf per month). MT-01 uses twice the energy of MT-08 although it is in the same neighborhood, is the same size, and has the same age and model air conditioner. One difference is that MT-01 has a manual thermostat and can achieve a temperature of 60.8^{o}F in the living room whereas MT-08 has a programmable thermostat that keeps the lower limit at 72^{o}F. On the other hand, MT-11 maintains the same temperature range as MT-08 but uses twice the energy, indicating there is a problem with the air conditioning system (most likely leaky ducts).

Table 4. Comparison of AC energy use (listed from highest to lowest per month per sf), percent time compressor was on, thermostat type[1], living room temperature range, and type of AC compressor.

ID	AC kWh/mo/sf	% time AC on	AC size	AC Make	AC year	Sq ft	Story	Bedrms	Type	Year Built	# of Residents
MT-11	1.20	60%	2.0	Carrier	1996	950	2	2	Duplex	1993	2
MT-01	1.20	80%	2.0	Carrier	1996	950	2	2	Duplex	1993	3
MT-04	1.11	73%	2.0	Carrier	1996	948	1	2	Duplex	1996	3
MT-02	0.96	82%	2.0	Carrier	1996	950	2	2	Duplex	1993	2
PH-06	0.90	74%	2.5	Carrier	2001	1256	2	3	Duplex	2002	4
MT-03	0.88	71%	2.0	Carrier	1996	950	2	2	Duplex	1993	3
HO-03	0.78	34%	4.0	Carrier	1999	1284	2	4	Quad		5
MT-13	0.74	47%	2.0	Carrier	1997	949	2	2	Duplex	1996	3
MT-09	0.73	41%	2.0	Carrier	1997	949	2	2	Duplex	1996	3
MT-07	0.71	44%	2.0	Carrier	1997	949	2	2	Duplex	1996	2
PH-04	0.62	55%	2.5	Carrier	2001	1256	2	3	Duplex	2002	3
MT-08	0.62	41%	2.0	Carrier	1996	950	2	2	Duplex	1993	3
MT-16	0.62	39%	2.0	Carrier	1997	949	2	2	Duplex	1996	3
MT-14	0.60	39%	2.0	Carrier	1997	949	2	2	Duplex	1996	3
MT-06	0.60	57%	2.0	Trane	2008	950	2	2	Duplex	1993	2
HO-01	0.54	25%	4.0	Carrier	1999	1284	2	4	Quad		5
MT-12	0.54	53%	2.0	Trane	2007	950	2	2	Duplex	1993	3
HO-07	0.51	46%	3.5	Carrier	2007	1153	2	3	Quad		3
HO-02	0.49	27%	3.0	Carrier	1999	973	1	2	Duplex		3
HL-02	0.43	47%	2.5	Dayton		1431	1	4	Duplex	1999	5
MT-10	0.37	21%	2.0	Carrier	1997	949	2	2	Duplex	1996	2
HO-06	0.34	22%	3.5	Carrier	1999	1153	2	3	Quad		2
PH-02	0.33	42%	2.5	Rheem	2009	1251	2	3	Duplex	2002	2
HL-04	0.33	39%	2.5	Rheem	2008	1392	3	4	Duplex	1999	5
HL-03	0.30	22%	2.5	Carrier	1997	1392	3	3	Duplex	1999	2
PH-03	0.27	25%	2.5	Carrier	2001	1256	2	3	Duplex	2002	2
HL-01	0.25	23%	2.5	Carrier	1997	1273	3	3	Duplex	1999	4
HL-05	0.15	11%	2.5	Carrier	1997	1273	3	3	Duplex	1999	4

Factors that contribute to energy use by an air conditioning system include:

- Thermostat set point
- Duct, register and grille designs
- Condition of ducts
- Infiltration of outdoor air to conditioned air
- Condition of the compressor heat exchange fins and air handler coil
- Operating habits of the user.

[1] Thermostat types: manual = analog device with sliding control lever; prog. = programmable digital thermostat that has a lower limit of 72°F and can be programmed for different settings at different times of day; digital = a digital device without programming capability.

Figures 5 and 6 show the indoor temperatures achieved in two houses that are both equipped with 2.5- ton, 2001 Carrier compressors. PH-03 uses 342 kWh/mo for AC, has a programmable thermostat in the living room and the temperature in that room remains remarkably stable, in the 74-76°F range. The upstairs bedroom temperature is not as stable and reaches 80°F occasionally, indicating it is not receiving enough of the conditioned air. In comparison, PH-06 uses 1,125 kWh/mo for AC, has a manual thermostat and can achieve 70°F at night, but the temperatures reach 80°F in the afternoon both upstairs and downstairs. Further investigation is needed to determine the problem with PH-06, which could stem from leaky ducts or a problem with the compressor. Turning off the AC while they were gone for five days at Thanksgiving saved approximately 237 kWh for the November billing.

Figure 5. AC compressor power use vs. temperatures for home PH-03 which used 342 kWh/mo for cooling.

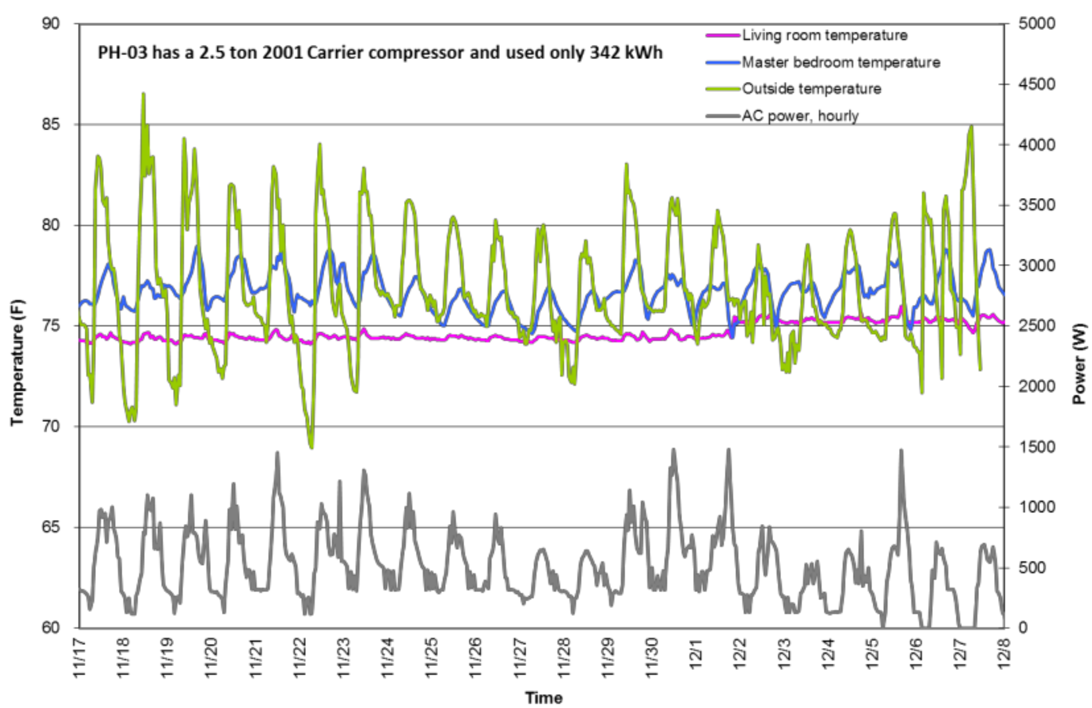


Figure 6. AC compressor power use vs. temperatures for home PH-06 which used 1,125 kWh/mo for cooling.

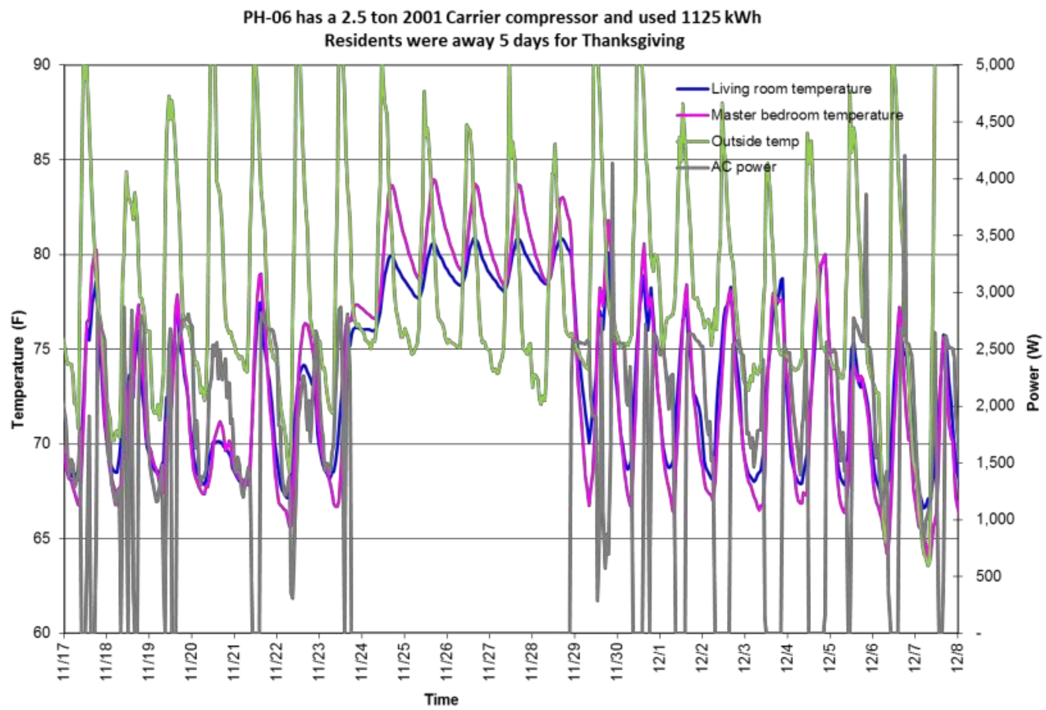


Figure 7 shows stable indoor temperatures for PH-02 which has a programmable thermostat, a 2.5 ton 2009 Rheem compressor and used 411 kWh/month for cooling. In contrast, Figure 8 shows MT-03 which also has a programmable thermostat but it has more variable temperatures, reaching well into the 80's in the master bedroom in the afternoon, and it consumed 840 kWh/month for cooling, or twice that of PH-02. Without further information, it cannot be determined if the new AC compressor contributed significantly to the improved efficiency or if it's a difference in tightness of the envelope and duct work.

Figure 7. Temperatures in PH-02 which used 411 kWh/month for cooling.

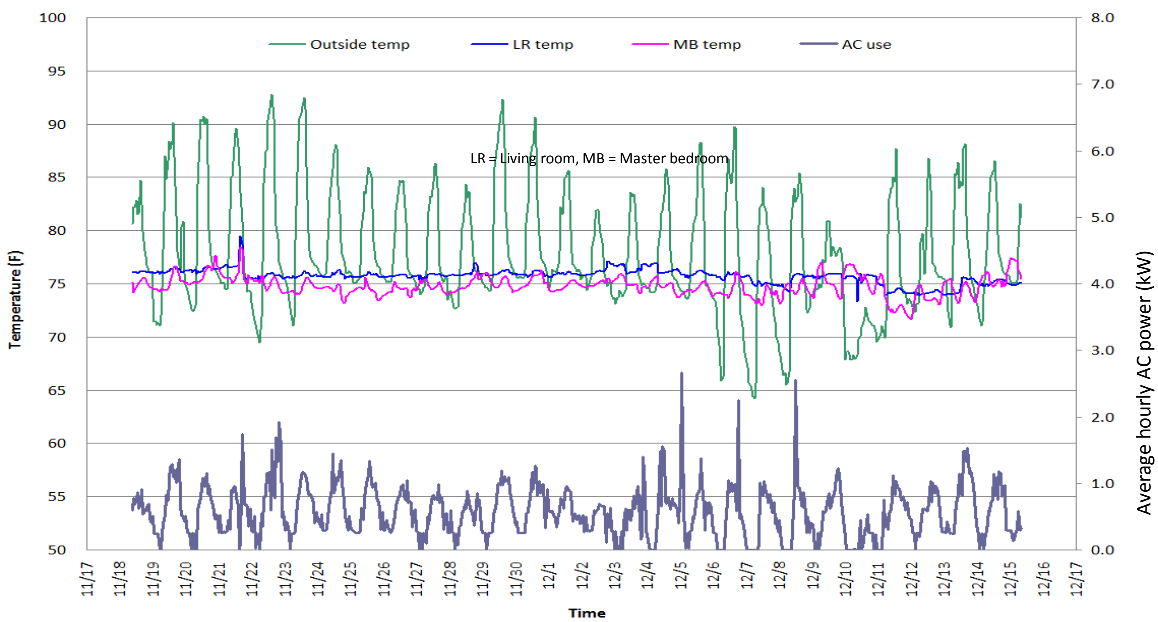
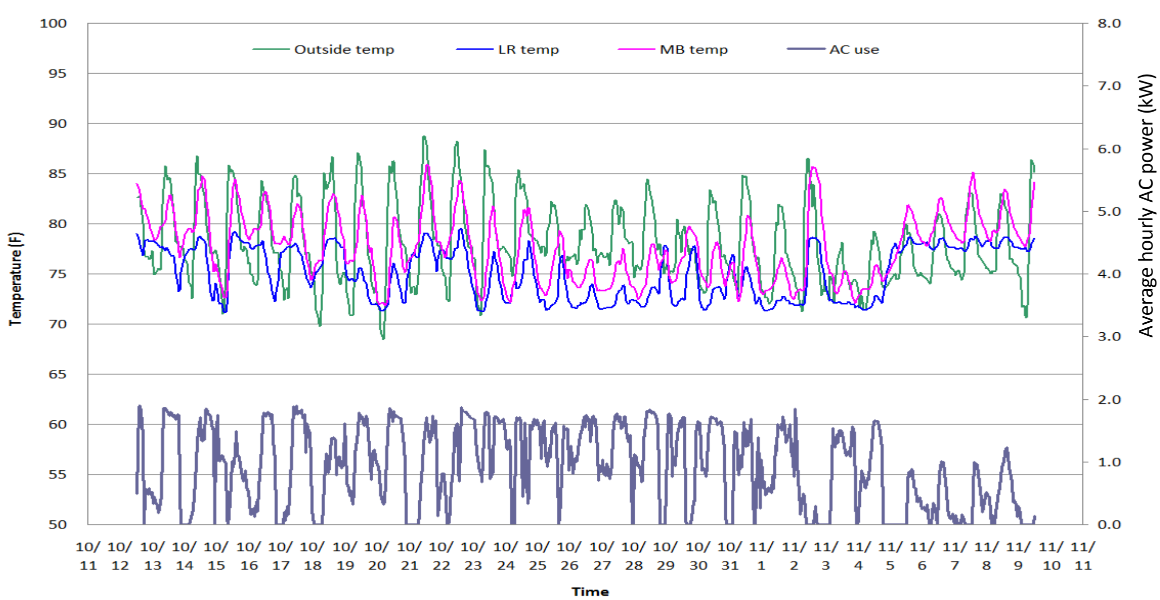


Figure 8. Temperatures in home MT-03 which used 840 kWh/month for cooling.



