Energy Consumption Data Analysis
Phase I Interim Report

Prepared for the

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Prepared by

UH Watt Watcher Team
(A UH multi-departmental collaboration between Hawai‘i Natural Energy Institute, School of Architecture, Sea Grant Program, Dept. of Information and Computer Sciences, Dept. of Economics, Botany Dept., & College of Engineering)

Submitted by

Hawai‘i Natural Energy Institute
School of Ocean and Earth Science and Technology
University of Hawai‘i

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Forest City Military Communities
Hawaii

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Department of Economics
Botany Department
College of Engineering

Principal Investigators:
Steven Meder, Arch.D.
UH School of Architecture

James P. Griffin, PhD
Hawaii Natural Energy Institute

Researchers:
Eileen Peppard Ellis, MS
A. James Maskrey, MBA, MEP

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INTRODUCTION

The UH Watt Watcher Program is a collaboration between the Hawaii Natural Energy Institute and the University of Hawaii School of Architecture united in the intent to develop skills and resource capacity within the University for building energy design, evaluation and management. In its first project, the UH Watt Watcher program teamed with Forest City Military Communities-Hawaii to evaluate energy usage in military housing on Oahu. The overall project consists of three phases that includes initial monitoring of residents prior to the implementation of a pilot billing program, resident education, and post-education/post-billing monitoring.

This interim report is a preliminary summary of the first round of data collected in late 2010 on two bases in Hawaii. The Watt Watcher Team monitored 8 homes in Moanalua Terrace, a military neighborhood near Pearl Harbor, for approximately one month. During the second month the team monitored 5 homes in Pa Honua, a Marine Corps neighborhood on the Kaneohe based Marine Corps Base Hawaii (MCBH).

In each of the homes temperature and humidity were recorded, while at the same time energy consumption was recorded on the individual circuits for the air conditioner, the domestic water heater system and the clothes dryer. Other energy consuming equipment, appliances and devices were noted; along with anecdotal self-description of the residents own usage patterns.

During this initial rollout of the program the Watt Watcher team experienced a number of technical problems with the current transducers used to monitor the individual circuits. This resulted in compromised data for several of the samples. Three homes in each of the two neighborhoods had enough useful data for this initial comparison. The team discontinued using the inconsistent instruments, obtaining new instruments by another manufacturer for future data collection.

This preliminary report summarizes for Forest City the observations and findings of this early stage of the project that will be useful in addressing resident feedback in response to the pilot billing project.

The single most compelling observation resulting from this first round of homes is the dominance of the air conditioning load in the overall energy consumption. ***On average, air conditioning accounts for more than 50% of the energy consumption in the monitored homes, during the period monitored*.**

OBJECTIVES

The objective of Phase I was to "jumpstart" the data collection and reporting in order to inform Forest City of key observations they can use to assist in managing its Resident Energy Conservation Program (RECP) LIVE billing program, implemented in January of 2011. The results of Phase I will provide snapshot of how Forest City residents are using energy in their households.

The report provides data and anecdotal insight into how energy is being consumed. Specific objectives of this report include:

- Quantify energy consumption for air conditioning, clothes drying, water heating and "other" energy end uses.
- Estimate common energy end-uses in the home
- Compare the energy consumption of the energy end-uses against each other
- Compare the energy profiles of homes in one community against the other
- Observe relationships between temperature and comfort
- Make preliminary recommendations to improve energy consumption
    - Recommendations to Forest City management
    - Recommendations to residents of Forest City properties

Key Results

Summary of Energy Consumption

The Watt Watcher Team instrumented 13 homes. Data were successfully captured on 11 homes, with two homes yielding no useful data. Of the 11 homes, six yielded useful information for all four pairs of current transducer (CT) instrumentation: total energy, domestic hot water, air conditioner and clothes dryer. The refrigerator was monitored using a plug-in Kill-A-Watt® meter. Figures 1-6 reflect the units with complete monitored information. Figure 7 reflects air conditioning data that was successfully collected in all 11 units. Because the "total" energy could not be validated for 5 of the 11 units due to equipment malfunctions, Figures 1-6 reflect the homes with complete data.

Monthly energy consumption for these monitored end-uses is presented graphically in Figures 1-6. This gives a preliminary indication of a high proportion of air conditioning use. Figure 7 drills in a bit deeper, showing monthly air conditioning energy use per home illustrating a wide variation in energy consumption for this end-use. Figure 8 shows the average proportion of air conditioning consumption to whole house energy consumption, averaged by neighborhood.

In addition to these graphic illustrations of measured consumption, a section is presented on energy disaggregation in a home. These are estimates of non-measured end-uses within each home.

Observed and Estimated Energy Consumption Summary

Figures 1-6 compare the monitored energy consumption over a 30 day period for the 4 instrumented end-uses. The total energy consumption per home was monitored and plotted to determine the magnitude of the "other" end-uses, which include entertainment (TV, VCR/DVD, stereo, game consoles), lighting, fans, cooking, dish washing, computer, phantom loads. These "other" end uses were not monitored. Approximations of the magnitude were estimated using a variety of sources including Department of Energy, Hawaiian Electric Company, National Laboratories, and others. Results of these estimates are shown in Figures 9 and 10, which show how the estimated energy use is disaggregated in the homes and how these averages differ by neighborhood.

Observations: Figures 1-3 show the results from the monitored circuits in Moanalua Terrace, Figures 4-6 for Pa Honua. Air conditioning is the dominant load for these homes. The water heater, dryer and refrigerator use only a fraction of the energy that air conditioning consumes.

Measured Results from Instrumented Circuits

Neighborhood 1 (M)

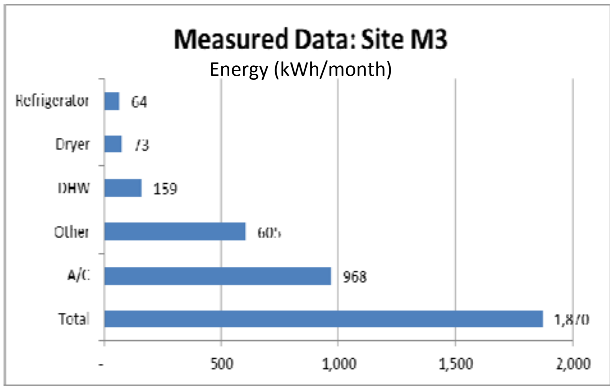


Figure 1

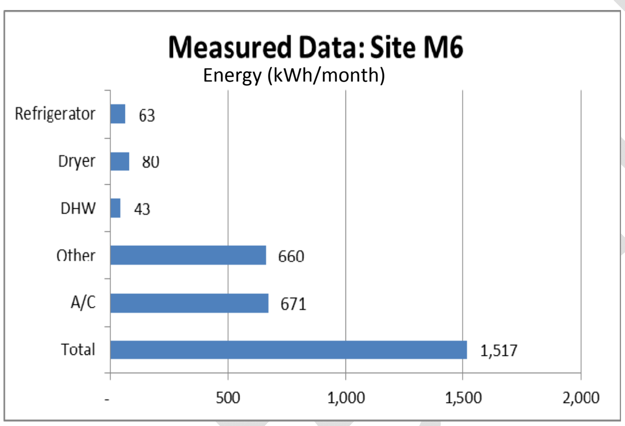


Figure 2

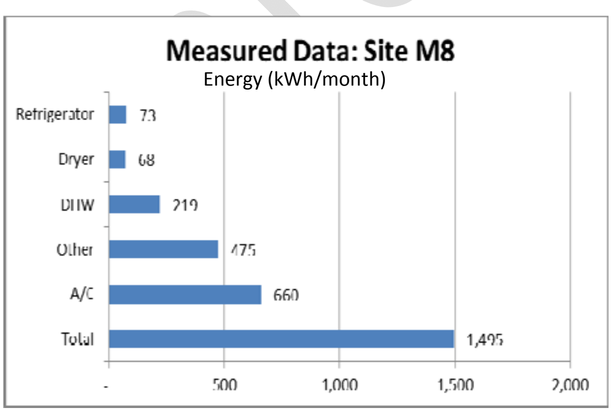


Figure 3

Neighborhood 2 (P)

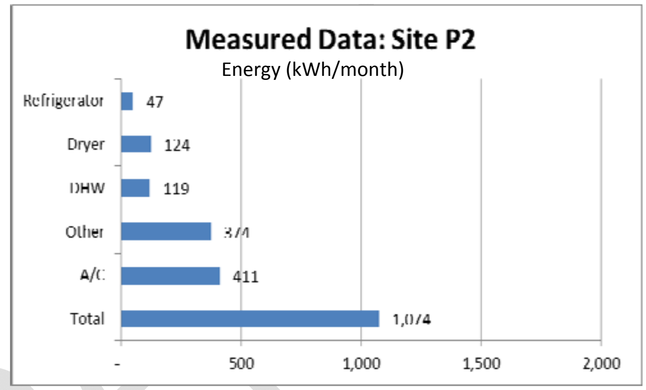


Figure 4

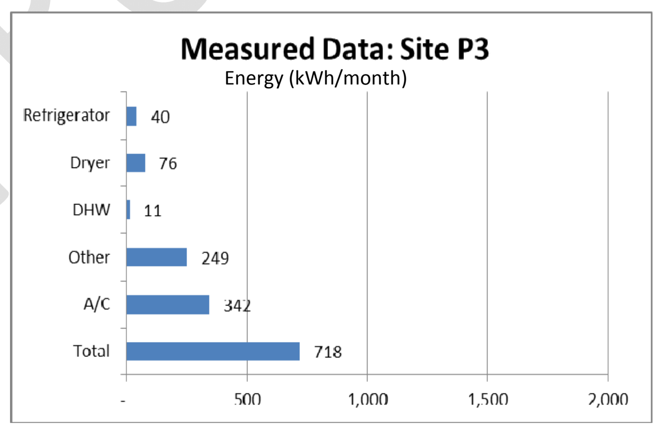


Figure 5

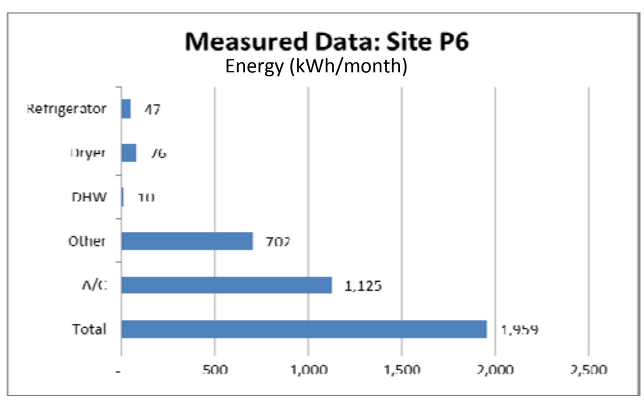


Figure 6

Air Conditioning Observations

Air conditioning data was successfully collected in 11 samples. Figure 7 shows the energy consumption is highly variable, ranging from 342 to 1,125 kWh per month. The average for Neighborhood P is 625 kWh/mo, and the average for Neighborhood M is 963 kWh/mo.