Relationships between Temperature, Humidity, Comfort, and Energy Consumption for Air Conditioning

Comfort is the individual's perception of environmental conditions within a home, most specifically a function of temperature and humidity. As temperature rises, evaporation of moisture from the skin cools the body by removing the "heat of evaporation." As relative humidity (% saturation) rises, evaporation does not occur as readily, leaving the person feeling warmer. Architects and engineers often refer to humidity as "latent heat." Other factors play a role in comfort such as air movement, direct solar exposure through a window, and mean radiant temperature of the walls, floor and ceiling. These secondary factors are difficult to quantify because they are transient in nature. As such, for the purposes of this discussion of comfort in residential dwellings in Hawaii, only dry-bulb, wet-bulb temperatures and relative humidity will be discussed as variables affecting comfort.

In order to combine temperature and humidity conditions into a single measurement of comfort, we will use a Temperature Humidity Index (THI), also referred to as a comfort index or effective temperature. The equation for this index is: $THI = T_d - (0.55 - 0.55RH)(T_d - 58)$, where T_d is the dry bulb temperature in ^oF, RH is the relative humidity expressed as a decimal[2]. In general, occupants strive to maintain a comfortable environment. Our discussion will describe a space as "comfortable" when conditions maintain a THI of 70 or less (THI_{70}). Moderate comfort is when the THI is between 70 and 75, and discomfort will be described as conditions of THI of 75 or greater, a statistical measure of when 50% of the population would report being uncomfortable. Table 5 demonstrates how the maximum temperature that most people find comfortable (THI_{70}) rises as the relative humidity decreases.

Table 5. Relationship between dry bulb temperature (^oF), relative humidity (%) and temperature- humidity index. A THI of 70 is the marginal comfort level.

Td	RH	THI	Td	RH	THI	Td	RH	THI	Td	RH	THI
70	80%	68.7	70	70%	68.0	70	60%	67.4	70	50%	66.7
71	80%	69.6	71	70%	68.9	71	60%	68.1	71	50%	67.4
72	**80%**	**70.5**	72	70%	69.7	72	60%	68.9	72	50%	68.2
73	80%	71.4	**73**	**70%**	**70.5**	73	60%	69.7	73	50%	68.9
74	80%	72.2	74	70%	71.4	**74**	**60%**	**70.5**	74	50%	69.6
75	80%	73.1	75	70%	72.2	75	60%	71.3	**75**	**50%**	**70.3**
76	80%	74.0	76	70%	73.0	76	60%	72.0	76	50%	71.1
77	80%	74.9	77	70%	73.9	77	60%	72.8	77	50%	71.8
78	80%	75.8	78	70%	74.7	78	60%	73.6	78	50%	72.5
79	80%	76.7	79	70%	75.5	79	60%	74.4	79	50%	73.2
80	80%	77.6	80	70%	76.4	80	60%	75.2	80	50%	74.0

[2] American Meteorological Society, 2011, http://amsglossary.allenpress.com/glossary/search?id=temperature-humidity-index1

In the neighborhoods evaluated, there is a wide range of average internal environmental conditions. Comfort can be affected by:

1. Air conditioning system factors:
   a. Operating duration as a function of owner's preference and thermostat settings. Manual analog thermostats can be set at lower temperatures causing the A/C system to run longer in order to drop the temperature to resident preference (e.g. 68^{o}F). Programmable thermostats have a fixed minimum setting of 72^{o}F, thus limiting the duration of operation.
   b. Oversized A/C can cause the compressor to cycle on and off as the house rapidly cools down, satisfying the thermostat and sending signal to the compressor to shut off. This interrupts the system's ability to dehumidify.
   c. Thermostat location: the thermostat is usually located in living room, often near the airflow of a nearby supply air register. This has the effect of maintaining a higher level of comfort on the first floor while not satisfying the comfort requirements of the second floor.
   d. Note: The second floor has more direct heat gain from the roof, is warmer because hot air rises from the first floor, and the rooms are at the ends of the ducts furthest from the fan coil blower.
   e. Condition of compressor: poor fin condition leads to poor heat transfer and reduced effectiveness.
   f. Design of the duct system: oversized, undersized, damaged, or constricted supply air ducts can reduce the effectiveness of the A/C system to deliver cooled and dehumidified air.
   g. Leaks in either ducts or plenum system result in conditioned air blowing to the outside or unconditioned attic.

2. Solar Heat Gain:
   a. The sun in Hawaii contributes a significant portion of the cooling load to a home. The roof, windows and walls are the primary paths for solar heat gain.
      i. Walls: Most walls are insulated to a minimum of R-11. Steel frame walls create a direct thermal bridge that easily transmits heat through the wall. Wood framed walls also have a bridging affect, but to a lesser degree. Some of the wall construction utilizes Styrofoam sheathing on the external wall, adding an additional R-value to the wall assembly while disrupting the thermal bridge.
      ii. Roofs: Most in the sample are insulated with R-19 fiberglass batt. However, due to careless placement by various contractors that have accessed the attic, sections of insulation are frequently not in their proper location, leaving ceiling areas exposed.
      iii. Windows: Window placement has the largest impact on solar heat gain directly to living space. South facing windows without overhangs see the sun most of the day, most of the year. East facing windows will see direct sunlight in the morning while west facing windows will get direct solar gain in the afternoon when temperatures are also the highest.

iv. Window treatments: Window treatments can range from adjustable mini-blinds to curtains, to no treatment at all. The ability to control the access of sunlight to a space is important when managing air conditioning load.
v. Exterior shading features: Exterior devices and features can prevent the sun's rays from reaching the windows. Overhangs can help shade the windows on the south side of the home, while vertical walls and fins can shade low altitude early morning and late afternoon sun. Trees and shrubs are often used as natural shading devices.

3. Occupant Behavior: Comfort can also be affected by users' habits.
   a. Open doors and windows (while air conditioning): Leaving doors and/or windows open while the air conditioning system is running will lead to ineffective A/C operation and discomfort in a conditioned home. Humid outdoor air is introduced to the interior air stream causing the compressor to work harder to maintain set point.
   b. Cooking and hot showers also can contribute heat and humidity to the load, although these are areas where little can be done other than manage effectively (close bathroom doors while showering, use exhaust fans to remove steam and heat, etc.)

Although the above issues can affect the individual heating patterns of a home, all the homes were built in a similar manner and exist in a similar environment, therefore should follow a basic pattern of: more air conditioning equals more comfort. Several homes did not follow this trend and show high internal temperatures despite extremely high air conditioning use. Figures 9 and 10 show the relationship between air conditioning energy use vs. comfort in the homes. The ideal home would use little to no air conditioning yet be low in the percent of time above THI 70 (some people report discomfort) and THI 75 (at least 50% of people would report discomfort). Thus the lower left corner of the graph represents an ideal situation and the upper right hand corner represents the worst scenario.

While the exact reasons for the differences can vary widely, it is clear that some homes are working much more efficiently than others in relation to the THI. Solutions for this problem may be as simple as: a better explanation to homeowners on how to set their programmable thermostats to fit their daily routine; assuring all the insulation is in place in the attic; and repairing leaky ducts and plenums. Less simple solutions are: replacing compressors and air handlers. Figures 11, 12, and 13 illustrate the performance of two homes, HO-03 and HL-04, which are of similar size, have the same number of occupants and temperature preferences, but the energy use for AC in HO-03 is more than twice that of HL-04. This may be due to the younger AC in HL-04, or it might be caused by leaky ducts in HO-03. The worst case scenario for comfort alone was MT-10 (Fig. 14). The overall worst case scenario for high energy consumption for cooling combined with low comfort was MT-11 (Fig. 15).

Figure 9. Percent time THI was over 70 vs AC energy (kWh/month per 1,000 ft^2).

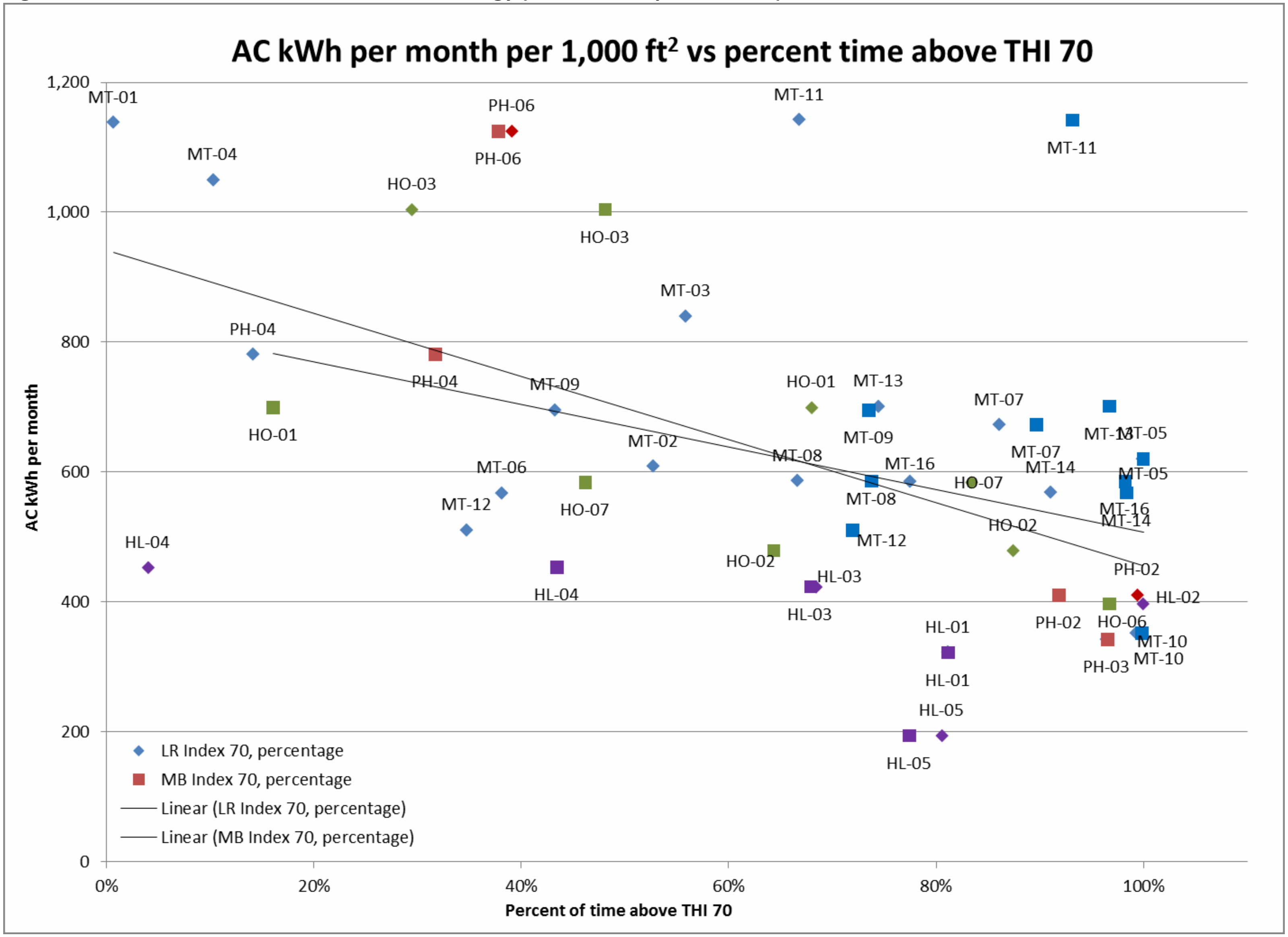


Figure 10. Percent time THI was over 75 vs AC energy (kWh/month per 1,000 ft²).