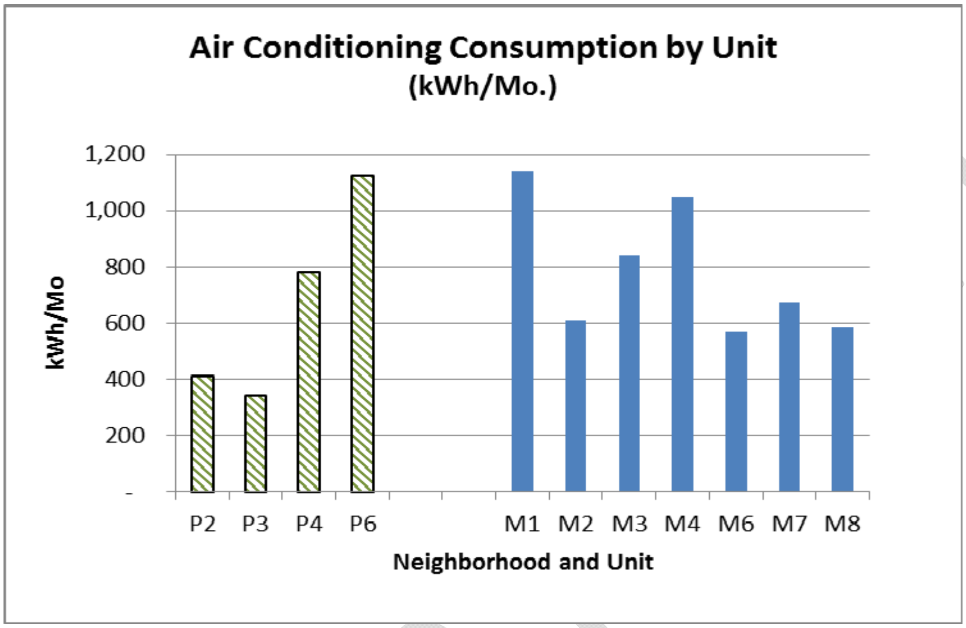


Figure 7

In six of the samples, there was acceptable instrumented data to determine air conditioning usage as a percentage of whole house consumption. Results are shown in Figure 8. On average Neighborhood P used approximately 50% of their month's energy on AC, whereas Neighborhood M used 59%.

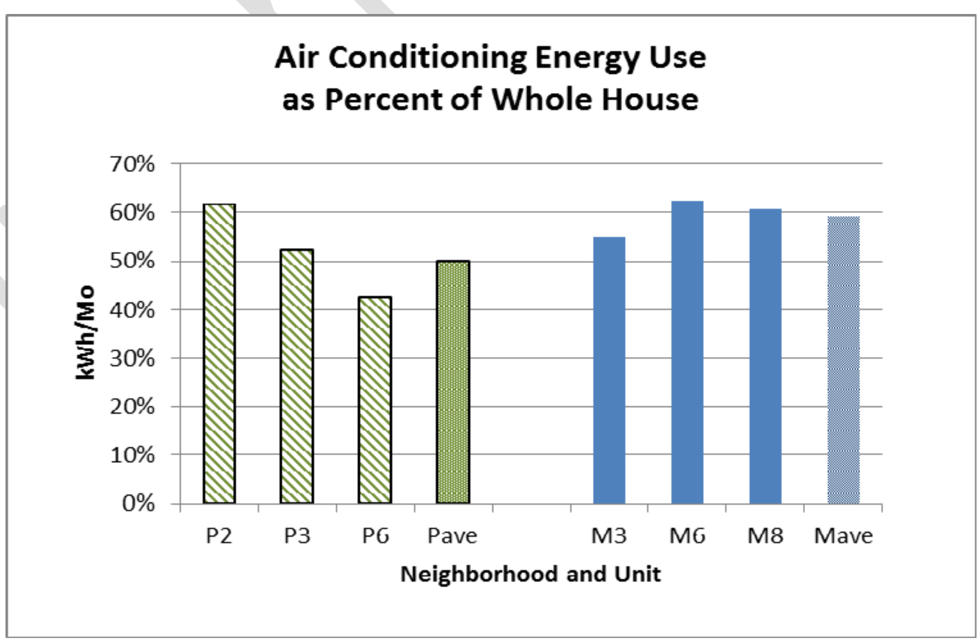


Figure 8

Estimated Average End-Use Disaggregation by Neighborhood

Figures 9 and 10 compare the relative energy consumption of common energy-consuming devices. While the data for the 4 monitored end-uses was instrumented, the remaining end-uses are approximations based on available research and information by others.

Many of the end-uses must be explained and integrated into the analysis as estimates rather than based on monitored data. These estimates are from a variety of sources, including Hawaiian Electric Company, the National energy labs, and private research organizations. The following categories were included for the comparisons between households and neighborhoods:

- Air Conditioner[1]
- Domestic Hot Water[1]
- Clothes Drying[1]
- Refrigerator[1]
- Ceiling Fan
- Lighting
- Clothes Washer
- Cooking
- TV/Entertainment
- Computer
- Phantom Loads

Note: [1] measured data. All others estimated

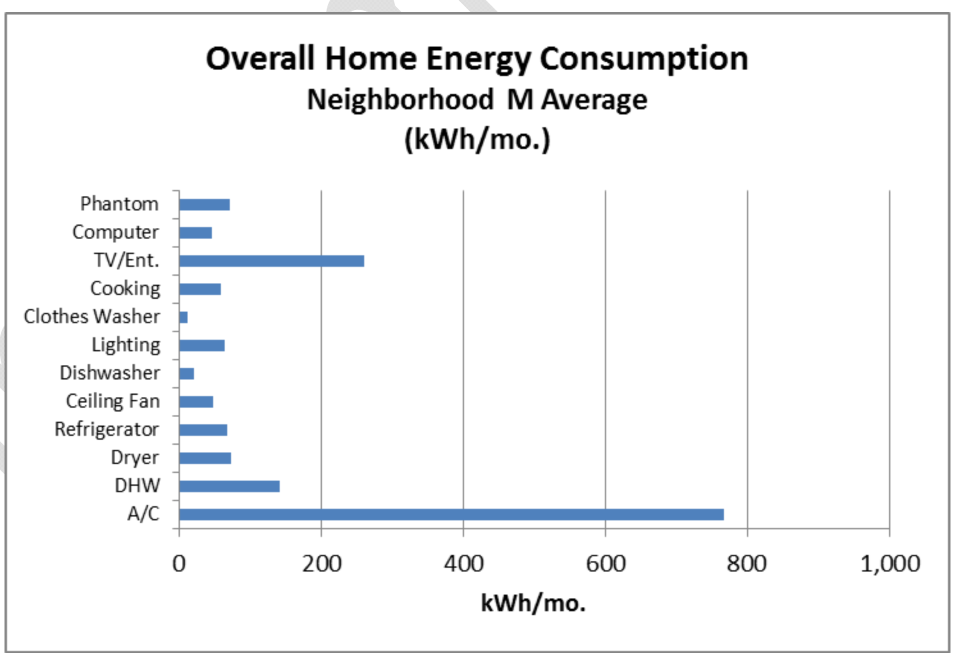


Figure 9

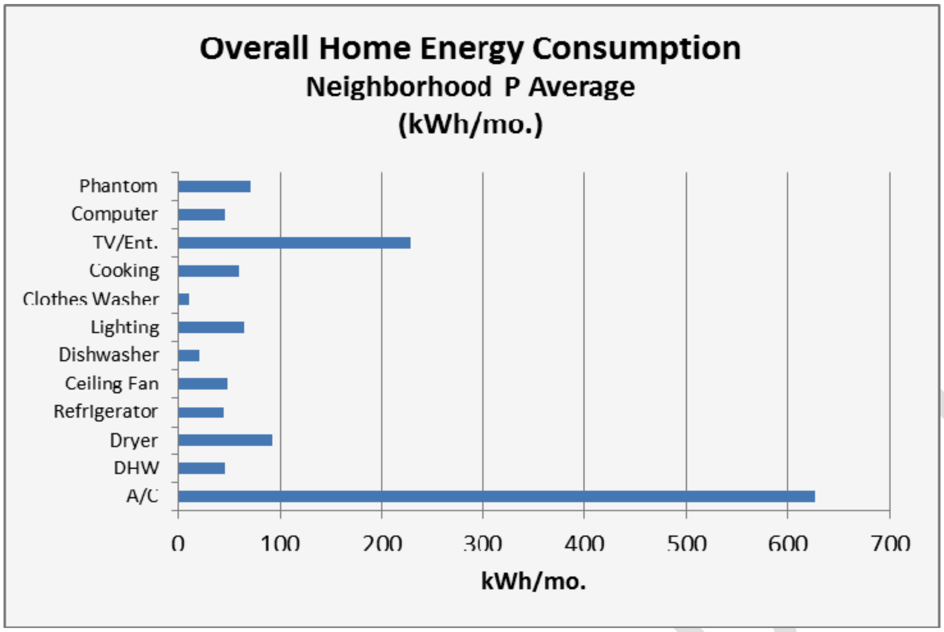
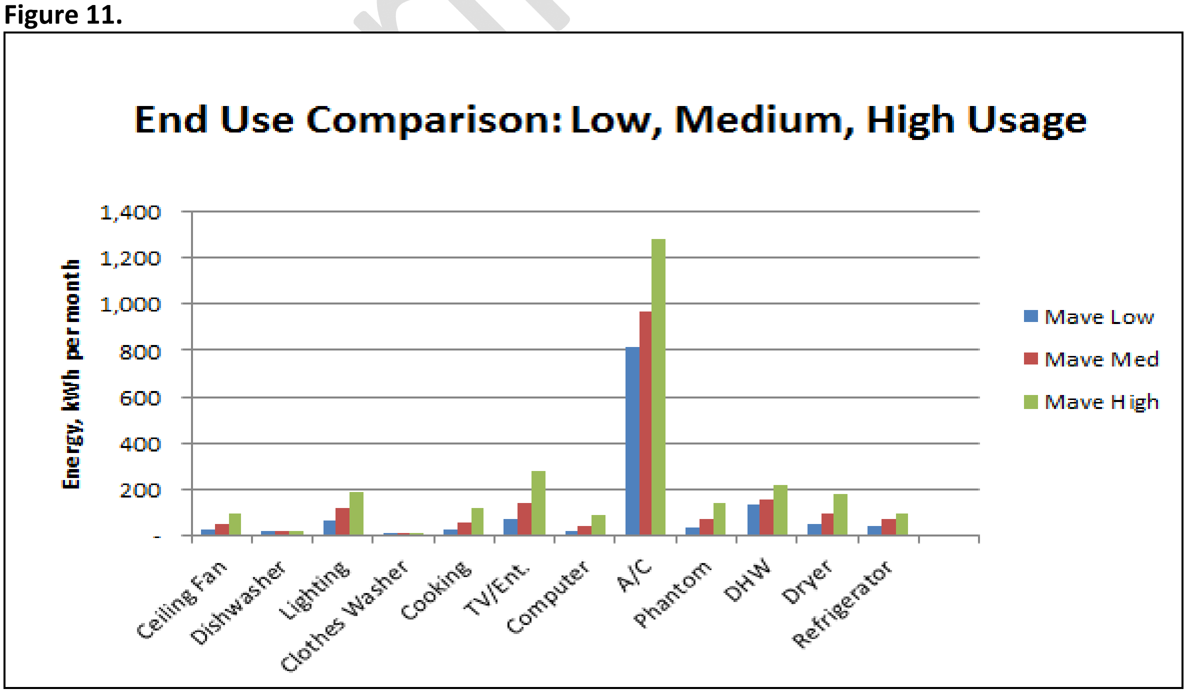


Figure 10

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 10A shows the estimated relative impact of low, medium and high use of several of these end uses in the Moanalua neighborhood sample. As indicated throughout this report, air conditioning is the major energy consumer in a household. Domestic hot water, lighting, TV/entertainment are all high consumers as well.

Figure 11.



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. For example, sample M1 data shows the AC compressor ran 80% of the time, yet used twice as much energy over the course of a month than did sample M2, whose compressor ran 82% of the time. This is likely due to the difference between manual and programmable thermostats. Manual thermostats have no lower set point limit, while programmable cannot be set lower than 72^{o}F.

Table 1. Comparison of AC power consumption, percent time compressor was on, thermostat type, living room temperature range, and type of AC compressor for 11 homes.

Unit	AC ave. kWh/mo	% time AC on	Thermostat	Temperature Range (^{o}F)	Air Conditioner
M1	1,138	80%	Manual	61-74	2T 1996 Carrier
M4	1,050	73%	Manual	67-82	2T 1996 Carrier
M3	840	71%	Program.	71-79	2T 1996 Carrier
M7	672	44%	Manual	72-82	2T 1997 Carrier
M2	609	82%	Program.	73-81	2T 1996 Carrier
M8	586	41%	Program.	72-76	2T 1996 Carrier
M6	567	57%	Program.	73-76	2T 2008 Trane
P6	1,125	74%	Manual	67-79	2.5 T 2001 Carrier
P4	781	55%	Program	72-76	2.5 T 2001 Carrier
P2	411	42%	Program	74-77	2.5 T 2009 Rheem
P3	342	25%	Program	74-76	2.5 T 2001 Carrier

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.