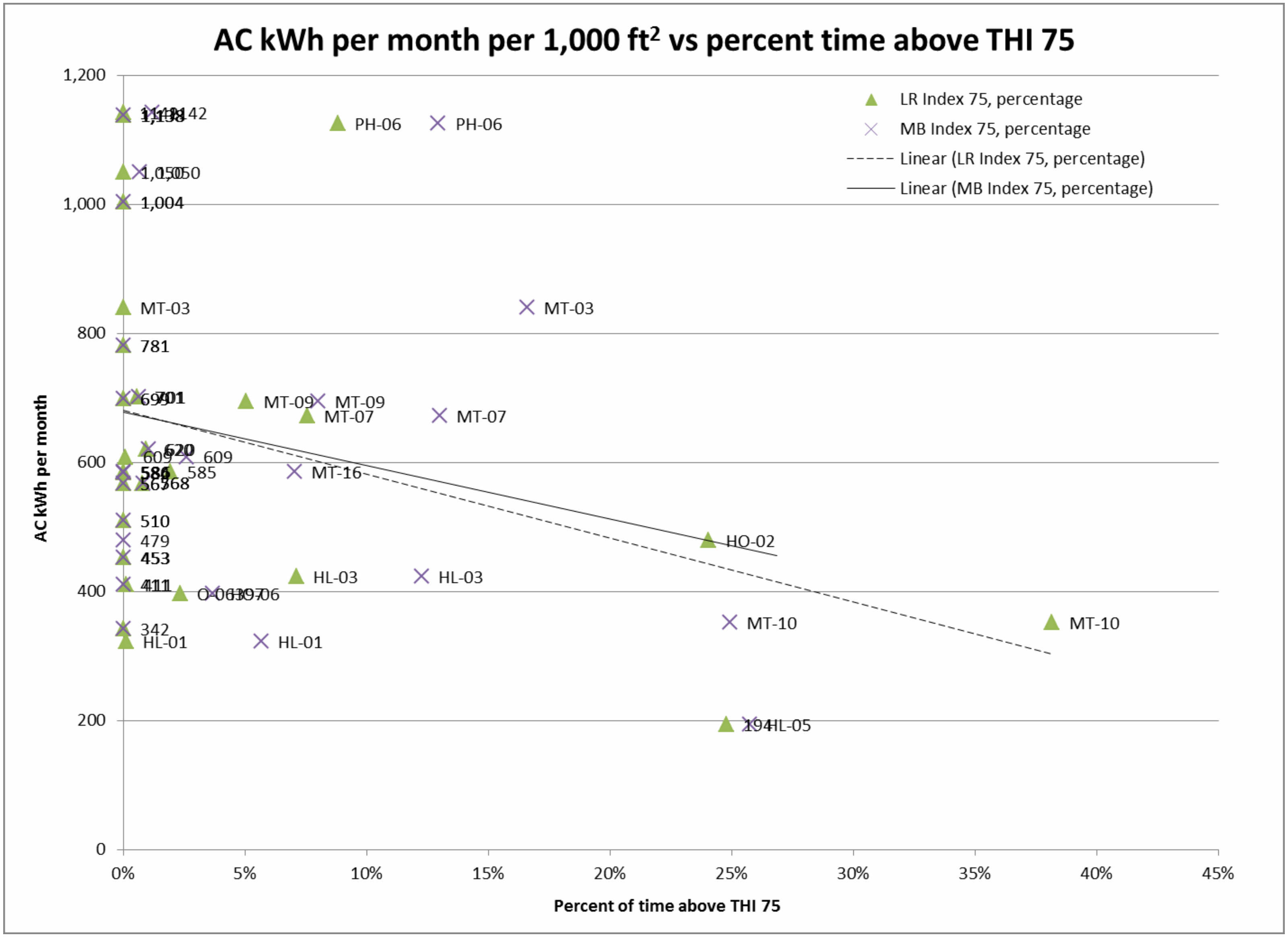


Figure 11. Comparison of two homes of similar size, number of occupants, temperature settings, but different energy use for AC.

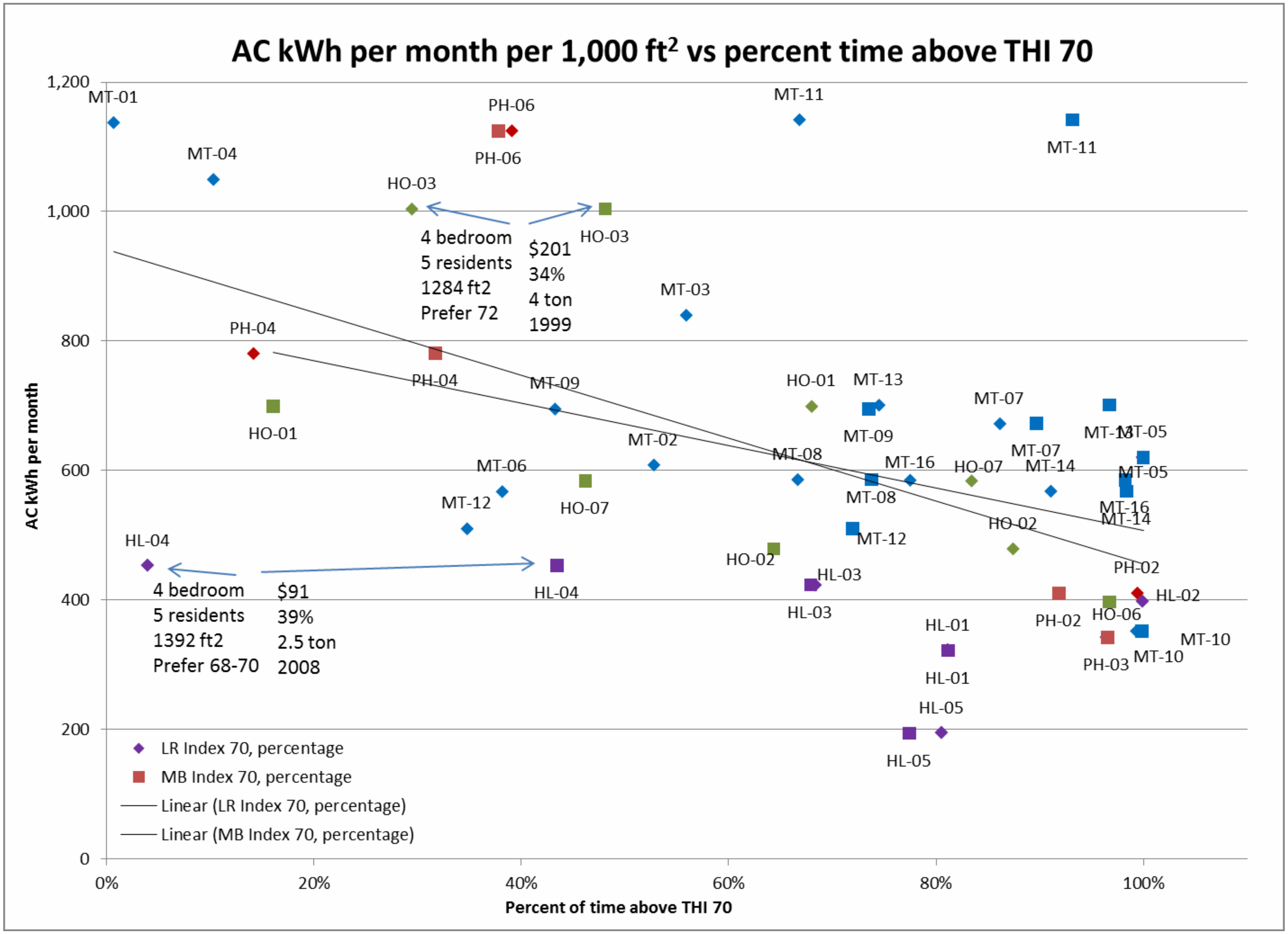


Figure 12. Comfort Index conditions within HL-04 were always below THI 75 and a considerable amount of time below THI 70.

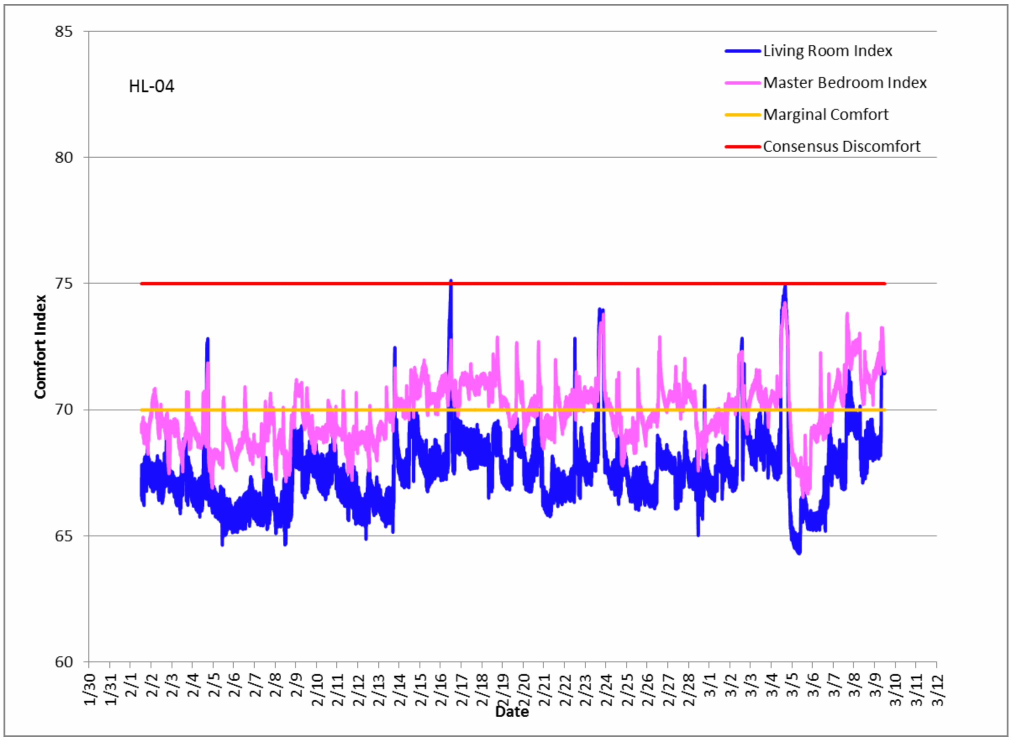


Figure 13. Comfort Index conditions within HO-03 were not better than HL-04 despite using more than twice as much energy for cooling.

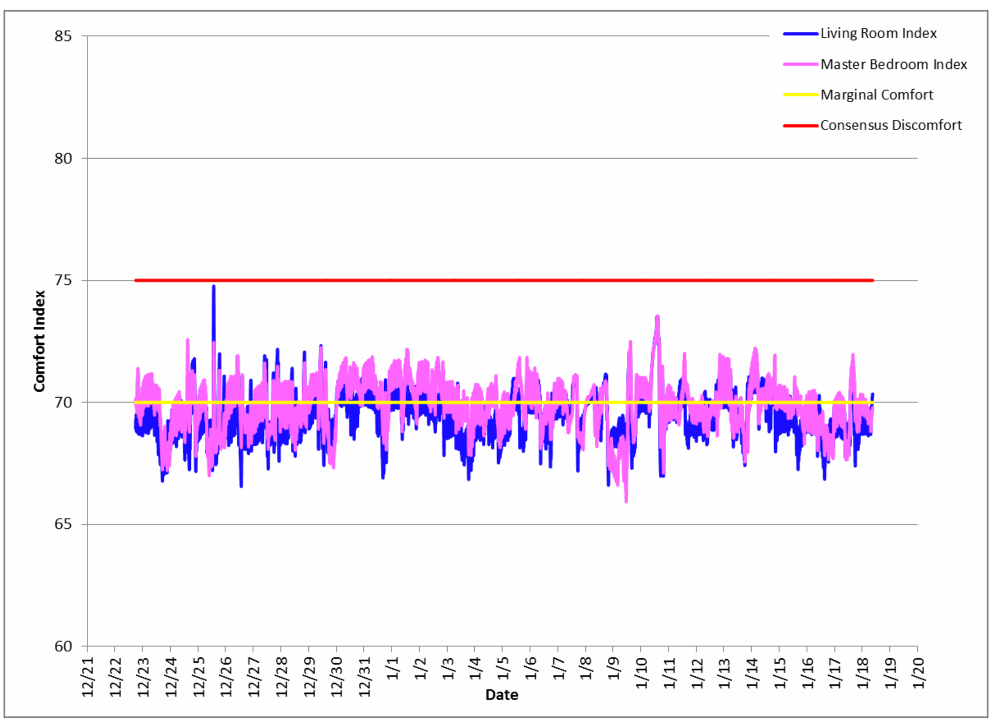


Figure 14. The worst case scenario for comfort alone was MT-10.