Figures 11 and 12 show the indoor temperatures achieved in two houses that are both equipped with 2.5-ton, 2001 Carrier compressors. P3 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, P6 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. Further investigation is needed to determine the problem with P6, 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 11. AC compressor power use vs. temperatures for home P3.

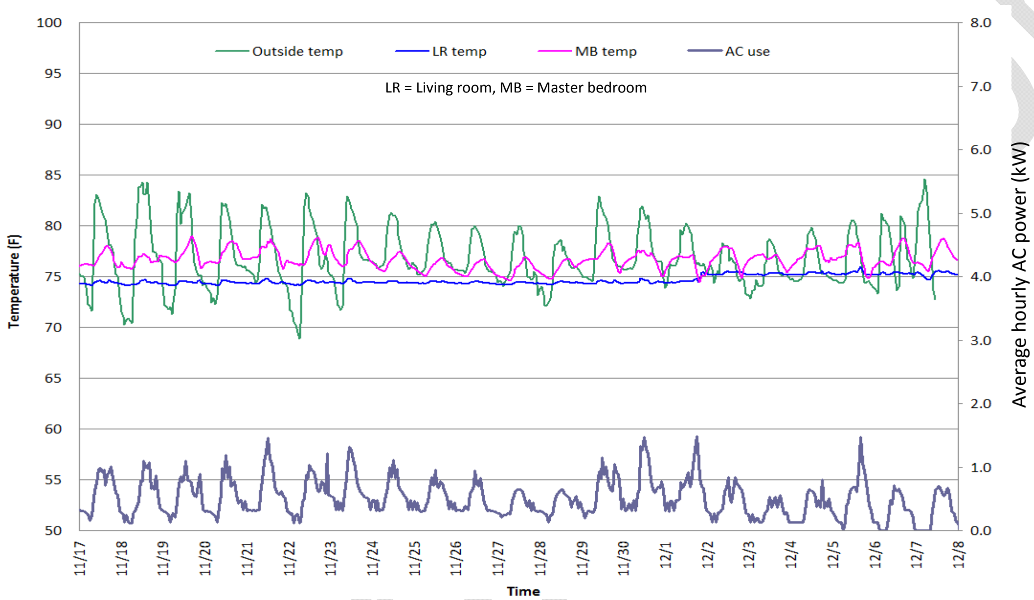


Figure 12. AC compressor power use vs. temperatures for home P6.

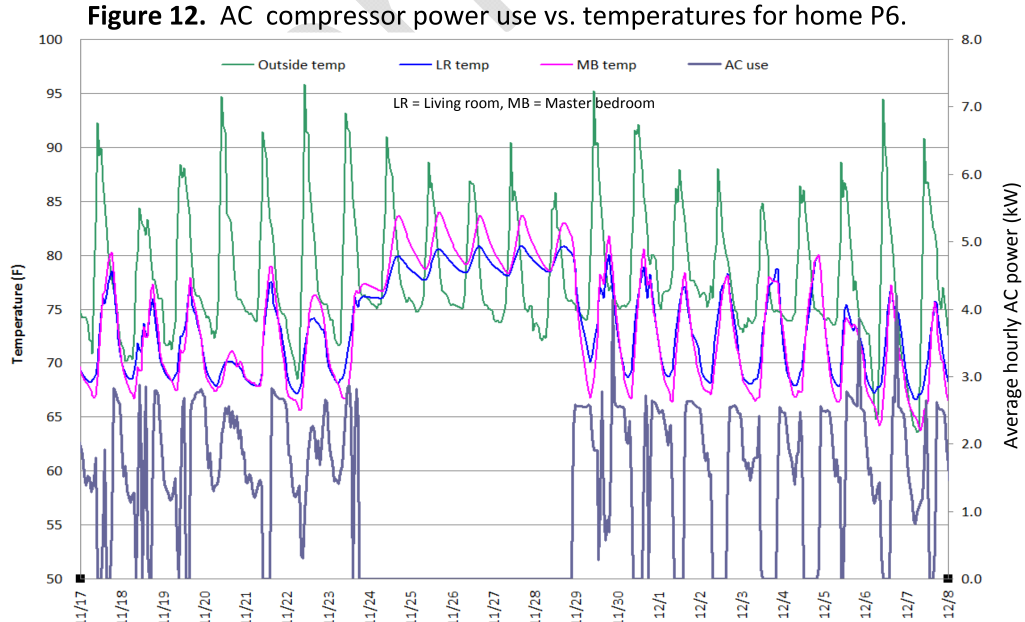


Figure 13 shows temperatures in M2 with a programmable thermostat, 2-ton 1996 Carrier compressor running 82% of the time. The Watt Watcher team found a broken AC duct in the attic and reported it to Forest City management. The repair was scheduled for later in the month and may have contributed to the reduced temperatures during the second half of the month. In comparison, Figure 14 shows temperatures in M1 with a manual thermostat (the same type of compressor and running time) using twice as much energy (1,138 kWh/mo) as M2 (609 kWh/mo).

Figure 13. Temperatures in home M2 with programmable thermostat.

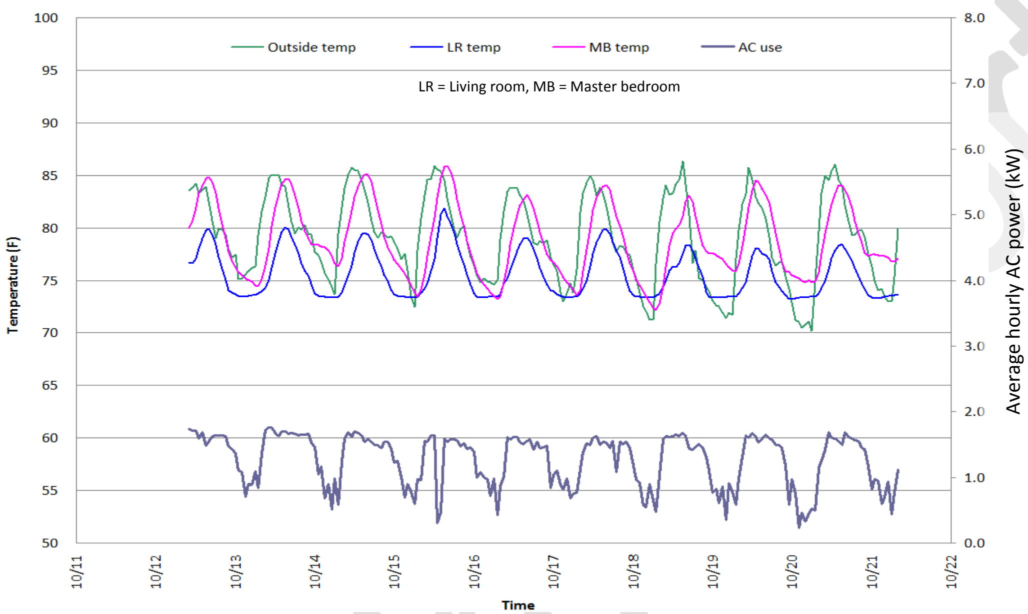
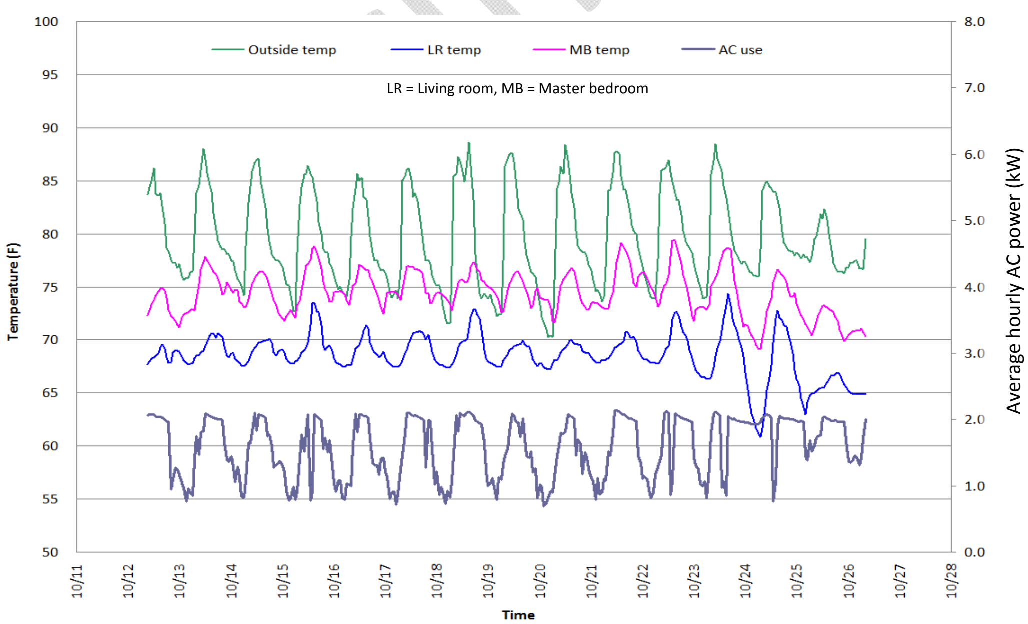


Figure 14. Temperatures in home M1 with manual thermostat.



Figures 15 shows stable indoor temperatures for P2 which has a programmable thermostat, a 2.5 ton 2009 Rheem compressor and uses 411 kWh/mo for cooling. In contrast, Figure 16 shows M3 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 consuming 840 kWh/mo for cooling, or twice that of P2. 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 15. Temperatures in home P2 with programmable thermostat.

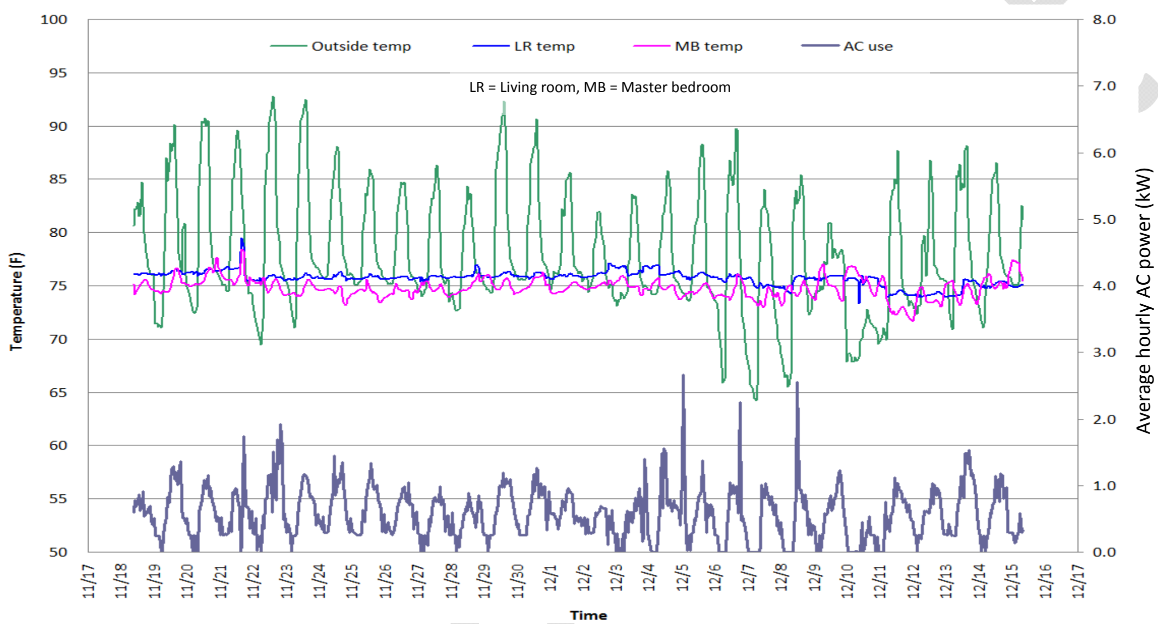
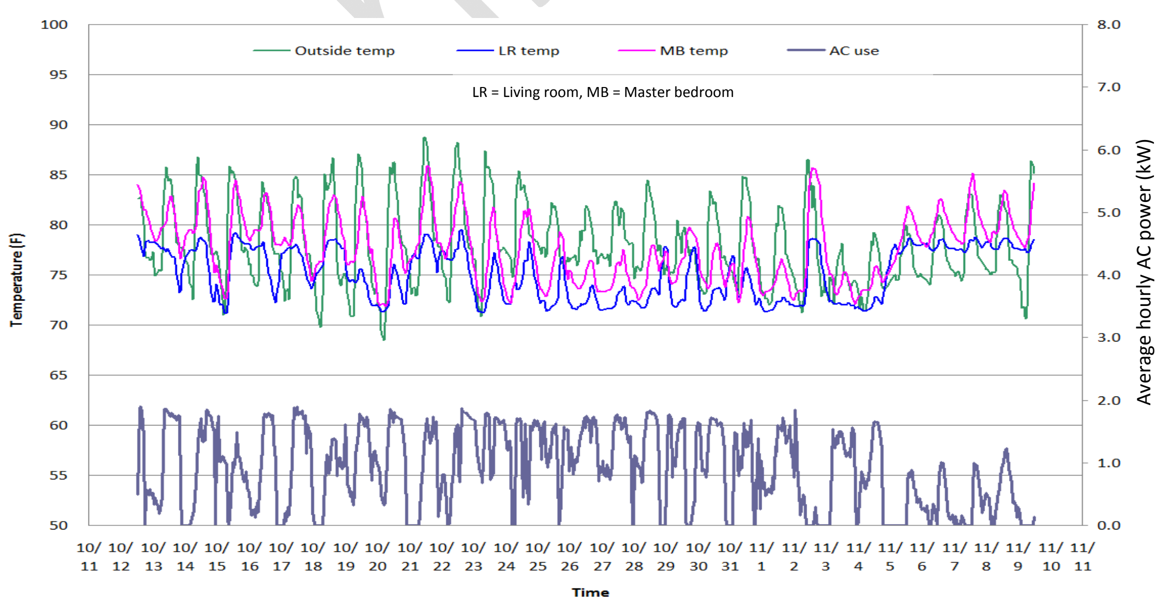