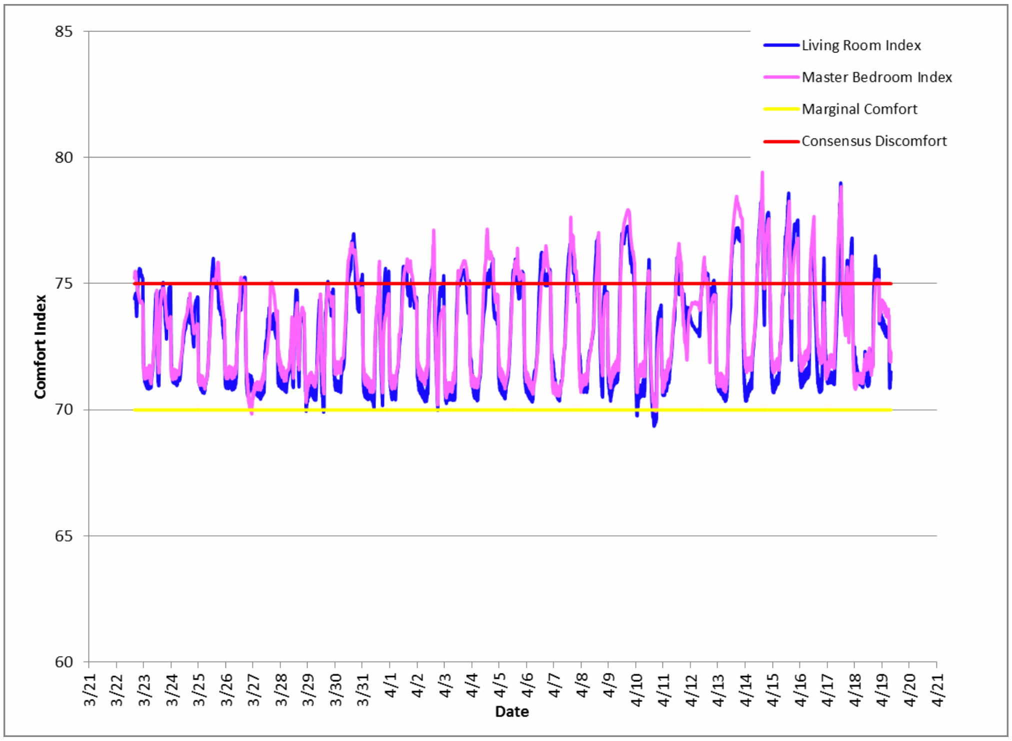
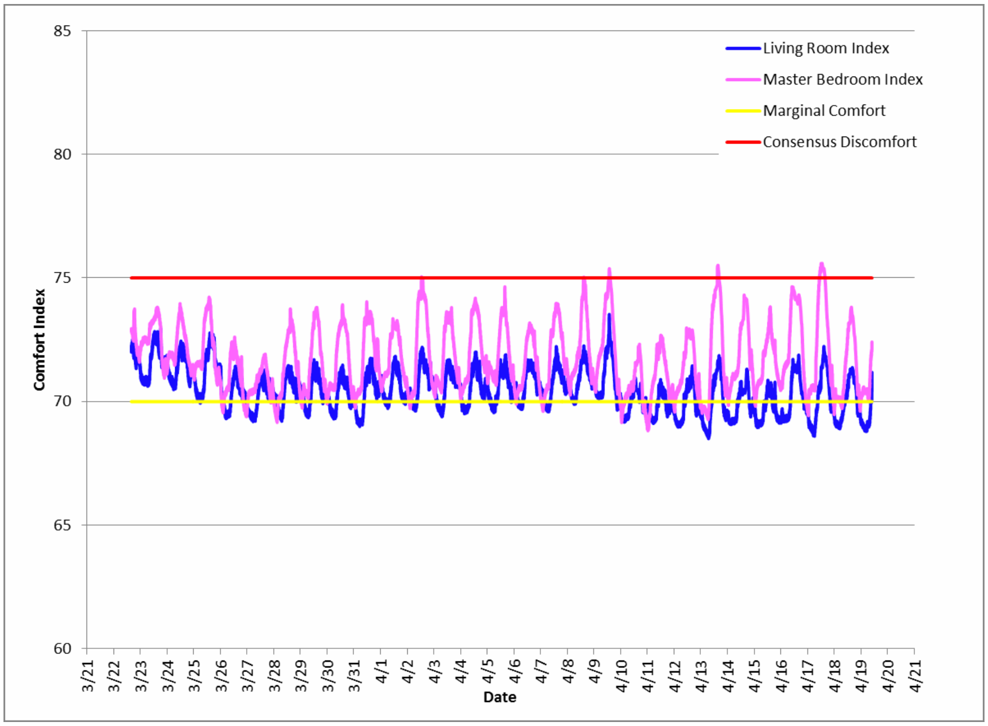


Figure 15. The worst case scenario for the highest energy use with the lowest comfort was MT-11.

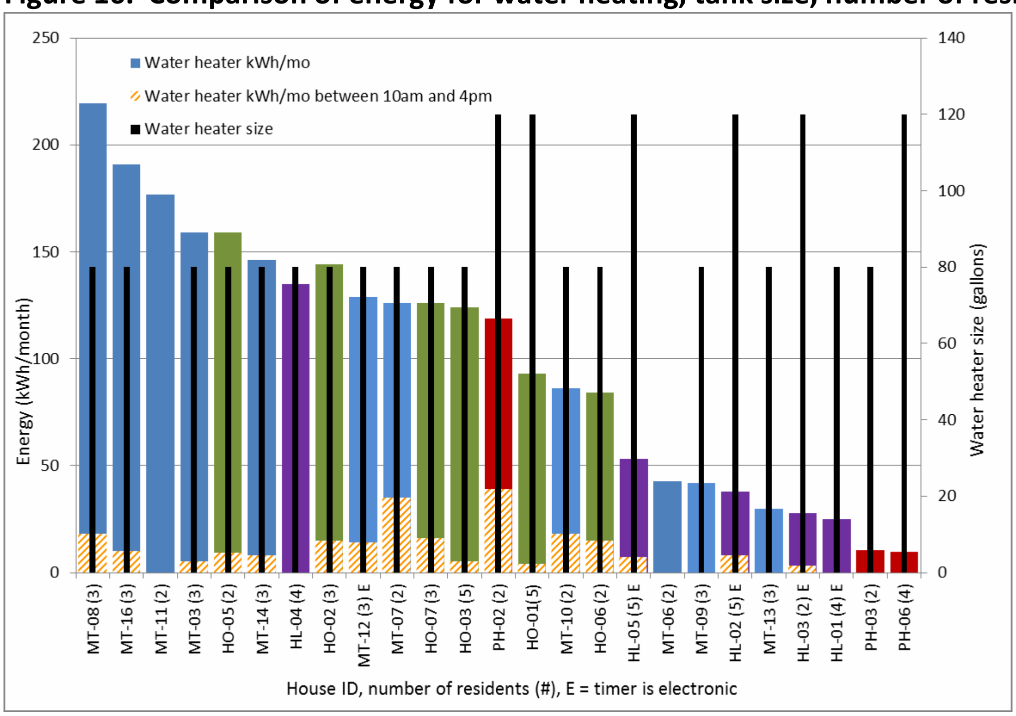


Energy Consumption for Water Heating

All houses were equipped with direct solar water heating with an electric backup heater that served as the storage tank (with R-16.7 to R-17.3 built-in insulation). Water is circulated to the panels on the roof with a 50-80W pump equipped with a differential controller (Delta T or Sun Earth). The backup water heater thermostat is set anywhere from 125 to 180°F. The heater is equipped with a timer that is set to allow the heater to turn on for several hours in the evening and then again in the morning. The heater should not come on between 10am and 4pm - the water should be heated by solar during those hours. Figure 16 compares the energy consumed for water heating per house (house ID), by neighborhood (color coded bar), energy consumed between 10am and 4pm (orange striped portion of bar), number of residents in home (# after ID), if the timer is electronic (E after the ID), and the size of the water heater (black bar). The consumption varies from 10 to 219 kWh/month. There are various reasons for this disparity. Conclusions which could be drawn from Figure 16:

- Some solar systems are not functioning. The system in MT-03 was turned off. Pumps in MT-09 and MT-10 ran all the time and in MT-12 it ran most of the time.
- Some water heater timers are not working (MT-03, MT-12).
- Some families might use a lot of hot water during the evening and early morning hours.
- Low or no energy use between 10am and 4pm but high energy use overall is indicative of a system with a functioning timer but a non-functioning solar heating system. Some data showed heaters often came on right at 4pm when the timer allowed it, indicating the solar system did not heat the water in the afternoon.
- Families with 4 or 5 people are not the highest users.
- Homes with 120 gallon tanks are not the highest users.

Figure 16. Comparison of energy for water heating, tank size, number of residents in home.



From Table 6 we can see that 80-gallon tanks were consistently installed in the smaller homes (<1,200 ft^2) but 120-gallon tanks were not always installed in the larger homes. The solar pump appears to be wired to the same circuit as the water heaters in neighborhoods MT and HL, but not the others, so it could not be determined for certain if the solar pumps function in those neighborhoods. In MT, 4 out of 11 data sets show no evidence of the solar pump functioning ("none"). In HL, all 5 of data sets show the pump functioning.

Table 6. Comparison of house size (sq ft) to number of bedrooms, number of residents, hot water tank size (gal), whether solar pump energy data[3] appeared on the water heater circuit, and brand of differential controller.

House ID	Sq ft	# Bedrooms	# Residents	Tank Size	Pump (W)	Solar Controller Brand
MT-04	948	2	3	80	no record	no record
MT-05	948	2	3	80	no record	no record
MT-07	948	2	2	80	None	no record
MT-09	949	2	3	80	53	Delta T
MT-10	949	2	2	80	54	Delta T
MT-13	949	2	3	80	54	Delta T
MT-14	949	2	3	80	49	Delta T
MT-16	949	2	3	80	56	Delta T
MT-01	950	2	3	80	no record	no record
MT-02	950	2	2	80	no record	no record
MT-03	950	2	3	80	None	no record
MT-06	950	2	2	*	70	no record
MT-08	950	2	3	80	None	no record
MT-11	950	2	2	*	None	Delta T
MT-12	950	2	3	80	88	Goldline
MT-15	950	2	2	*	no record	Delta T
HO-02	973	2	3	80	18??	Delta T
HO-06	1153	3	2	80	None	Delta T
HO-07	1153	3	3	80	None	Delta T
PH-02	1251	3	2	120	None	Delta T
PH-05	1251	3	4	120	no record	Goldline
PH-03	1256	3	2	80	None	Delta T
PH-04	1256	3	3	80	no record	Delta T
PH-06	1256	3	4	120	None	Delta T
HL-01	1273	3	4	80	80	Goldline
HL-05	1273	3	4	120	76	Goldline
HO-01	1284	4	5	120	None	Delta T
HO-03	1284	4	5	120	None	Delta T
HO-05	1290	3	2	80	None	Delta T
HL-03	1392	3	2	120	78	Goldline
HL-04	1392	4	5	80	87	Goldline
HL-02	1431	4	5	120	80	Goldline

[3] Solar pump energy data: no record = all energy data on water heating circuit missing; none = pump not on electric water heater circuit or pump not working.

Hot water use was not directly measured, nor was dishwasher energy monitored. The resident survey results showed 10% never used the dishwasher, 39% use it daily, 51% on alternate days. Most users (96%) wash full loads only. Some residents (23%) said they never hand wash dishes (Table 7).

Table 7. Survey responses to habits of washing dishes.

Dishwashing habit	Number respondents	Response rate
Never use dishwasher	31	10%
Use dishwater 7 days/week	31	39%
About every other day	31	51%
Dishwasher full loads only	28	96%
Never hand wash dishes	31	23%

Water used for bathing was estimated from the resident survey by the number of showers per week and the average length of time reported for showers multiplied an estimated flow rate of 2 gallons per minute. Numbers of baths taken per week were multiplied by 20 gallons to estimate quantity of bath water used per week. No relationship was observed between estimated volume of bathing water and energy used for heating water. The mean weekly estimated water use for bathing for families using less than 100 kWh/month for water heating was 678 gallons/week (N=13) and for families using over 100 kWh/month for water heating actually reported using less water, at an average of 638 gallons/week (N=11). The estimated weekly water use for bathing ranged from 200 to 1,480 gallons.

Energy Consumption for Clothes Dryers

Energy used monthly for drying clothes varied from 16 to 181 kWh (Fig. 17). Monthly hours of operation ranged from 7 to 95 hrs. This is mainly due to variations in lifestyles, but dryer efficiency could play a role. Some of the ventilation ducts were long and not venting the hot, humid air properly - adding to the heat and humidity ("latent heat") load of the home. A typical 12-pound load of dry laundry can hold 8 pounds of water when taken out of the washer.

Of 31 survey respondents, 13% said they air dry one to three loads of laundry each week. Table 8 shows dryer energy use and the number of people in the home. No relationship was observed between dryer energy use and total number of people, number of children (<age 11), or number of adolescents in the home.

Figure 17. Comparison of energy used for clothes drying (kWh/mo).

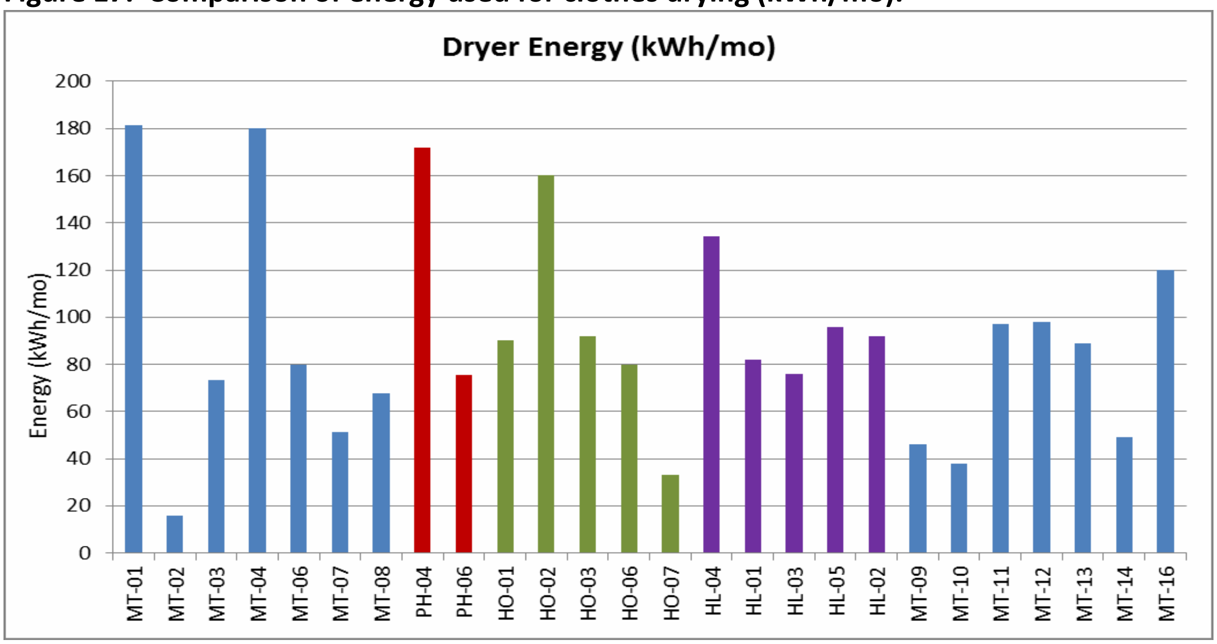


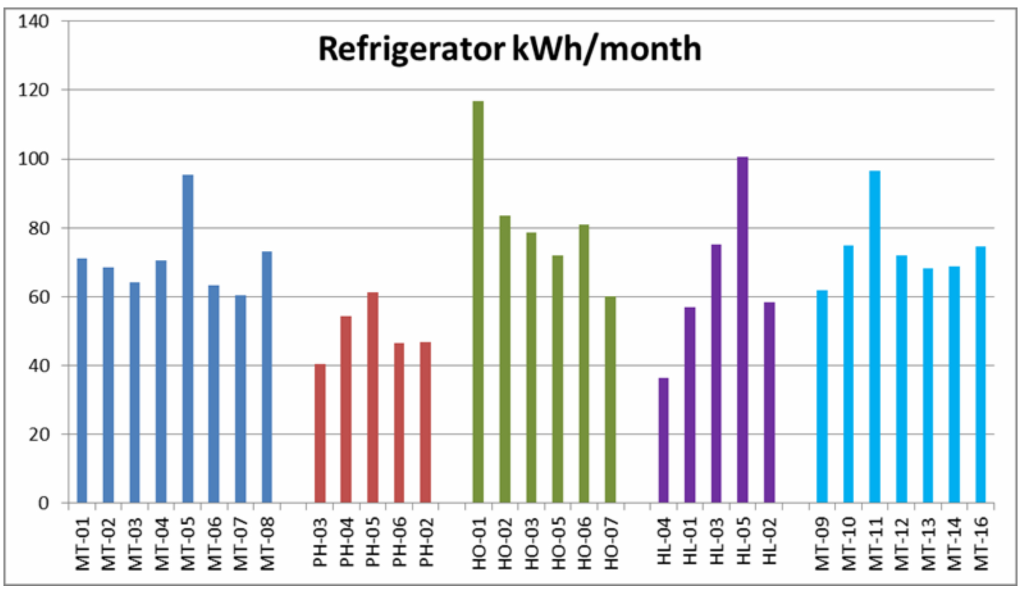
Table 8. Dryer energy use and the number of people in the home (N = number in sample).