Figure 16. Temperatures in home M3 with programmable thermostat.



PRELIMINARY RECOMMENDATIONS TO FOREST CITY

As a result of the Watt Watcher team's data collection, monitoring and site observations, there are a whole host of recommendations. We presume, but do not take for granted, that Forest City has already made similar observations. Notwithstanding prior observations and conclusions by Forest City, the Watt Watcher Team has begun to catalog observations and recommendations as follows:

Air Conditioning System

Modifications to Existing Air Conditioning Systems

1) Inspect attics for duct leakage and missing attic insulation.
   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 the Sentech report in September 2009.
   c) Soffit areas need insulation
   d) Seal chase and ducts in attic
   e) 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 and when steel framing is used, at door jambs. We have found leaking at these locations.
5) Supply clearly stated instructions for use of AC and hot water systems for occupants. Better: Post these instructions where resident can regularly see them, near water heater, in laundry room, etc.

Recommendations for Future Projects

6) Choose a compressor with good grill protection of cooling fins – the few that we've seen with good protection were in good condition.
7) Specify anticorrosion coating compressor fins.
8) Air handler located in an indoor closet is good; in the garage is the very worst. When not well sealed well, hot and sometimes contaminated air (exhaust fumes, VOCs , etc.) will be distributed to home.
9) High Temperature differential between floors: need a better balance of ducts/grill size – zoning and distribution.
10) Insure that the latent cooling capacity of fan coil matches the latent cooling load of home.
11) Advise use of transfer grills for bedrooms 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 no more than 3 pa difference from the hallway and we have seen 5 and 7 pa.
12) Observation: With security systems, they can't set alarms if windows open – inherent behavioral deterrent to natural ventilation. When they do open windows, it beeps.
13) 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 MCB).

Photo 1. Corroded cooling fins

Photo 2. Compressor on concrete pad protects it from weeds, weed whackers and piling up of leaves.

Photo 3. Leaves piled up by compressor.

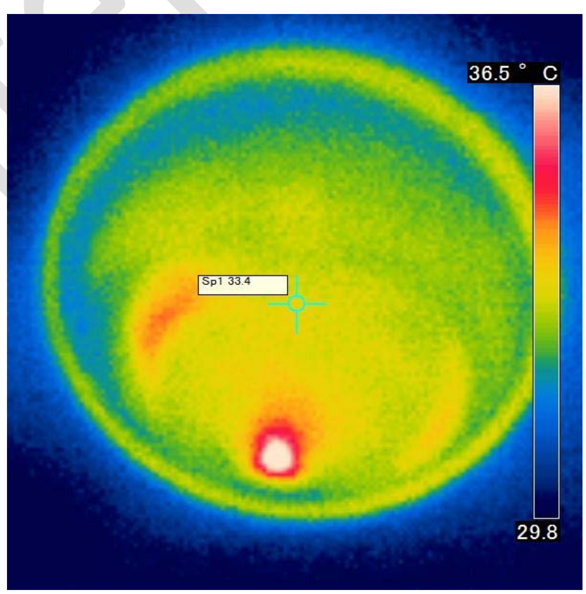
Photo 4. Bushes growing close to compressor.

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, resident has unscrewed 2 or 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 to the interior.
5. More ceiling fans – increased air speed means that a higher temperature/humidity condition can still be comfortable.
6. We observed in a home at 1023 McCurry, Moanalua Terrace 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 at 1023 McCurry, Moanalua Terrace.