# people	range (kWh/mo)	average (kWh/mo)	N
5	90-96	93	4
4	75-134	97	3
3	33-181	106	12
2	16-97	63	7

Energy consumption for refrigerators

The variation in energy consumption (Fig. 18) of refrigerators is mainly a factor of size (Table 9) and age (Table 10). The average age of refrigerators in the MT and HO neighborhoods is 1997, but the average age of the appliance in PH and HL is 2001-2002. Refrigerators supplied by Forest City are all 18 to 22 ft^3 in size and are standard top-mount freezer design (the most efficient configuration; Table 11). The refrigerator in HL-05 was a 21 ft^3 Hotpoint instead of the standard Whirlpool found in Forest City homes and consumed 101 kWh/mo. This was considered an outlier and omitted from further analyses along with the resident-supplied 26-ft^3 side-mount freezer Frigidaire model in HO-01.

Figure 18. Comparison of monthly energy consumption of refrigerators at Forest City.



The refrigerator in HO-01 was a recent model 26 ft^3 side-mount freezer model refrigerator supplied by the resident. Although this model gave the resident 44% more space than the 2005, 18 ft^3 refrigerator in HL-04, it used 320% of the energy. From an energy standpoint, it would be more efficient for this family of five to own two efficient, standard design refrigerators. In fact, this family did have an extra refrigerator and a freezer, but we did not have enough equipment to monitor them. An example of an old second refrigerator kept for extra space: a spare refrigerator in the garage at HL-02 (1994, 22 ft^3) used 148% of the energy the Forest City-supplied refrigerator in their kitchen (2003, 21 ft^3). In our sample (N=31), 32% had an extra refrigerator or freezer (or both) and we found no relationship between the use of an extra refrigerator and family size or the size of the refrigerator supplied by Forest City.

The difference between annual energy use of the older (pre-2001) refrigerators and younger refrigerators supplied by Forest City is 261 kWh (Table 10) which realizes a savings of $65/year at the 25 cents/kWh. If the old refrigerators were replaced with new ENERGY STAR refrigerators, the annual energy savings would amount to somewhere between $96 (20% less energy than the 2001-2005 models in use and Forest City) and $124 (energy use taken from the ENERGY STAR website for brand new 20 ft^3 models; Table 11). When Forest City is choosing a new refrigerator, it should be noted that the energy savings of an ENERGY STAR-rated 20 ft^3 top mount freezer configuration (the best-case scenario from Table 11) vs. the same design one that is *not* ENERGY STAR-rated, is approximately $24 annually. If the life expectancy is 15 years (the oldest refrigerator in our sample was 16 years at the time of measurement), that amounts to a $354 lifetime energy savings. The lifetime energy use difference between this best-case scenario and the worse-case scenario design (side-mount freezer with through- the-door ice, not ENERGY STAR; Table 11) is $864.

Table 9. Forest City refrigerator size and average annual energy use (excluding 1 outlier and one resident-supplied refrigerator; N = number in sample).

Refrigerator size (ft^3)	Annual energy use (kWh)	N
18	599	5
20	822	6
21	885	10
22	889	6

Table 10. Forest City refrigerator age and annual energy use (excluding 1 outlier and one resident- supplied refrigerator; N = number in sample).

Refrigerator year of manufacture	Annual Energy use (kWh)	N
1995-2000	877	21
2001-2005	616	6

Table 11. Comparison energy consumption for new refrigerators of different configurations and ENERGY STAR-rated vs. not rated.[4] (Table adapted from ENERGY STAR website[5].)

Configuration	NAECA energy use (kWh/year) for 20ft^3 size	Annual energy bill at 25 cents per kWh	ENERGY STAR refrigerators use 20% less energy than the NAECA maximum.	Annual energy bill at 25 cents per kWh	Annual savings	15-year savings
Top Mount Freezer without through-the-door ice	472	$ 118.00	378	$ 94.40	$57.60	$ 864.00
Side Mount Freezer without through-the-door ice	606	$ 151.43	485	$ 121.14		
Bottom Mount Freezer without through-the-door ice	551	$ 137.75	441	$ 110.20		
Top Mount Freezer with through-the-door ice	560	$ 140.00	448	$ 112.00		
Side Mount Freezer with through-the-door ice	608	$ 152.00	486	$ 121.60		

[4] Annual and 15-year savings calculated between worst case (orange) and best case (green) scenarios in table.

[5] http://energystar.supportportal.com/ics/support/kbAnswer.asp?deptID=23018&task=knowledge&questionID=23690

RECOMMENDATIONS TO FOREST CITY

The Watt Watcher Team cataloged observations and recommendations as follows:

Modifications to Existing Air Conditioning Systems

1. Inspect attics for duct leakage and missing attic insulation (See Appendix A for infrared images).
    a. We have seen a duct completely disconnected (it was reported and repaired).
    b. Insulation in the attic of many homes had been pushed aside – presumably for installation of the security wiring. This was included in a 2009 report for Forest City by Sentech consultants.
    c. Soffit areas need insulation.
    d. Seal chase and ducts in attic.
    e. Seal return plenum under air handler.
    f. Attic hatch panel should be insulated.
2. Compressor needs protection from leaves, weeds, vines, and weed whacker; providing a clear space and up on small concrete pad is good. Advise residents (better: post sign to keep clear).
3. A better filter or a grill to support filter in air handler. These soft ones are collapsing. (Some houses have had a better filter)
4. Check for leakage and infiltration around air handler, air return plenum, wall outlets, between drywall and duct behind each register and when steel framing is used, at door jambs. We have found leaking at these locations.
5. Seal around door from home to garage.
6. Supply clearly stated instructions for use of AC, thermostat, and hot water systems for occupants. Better: Post these instructions where resident can regularly see them, near water heater, in laundry room, etc.
7. Provide a small wall penetration for residents wishing to install a satellite dish to deter them from running the cable through a window, thus leaving a window cracked open for the duration of their residence.

Recommendations for Future Air Conditioning Projects

1. Choose a compressor with good grill protection of cooling fins – the few observed with good protection were in good condition.
2. Specify anticorrosion coating compressor fins.
3. Air handler located in an indoor closet is good; in the garage is the very worst. If not well sealed, hot and sometimes contaminated air (exhaust fumes, etc.) will be distributed into the home.
4. High Temperature differential between floors: need a better balance of ducts/grill size – zoning and distribution.

5. Ensure the latent cooling capacity of fan coil matches the latent cooling load of home.
6. The use of transfer grills for bedrooms is recommended for well-balanced supply and return. Otherwise, check that the door is sufficiently undercut (Gentry uses transfer grills). If the bedroom door is closed and the door is not undercut adequately, there is no place for the air to flow out; therefore little air gets pumped into the room, leaving it warm and humid. The pressure in the room should be less than 3 pa higher than the hallway (5-7 pa has been observed in Forest City homes).
7. Observation: With security systems, residents can't set alarms if windows are open – this is an inherent behavioral deterrent to natural ventilation. When they do open the windows, the alarm system beeps.
8. Replace missing piece to close off air filter access slot – many of these are missing and the gap sucks in hot, humid air – this is particularly dangerous in the homes where the air handler is located in the garage which can have toxic fumes. (e.g. Hawaii Loa neighborhood on the Marine Corps Base).

Photo 1. Corroded cooling fins.

Photo 2. Compressor on concrete pad protects it.

Photo 3. Leaves piled up by compressor.

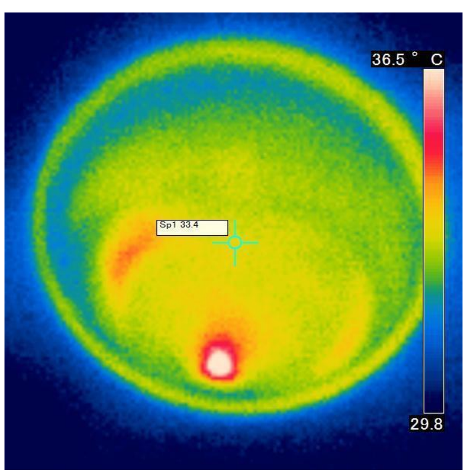
Photo 4. Bushes growing too close.

Photo 5. Good cooling fin protection.

Lighting

1. Promote CFLs.
    a. Ceiling fan CFLs are frequently dimmable. Conventional, non-dimming CFLs may experience shorter life and may hum when dimmed.
    b. Keep up and advertise the light bulb exchange program, possibly supply them with a few spare bulbs. There is evidence they replace with incandescent bulbs (we find CFL and incandescent in the same fixture).
    c. CFL specification needs to be visually consistent (same color temperature).
    d. There are performance issues associated with mounting CFL in side and down mounted configurations. These impact performance and life of the lamps. CFLs that are designed for inverted and side mounting are preferred.
2. 1 or 2-lamp fixtures are better than 4-lamp fixtures – extra light is not necessary. In many fixtures, the resident has unscrewed some of the lamps.
3. The specialty PL fluorescent tubes are a good choice.
4. We recommend use of solar tubes. Some manufacturers have Solar Heat Gain Coefficients (SHGC) as low as 0.20, and qualify for EPA Energy Star labeling. Low SHGC means that visible light is transmitted with minimal heat transfer.
5. More ceiling fans – increased air speed means that a higher temperature/humidity condition can still be comfortable.
6. We observed in a home that the recessed lighting upstairs (master bedroom) is conducting a lot of heat – they are equipped with CFLs but a sticker on the light housing states "*Warning Risk of Fire, do not install insulation within 3 inches of any part of this luminaire, remove this label if installed in an IC application.*" The warning to not insulate may have been for when the fixture was equipped with incandescent bulbs.
7. The ceiling fan in the master bedroom was also seen to be transferring heat from the attic.

Photo 6. Infrared image of recessed light upstairs of a 2-story house, allowing heat transfer from attic into master bathroom. The light is *not* turned on. Temperature range of the fixture is 85.6 to 97.9°F.

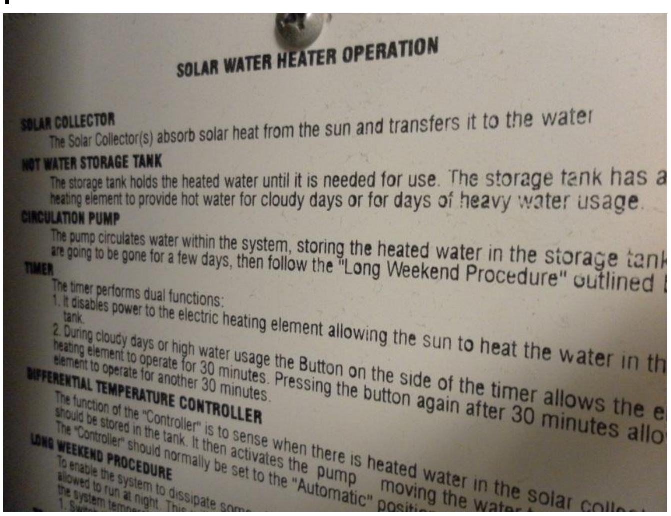


Hot water

1. Post clear instructions for the occupant.
2. Pins on manual timer – sometimes these are missing and the occupant never touched it, so FC did not check it on turnover.
3. Digital timer - Check /replace battery at occupancy change. Set for occupant upon moving in; they are less likely to tamper with it than the manual timer.
4. Set differential controller (Delta T) on auto (not “on”).
5. Temperature differential settings should be consistent and set to a temperature difference of 12 and high limit of 170°F[6] and checked on turnover.
6. Temperature setting on electric water heater should be set to 120°F.[7,8]
7. Check that the pump and sensors are functioning.
8. Solar panels NOT in shade and at optimal angle if possible (some panels in the shade in Hokulani neighborhood).
9. The anode rod should be removed from the water heater tank every 3 years for inspection. If the rod is more than 50% depleted, the anode rod should be replaced.[9]

5. It is recommended that the tank be drained, and flushed every 6 months to remove sediment which may buildup during operation.
6. On turnover[10], the entire solar hot water system should be given a thorough inspection and maintained as per the checklist compiled by Hawaii Energy (see Appendix B).

Photo 7. Solar water heater instructions posted in one home. Instructions should be posted in all houses.



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6 Ron Richmond, Inter-Island Solar; personal communication.
7 DOE website http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090
8 Whirlpool DU900 series dishwasher manual.
9 American SE62-119R-045S water heater operators manual.
10 DOE recommends maintenance every 3 to 5 years.

http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

Dryer

1. Dryer duct lengths are often too long with a couple of 90^o elbows. Avoid this in new builds and retrofit existing houses with long duct runs by installing a clean-out access. In one 2-story house we inspected, the dryer duct ran from the first floor up to the attic.
2. Dryer duct needs regular inspection/clean out.
3. Dryer located in the garage is a good idea – it is isolated and will keep heat and humidity out of house.

Photo 8. Clogged dryer duct in an empty home.

Refrigerator

Supply the same standard design (top-mount freezer configuration) that you are currently using; choose only ENERGY STAR rated models. Keep the capacity to no smaller than 20 ft^3. Although only anecdotal, it's likely if a smaller refrigerator is supplied, it's more likely the resident will use a second refrigerator.

Dishwasher

Choose only ENERGY STAR dishwaters in future. This will save water as well as electricity. The model should have built-in heater to get water to 140^oF so the house's electric water heater can be set to 120^oF. Future models should have an air dry function as opposed to heated dry and should have a delay timer to run at off peak or during midday when solar water heating is available.

ADDITIONS TO FOREST CITY'S TURNOVER PUNCH LIST

These items don't appear to be checked on a regular basis and we would recommend making a specific section on the turnover punch list to cover them.

- ✓ Check all sinks, showers, toilets for leaking/dripping (use dye tabs in toilet tank).
- ✓ Check functioning of solar hot water system:
  - o Visually inspect panels on roof for cracking or water pooling inside.
  - o Confirm the circulation pump is functioning.
  - o Check the temperature sensors are functioning.
  - o There are currently 2 models of differential controllers at Forest City:
  - o Delta T set to "auto."
  - o Goldline Sun Earth set to temperature differential of 12^{o}F and high limit at 170^{o}F.
  - o Set electric heater to a temperature of 120^{o}F (170^{o}F has been observed).
  - o Program digital timer or set pins and time on manual timer.
  - o Flush out water heater tank.
  - o Check water heater tank anode and replace if necessary.
- ✓ Check AC system:
  - o Check coolant charge.
  - o Check for air leakage around return box and air handler.
  - o Check if the condensate drain is blocked.
  - o Clean air handler coils.
  - o Replace missing cover to filter access area.
  - o Change air filter.
  - o Leave spare filters for occupant.
- ✓ Post instructions for resident: setting AC thermostat, changing AC filter, setting water heater timer, etc.
- ✓ Clean out dryer ventilation duct.
- ✓ Check for incandescent light bulbs and switch out for CFL.
- ✓ Check attic for:
  - o Broken ducts
  - o Insulation that has been moved aside
  - o Evidence of rat infestation.

ENERGY AUDITS RESULTS: FOREST CITY PHASE I

Changes in Proportion of End-Uses over the Study

As seen in Phase I, air conditioning is the predominant end-use in Forest City homes in Hawai'i. Figures 19 and 20 show the energy consumption of air conditioning compared to other major appliances in the home.

Figure 19. Comparative energy use of major appliances, pre- and post-retrofit.

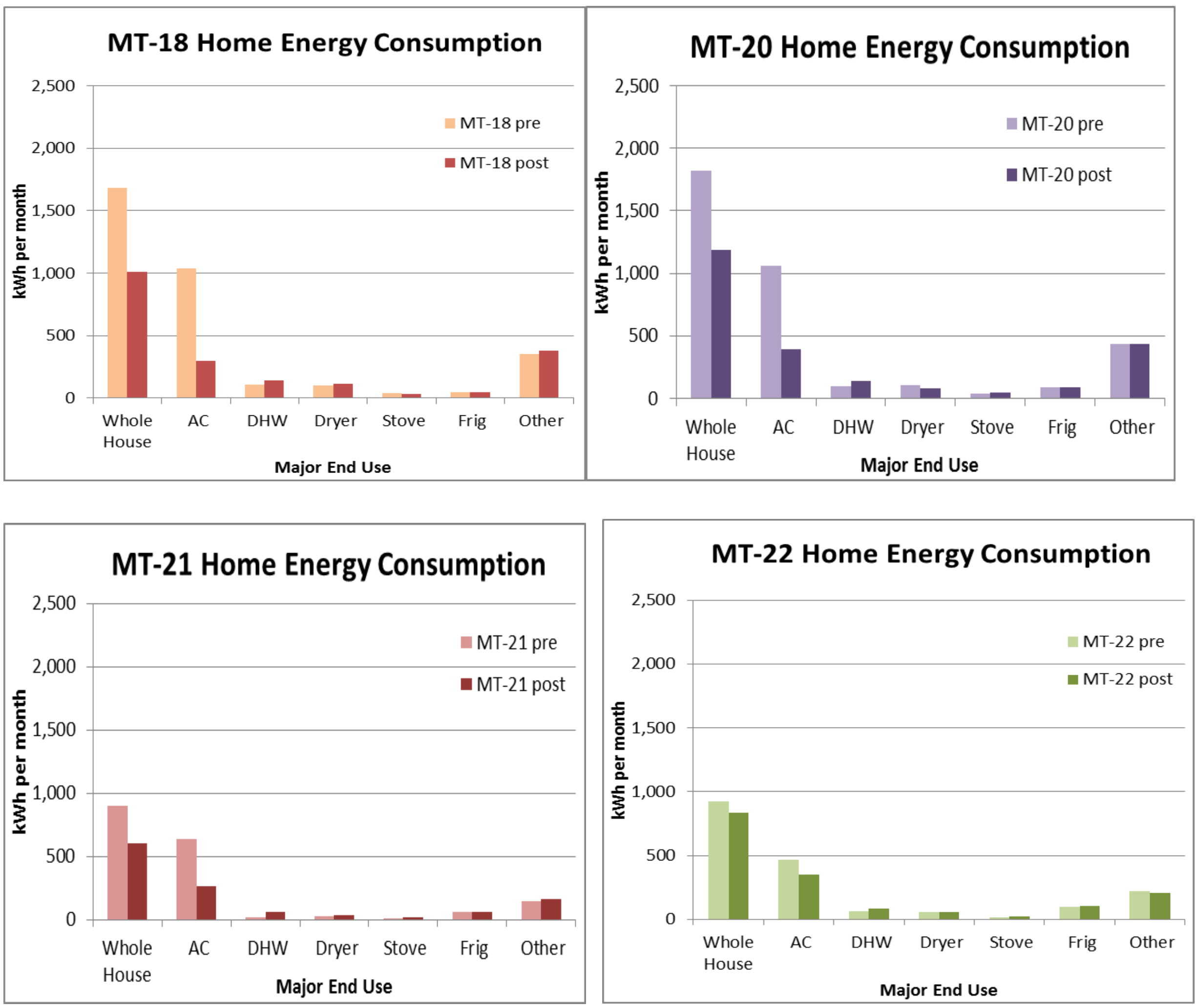
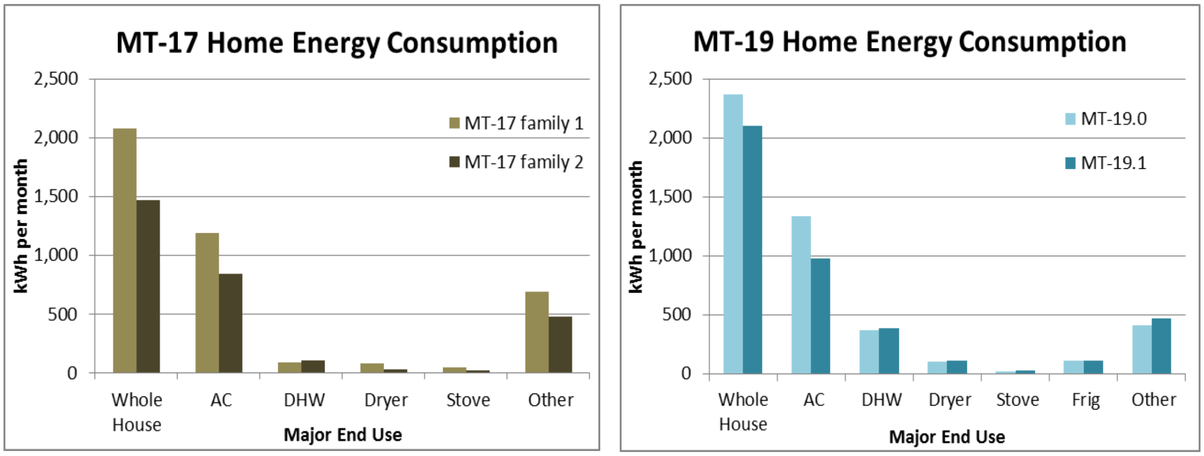


Figure 20. Comparative energy use of major appliances for control homes, MT-17 family 1 and then family 2, and MT-19 for just 1 family but split over time to show seasonal change.



Figures 21a and 21b show the difference in total energy use during the pre- and post-retrofit periods. Both graphs are set to the same total energy use so Figure 3b shows the amount of savings in total energy due to the retrofits and the seasonal change. The retrofitted houses reduced their AC energy consumption by an average of 59%, from 798 kWh/month to 326 kWh/month. As time progressed from the start of the study (September) to the end (February), the outdoor temperature and solar radiation decreased. The control home had a decrease in AC energy use of 27%, from 1,337 kWh/month to 976 kWh/month (Fig 22a and 22b). A very conservative estimate in energy savings from the retrofits would be a net 32% reduction for AC (59% - 27% = 32%) to adjust for this seasonal change. One confounding factor is that the thermostats were changed as part of the retrofit and residents did not use the same set-point as they did before the retrofit. MT-20 and MT-22 maintained lower living room temperatures and MT-18 maintained a higher temperature. Figure 23 is a graphical representation of estimated energy savings from the AC retrofit, generated using BEopt energy simulation software[1]. The relative energy reduction is a steady 44% over the year, but since much more AC is required in the summer, the kWh/month savings is highest in the summer. This study did not provide us with enough information to state whether the different thermal insulation treatments contributed to the energy reduction.

While the air conditioning load decreased in all homes over the study period, there was an increase in energy consumption for DHW and the “other” category. This was attributed to the decrease in solar radiation for the solar hot water system, and an increase in plug loads and lighting due to the shorter daylight hours and the holiday season when people spent more time in the home.

[1] http://beopt.nrel.gov/

Figure 21a and 21b. Average total energy use for retrofit houses pre- and post-retrofit.

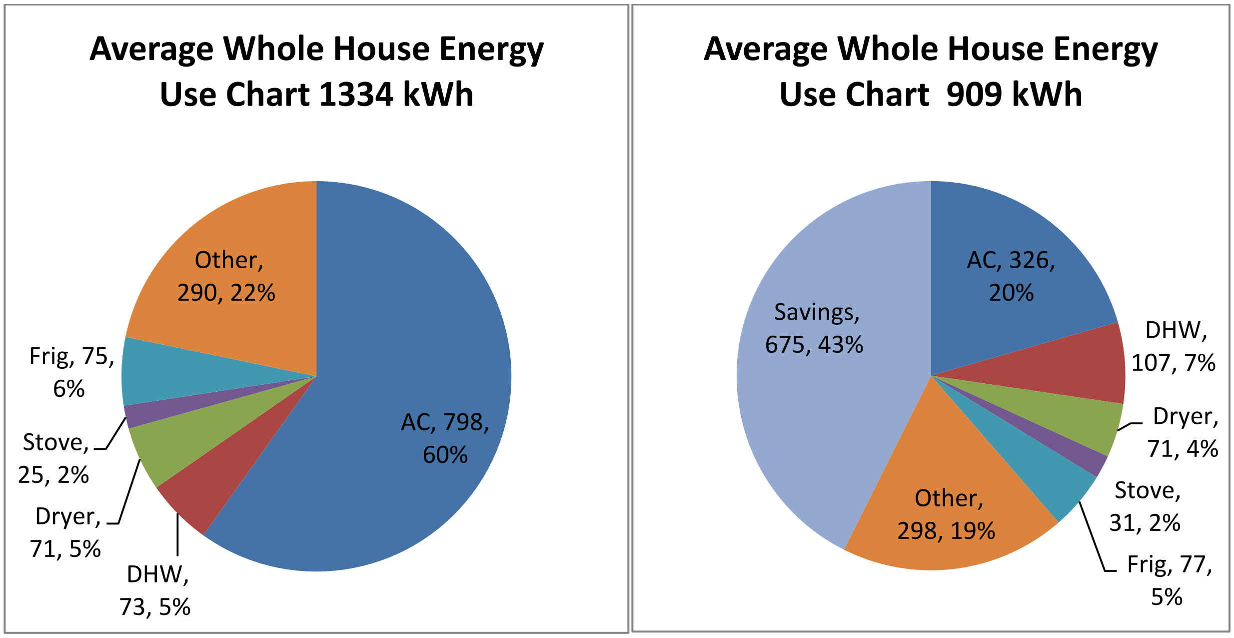


Figure 22a and 22b. Average total energy use for the control house before and after Nov 11, 2012.

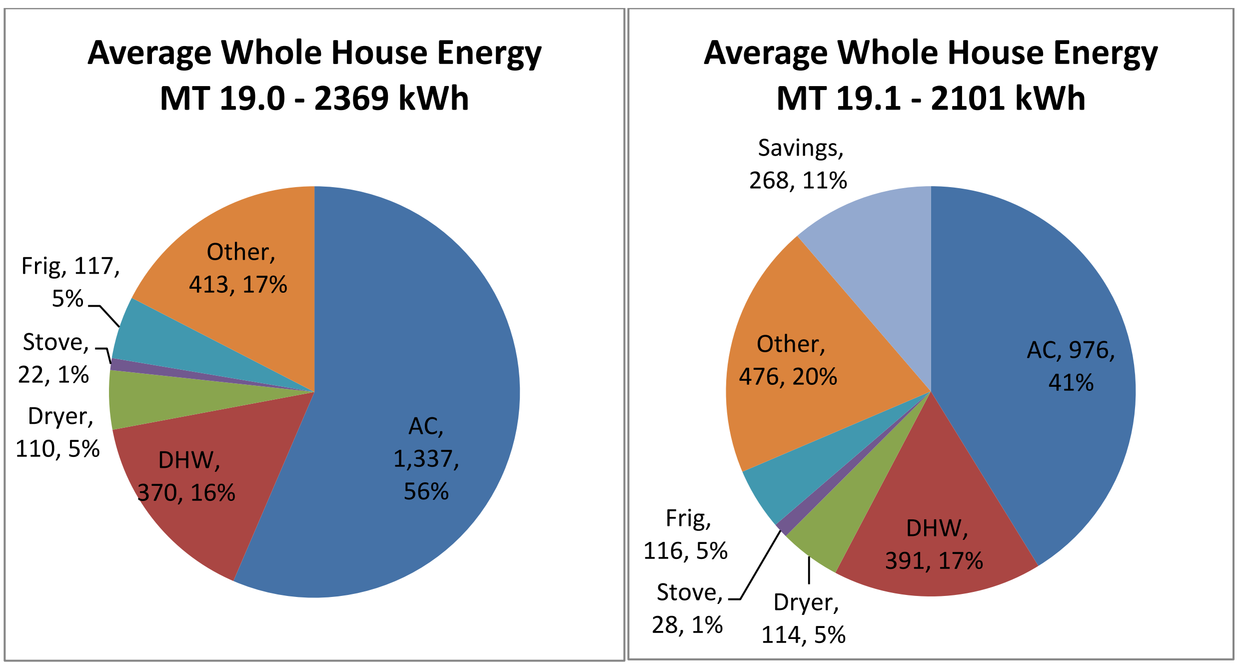
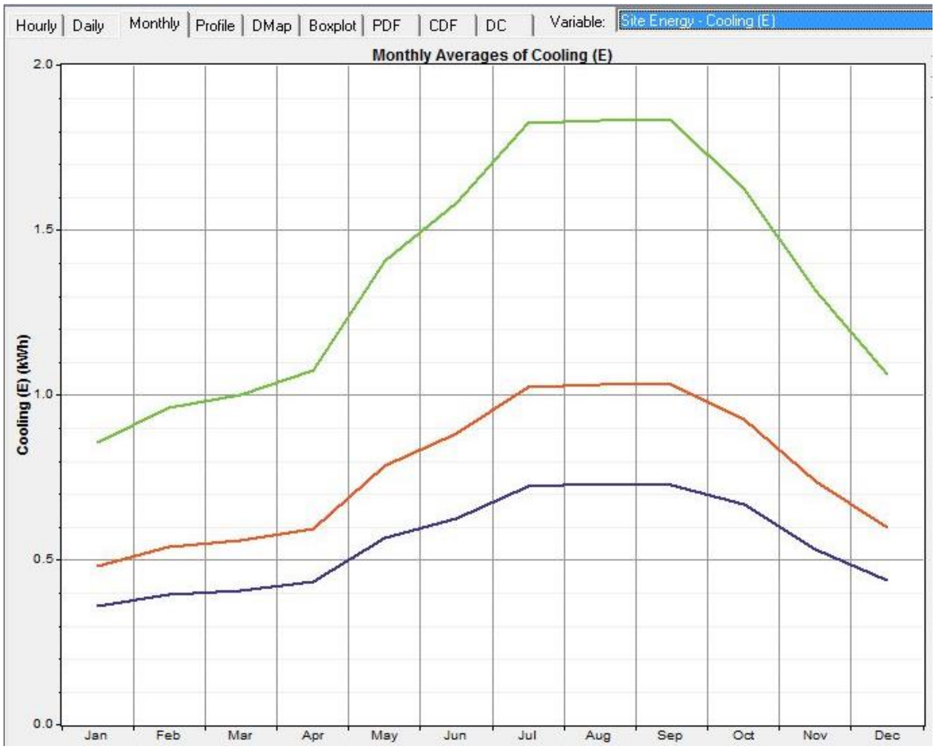


Figure 23. Energy simulation graphical output from BEOpt showing energy use over the year of a house before retrofit (green line), a retrofitted house (red line), a hypothetical retrofitted house with a deeper retrofit.



Relationships between Temperature, Humidity, Comfort, and Energy Consumption for Air Conditioning

The AC energy consumption is expended to reduce humidity ("latent heat") as well as reduce the air temperature in the home. There is also a complex relationship between temperature, humidity and comfort. One temperature coupled with a low humidity may be considered comfortable, but the same temperature with a higher humidity would be considered uncomfortable (Table 12). Other factors play a role in comfort such as air movement, direct solar exposure through a window, and mean radiant temperature of the walls, floor and ceiling. These secondary factors are difficult to quantify because they are transient in nature. As such, for the purposes of this discussion of comfort in this report we will refer to only temperature ("dry bulb") and relative humidity.

In order to combine temperature and humidity conditions into a single measurement of comfort, we will use a Temperature Humidity Index (THI), also referred to as a comfort index or effective temperature. The equation for this index is: $THI = T_d - (0.55 - 0.55RH)(T_d - 58)$, where T_d is the dry bulb temperature in ^oF and RH is the relative humidity expressed as a decimal. In general, occupants strive to maintain a comfortable environment. Our discussion will describe a space as "comfortable" when conditions maintain a THI of 70 or less (THI70). Moderate comfort is when the THI is between 70 and 75, and discomfort will be described as conditions of THI of 75 or greater, a statistical measure of when 50% of the population would report being uncomfortable. Table 3 demonstrates how the maximum temperature that most people find comfortable (THI70) rises as the relative humidity decreases.

Table 12. Relationship between dry bulb temperature (^{o}F), relative humidity (%) and temperature-humidity index. A THI of 70 is the marginal comfort level.

Td	RH	THI	Td	RH	THI	Td	RH	THI	Td	RH	THI
70	80%	68.7	70	70%	68.0	70	60%	67.4	70	50%	66.7
71	80%	69.6	71	70%	68.9	71	60%	68.1	71	50%	67.4
72	**80%**	**70.5**	72	70%	69.7	72	60%	68.9	72	50%	68.2
73	80%	71.4	**73**	**70%**	**70.5**	73	60%	69.7	73	50%	68.9
74	80%	72.2	74	70%	71.4	**74**	**60%**	**70.5**	74	50%	69.6
75	80%	73.1	75	70%	72.2	75	60%	71.3	**75**	**50%**	**70.3**
76	80%	74.0	76	70%	73.0	76	60%	72.0	76	50%	71.1
77	80%	74.9	77	70%	73.9	77	60%	72.8	77	50%	71.8
78	80%	75.8	78	70%	74.7	78	60%	73.6	78	50%	72.5
79	80%	76.7	79	70%	75.5	79	60%	74.4	79	50%	73.2
80	80%	77.6	80	70%	76.4	80	60%	75.2	80	50%	74.0

Figure 24 shows the monthly air conditioning use for the pre- and post- retrofit homes along with the one true control home, MT-19C. The retrofits brought the homes within range of the Hawaiian air conditioning residential usage of 354 kWh/month for a family of four[2]. The post-retrofit monthly AC average for the three retrofitted homes was 326 kWh/month for the winter. The summer AC use is expected to be higher, but will be drastically better than the control home. The difference in temperature between the master bedroom and living room was reduced in several homes, most likely due to the repairs to the ducts. Although great improvement was made in the air tightness of the house and duct system, three of the four experimental homes were still technically leaky upon testing after the retrofit (Table 13). More supervision or better quality control in the retrofit could result in better reductions in energy for air conditioning. Also observed by team members was that - even after some air infiltration points were supposedly sealed by contractors - a visible gap still existed.

[2] http://www.heco.com/vcmcontent/StaticFiles/pdf/HECO_Energy_Tips.pdf

Figure 24. Energy consumed by AC (kWh/mo) vs percent time temperature-humidity index exceeded 70. The arrows show changes from pre- to post- retrofit. MT-19 is the control and shows differences between pre- and post- retrofit dates and in this case, the difference indicates the seasonal change.

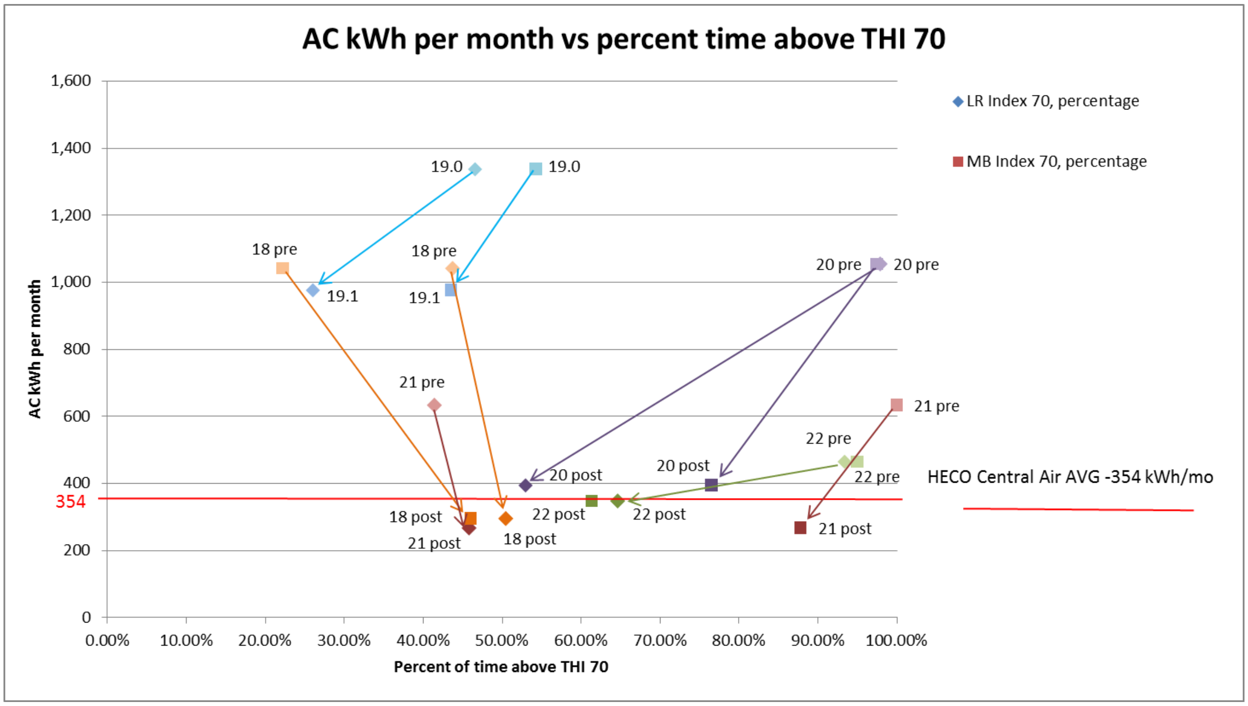


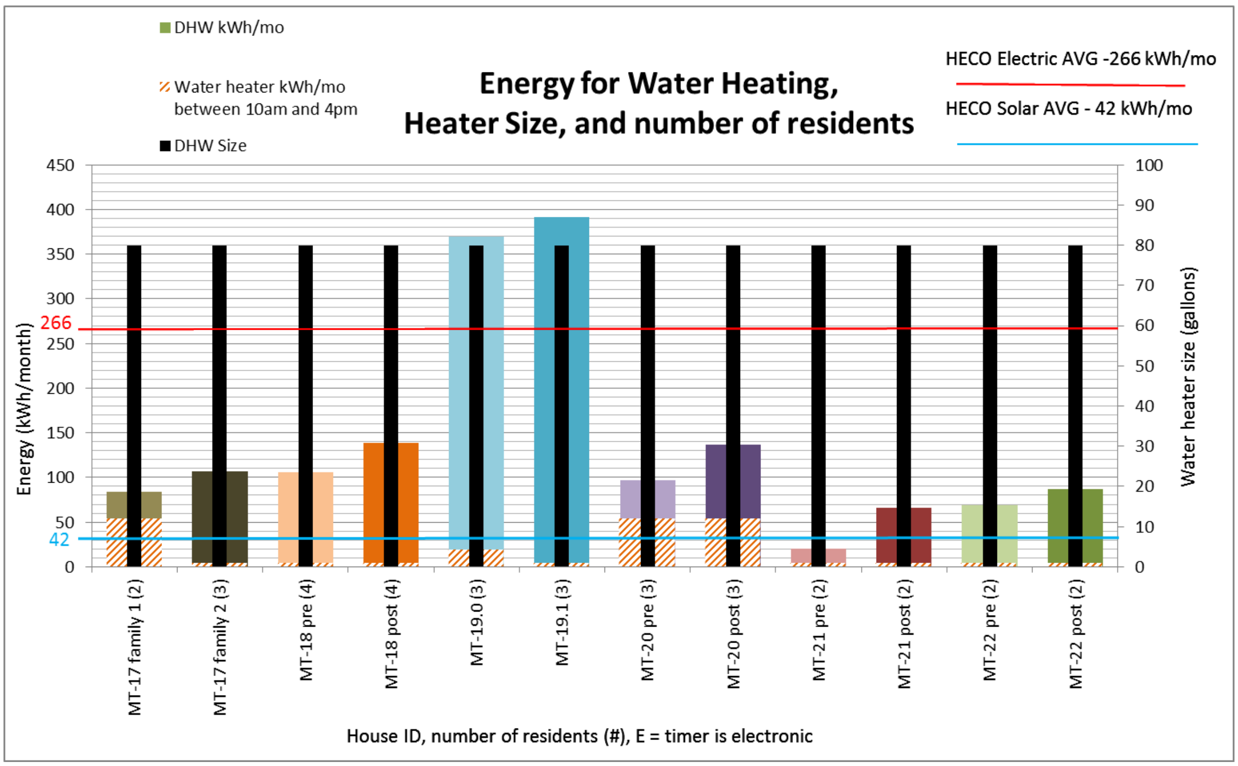
Table 13. Results of pressurization tests for houses and ducts.

ID	Blower Door Test		Duct test - total leakage (goal 90 CFM)		Duct Leakage Fraction (goal 15%)	
	pre-retrofit	post-retrofit	pre-retrofit	post-retrofit	pre-retrofit	post-retrofit
MT-18	2500 CFM @ 50 PA	1960 CFM @ 50 PA	101 CFM @ 5 PA	150 CFM @ 25 PA	61%	25%
MT-20	2510 CFM @ 50 PA	2130 CFM @ 50 PA	485 CFM @ 10 PA	181 CFM @ 25 PA	61%	30%
MT-21	2480 CFM @ 50 PA	Not recorded	487 CFM @ 11.3 PA	83 CFM @ 25 PA	61%	14%
MT-22	2400 CFM @ 50 PA	1825 CFM @ 50 PA	474 CFM @ 11.6 PA	137 CFM @ 25 PA	59%	22%

Energy Consumption for Water Heating

There is a problem with the functioning of the solar water heaters. Only one of the solar water heaters in this study was operating below the HECO Solar Hot Water Heater energy use estimation for a family of four. Energy use increased during the winter months due to the reduction of solar radiation and increased cloud cover. Two houses showed significant electric hot water usage during the peak solar periods of 10am to 4pm indicating there may be a problem with the timer as well as the solar heater (Fig. 25).

Figure 25. Comparison of energy for water heating, heater size, and number of residents in the home.



RECOMMENDATIONS TO FOREST CITY MANAGMENT

- Roll-out the AC and duct retrofits as soon as possible.
- Test ducts after retrofit, there should not be more than 90 CFM leakage to the outside. The calculation: 400 CFM per ton of AC compressor capacity = 1.5 * 400 = 600 CFM. Tolerance level for retrofit is 15% of 600 = 90 CFM.
- Have a third party verify ducts with pressurization test for the first 3 homes - if they pass, then test every 7th house thereafter. (Confirm frequency and protocol with Consol.)
- The opening created for air handler filter access was leaky – we recommend a tighter design.
- Have contractor check ducts in attic and re-position insulation (have insulation spot-checked by FC or third party).
- Insulate attic hatch. It's a simple installation and should be sized and positioned to not obstruct the locking mechanism or access in any way.
- Insist on a better weatherization strip application for the door between laundry room and garage. This should be inspected by FC or third party.

RECOMMENDATIONS TO FOREST CITY RESIDENTS

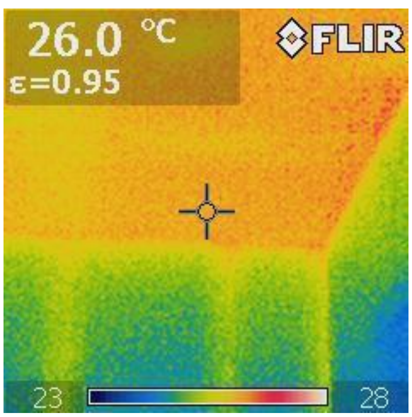
- Setting your thermostat to "auto" instead of "on" can save you $12/month on your monthly energy bill (60 kWh).
- Program your thermostat to turn the AC off or maintain a warmer temperature when you are not home.
- Set the hot water heater timer to meet your personal showering schedule.
- To test if your solar water heating system is working – remove the "on" pins in your water heater timer to leave the electric element off for a few days and see if you are receiving hot water (do not try this test during severe rainy weather).

APPENDIX A
Infrared Observations with Thermography

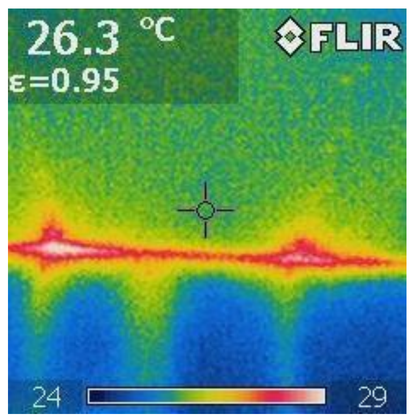
Much of the perception of warmth comes in the form of radiant heat from the walls, ceiling and other surfaces, including furniture. A room air temperature reading does not capture the true impact of the elevated temperature of a wall, window or ceiling. The following thermographic infrared images show pathways that heat will enter a home. Photo 9 shows heat being transmitted through the wall studs and Photo 10 through ceiling plate. Photo 11 shows heat being transmitted through ceiling joists and Photo 12 through the ceiling directly in areas where the attic insulation has been moved but not replaced. It is also clear in Photo 13 the radiant energy transmitted by the glass in a window.

Photos 9-13. Thermography images from houses in PH neighborhood.

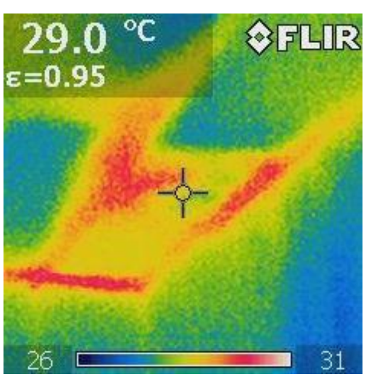
9) wall studs; ceiling



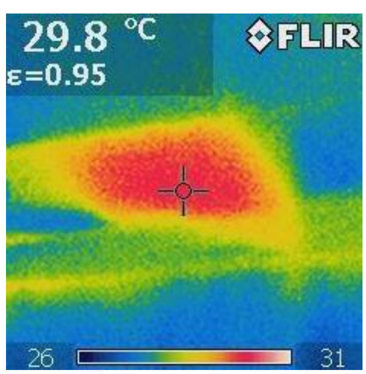
10) ceiling plate; soffit areas not insulated



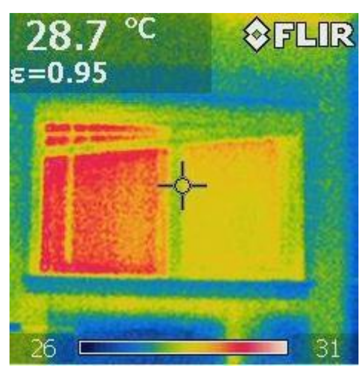
11) ceiling joists



12) ceiling; attic insulation missing



13) window



APPENDIX B

Hawaii Energy Efficiency Program's Water Heating System Inspection Check List

Customer		Contractor	Authorization No.		
Present		☐ Post ☐ Re ☐ Other	Authorization No.		
Homeowner's Manual ☐ Received ☐ Not Received ☐ Undetermined			Inspection number 1 / 2 / 3 / 4 / 5 / 6		
Line	**Description**	**Requirement**	**Accepted**	**Denied**	**Section**
1	Collector Exposure	unshaded			1.09
2	Multiple Collector Connection Method	parallel			1.04
3	Collector Mounting Brackets	manuf / num / seal / fast / secure			2.04/3.02.2
4	Collector Leg Sets	manuf / brace / fast / secure			2.05/3.02.4
5	Collector Support Structure	non-corr / spacing / fast / secure			2.06/3.02.5
6	Support Structure Anchoring	num / location / freq / secure			2.19/3.02.5
7	Collector Sensor Attachment	clamp /seal / tape / location			3.04
8	Clearance From Roof	collector / support structure			3.021/3.02.5
9	Collector Pressure Relief Valve	Watts 3L / other			2.01
10	Roof Penetration Sealed	piping / elec / fasteners			3.09
11	Roof Sealing Method	/ /			3.09
12	Roof Piping	supports / adhered / freq / bends			3.07
13	Roof Piping Insulation	UV protected			3.08
14	PV Make / Model / Wire Size	/ /			2.01/3.06
15	Collector Mounting Method	lag / lag w/cup / hanger / rod / other			2.06/2.19/3.02
16	Tank #1 Make / Model / Age	/ /			2.01
17	Tank #2 Make / Model / Age	/ /			2.01
18	Optional Equipment	Circ OTD Mix Temp. Exp. Tank other			2.23
19	Multiple Tank Connection Method	series / check valve / location			1.04/3.03.1
20	Tank Cover Plates / Warning Labels	accesssible / visble			3.03
21	Tank Heat Loop	12" / secure			3.03
22	Tank Sensor Connection	clamp / seal / tape / stud / location			3.04
23	Tank Thermostat Setting	120 deg. F / 50 deg. C			3.03
24	Tank Support	slab / bricks /shims stable / EQ strap			3.03.1
25	Tank TPR	100XL NCLX HT575 other / tight			2.01/3.01
26	Tank Overflow Line	attached / tight			3.03
27	Pump Heliodyne Pack	Grundfos Laing 809 Taco other			2.01/3.03
28	Controller Heliodyne	DTT 84 94 GL30-LCO 0301U / access			2.01/3.04
29	Controller Setting	automatic			3.04
30	Time Switch	EH-40 WH-40 other / access			2.01/3.05
31	Time Switch Settings	on off on off			3.05
32	Temperature Gauge / Temp.	Pasco Winters 0301U other / access			2.01
33	Plumbing Material	piping / fittings / valves / caps			2.13 - 2.17
34	Isolation Valve Type	ball / isoflange / other			2.16.1
35	Isolation Valve Location	CWL / LSSL / USSL / SRL			3.07
36	Check Valve	swing / horizontal / location			2.16.2/3.03.1
37	Pipe supports	material / frequency / location			2.15/3.07
38	Fastening Hardware	stainless steel			2.19
39	Piping Insulation	SSL / SRL / HWL / CWL / overflowline			2.20/3.08
40	Wall / Ceiling Penetrations	Pipe / wire			3.09
41	Insulation Joints	sealed / butted / packed			3.08
42	System Design Type	Top / Side / Bottom / Multi / Passive			1.04
43	Overall Installation / Equipment	workmanlike / protected			3.01
44	System Design Type	operational			3.01
45	**Inspection Results**	**System**			**1.03**
Line	**Comments**	**Inspection Date / Time**		**Inspector**	
			For Office Use Only:		
	Leak at:		Annual Maintenance Sticker ☐ Yes ☐ No		

AC: ☐ Yes ☐ No -- Picked up: ☐ Energy Scout ☐ Timer -- ☐ Partial ☐ Full Waive: ☐ No Access ☐ Multiple Stories

Version Sept. 23,2011 Checklist

Solar Water Heating System Tune-Up Worksheet

Hawaii Energy

Participating Contractor must complete the following work items in order for the SWH System to qualify for a rebate.

Work Order Number:

LINE	DESCRIPTION	P	PARTICPATING CONTRACTOR: REQUIREMENT	A	REASON FOR AND DESCRIPTION OF ACTION	INSPECTOR: A	D	COMMENTS
	Collectors							
1	Pressure Relief Valve		(open/close) / (check for leaks) / (replace, if necessary)					
2	Panel Sensor		(test to confirm operation) / (replace, if necessary)					
3	Stuctural Support Condition		(check condition of hardware, struts and braces)					
4	Panel Condition		(check condition of collector surfaces) / (clean glass)					
	Roof Piping & Penetrations							
5	Piping		(check all connections for leaks)					
6	Roof Penetration		(check condition) / (reapply sealant to all penetrations)					
7	Pipe Insulation / UV Protection		(check condition) / (replace, if necessary) / (apply UV coating)					
8	Wiring		(check condition) / (replace, if necessary)					
	Tank							
9	Tank Anode Rod		(replace)					
10	Electrical Back-Up		(test to confim operation) / (reset thermostat – red button: IN)					
11	Temp. and Pressure Relief Valve		(open/close) / (check for leaks) / (replace, if necessary)					
12	Tank Sensor		(test to confirm operation) / (replace, if necessary)					
13	Tank Flush		(flush from lower tank drain)					
	Plumbing							
14	Visual Inspection		(check all connections for leaks)					
15	Check Valve		(test to confirm operation)					
16	Isolation Valve		(ensure open position)					
	Components							
17	Controller		(proper differential and high limit setting) / (secure mounting)					
18	Circulating Pump		(ON-OFF-AUTO to test operation) / (secure wiring, if necessary)					
19	Temperature Gauge		(check condition) / (ensure operation)					
20	Electric Water Heater Timer		(verify operation) / (ensure setting=off between 9AM and 3PM)					

Questions – *Must be completed to receive rebate*	
1. Were there any maintenance issues found that would have resulted in likely system failure in next 3-5 years? If so, what components?	
2. Was unit working at time of inspection?	☐ Yes ☐ No
3. What was the condition of the tank anode rod?	☐ Good ☐ Fair ☐ Poor ☐ Broken
4. What was the setting of timer?	☐ The timer was not set. ☐ The timer had following settings:

- I certify that a thorough tune-up has been completed, including all of the applicable actions indicated above. All work was performed in accordance with the Program Terms & Conditions and Standards & Specifications. Upon completion, SWH System was operational. Premise was left in a clean condition, free from any debris generated by the tune-up.
- I presented the customer with a SWH Timer magnet and reviewed the monitoring and resetting of the timer with the customer. I presented educational materials to the customer.

Participating Contractor Signature *Date*

Customer Signature *Date*

Inspector Signature *Date*

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