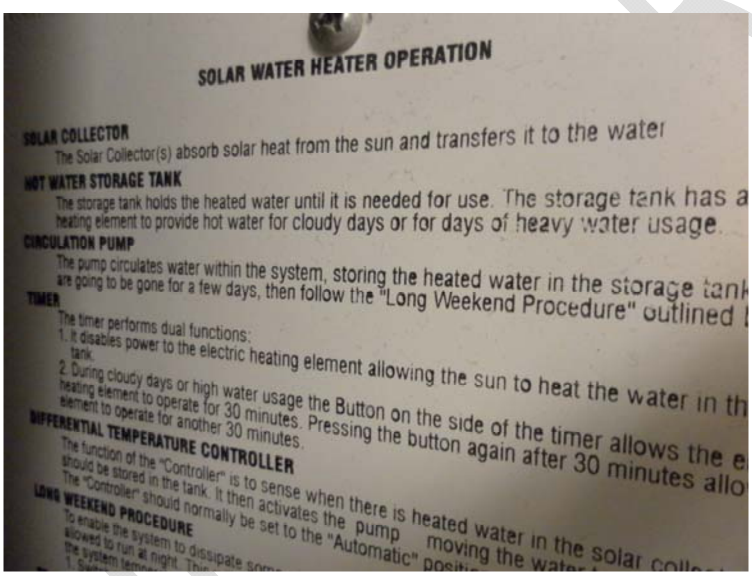
Photo 6. Infrared image of recessed light in upstairs of 1023 McCurry, Moanalua Terrace, allowing heat transfer from attic into master bathroom. Temperature range of the fixture in the image is 85.6 to 97.9 ^{o}F.



Hot water

1. Post clear instructions for the occupant.
2. Pins set on manual timer – sometimes these are missing and the occupant never touched it, so FC did not check it on turnover.
3. Digital timer would be better – the time doesn't drift. 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 Delta T on auto.
5. Temperature differential settings should be consistent and set to a temperature difference of 12 and high limit of 170 ^{o}F (Ron Richmond, Inter-Island Solar; personal communication) and checked on turnover.
6. Temperature setting on electric water heater set to 120^{o}F.
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).

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



Dryer

- Dryer duct lengths sometimes too long with a couple 90^{o} elbows. Avoid this in new builds and retrofit clean-out access for existing houses with long duct runs. In an empty home at 1847 Kou Hoale Loop, Moanalua Terrace, the dryer duct ran from the first floor up to the attic.
- Dryer duct needs regular inspection/clean out.
- 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; 1847 Kou Hoale Loop, Moanalua Terrace.

ITEMS TO ADD TO FOREST CITY 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 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:
    - ▪ Delta T set to "auto."
    - ▪ Goldline Sun Earth settings should be set to temperature differential of 12^{o}F and at high limit at 170^{o}F – the settings should be written on the checklist.
  - o The electric heater is set to a temperature of 120^{o}F (we have seen up to 170^{o}F, the technician may have accidentally set it to the Goldline Sun Earth settings).
  - o Program digital timer or set pins and time on manual timer.
- ✓ 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.
- ✓ 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.

APPENDIX A - METHODS

BACKGROUND

Forest City manages 27 military neighborhoods in Hawaii, some of which were built by the military prior to Forest City management, and some that Forest City had direct design and construction oversight.

Neighborhood selection was made by Forest City, based on multiple criteria. Moanalua Terrace in the Pearl Harbor region of Hawaii was selected because facility upgrades are in the planning stage. Pa Honua is located on Marine Corps Base Hawaii (MCBH) in Kaneohe, HI.

Moanalua Terrace consists of 752 single- and two-story homes ranging from 948 sf to 950 sf, all 2-bedrooms housing 2-4 residents. Moanalua Terrace was built in 4 phases, phases 1 & 2 in 1993 and phases 3 & 4 in 1996. Phases 1 & 2 are vinyl-sided and composition tile roof, while phases 3 & 4 feature stucco siding and concrete tile roof. While not physically verified, it is assumed that the walls are insulated with R-11 fiberglass, a standard for the industry at the time of construction. Thermal photography of the walls validated this assumption. The ventilated attics are insulated with 6" R-19 fiberglass batt. Energy consumption from 2009 to 2010 averaged 1,560 kWh per month and ranged from 690 to 2,583 kWh/mo.

Pa Honua on MCBH is comprised of 400 single- and two-story homes ranging from 1,234 sf to 1,518 sf 3 with 3-4 bedrooms housing 2-6 residents. Pa Honua was built between 1998 and 1973. These homes feature 2x4 steel framed walls with 1-1/2" rigid polystyrene exterior wall insulation. The ventilated attics are insulated with 6" R-19 fiberglass batt. Energy consumption from 2009 to 2010 averaged 1,485 kWh per month and ranged from 630 to 2,798 kWh/mo.

Table A1. Data Collection Periods

Neighborhood	Historical Consumption Data Period	Monitored Data Collection Period
Moanalua Terrace	Jan 2009 to August 2010	October 23, 2010 to November 17, 2010
Pa Honua	Sept 2009 to August 2010	November 19, 2010 to December 12, 2010

Table A2. Historical data for homes monitored in this phase.

Unit	SF	Bed	Year Built	Phase	Average Historical Energy Use (kWh/mo.)
M1	950	2	1993	2	2,354
M2	950	2	1993	2	2,184
M3	950	2	1993	2	2,172
M4	950	2	1993	2	2,059
M5	948	2	1996	3	690
M6	950	2	1993	2	2,039
M7	949	2	1996	3	8,61
M8	950	2	1993	2	2,081
P2	1251	3	2002	2	1,767
P3	1256	3	2002	2	974
P4	1256	3	2002	2	1,929
P6	1251	3	2002	2	2,034
P5	1251	3	2002	2	2,089

Range of 2009-2010 data from total population:

Pa Honua	Min= 630 kWh/mo	Max = 2,789 kWh/mo	Mean = 1,485 kWh /mo
Moanalua	Min= 690 kWh/mo	Max=2583 kWh/mo	Mean = 1,560kWh/mo

Energy Use Measurement

We collected data on the whole house electricity consumption and on the AC compressor, water heater, and clothes dryer, and the main refrigerator for four weeks on eight houses in Monalua Terrace (Navy base) starting on October 12, 2010, and five houses Pa Honua (Marine Corps Base) starting on November 16, 2010.

In this phase we used the TED 5000, manufactured by Energy Inc., with four pairs of current transducers (CTs) – all rated for 200 amps. This device proved to be unreliable. Some of the equipment failed. It also sends the signal over the neutral wire and appears to encounter interference from other devices in the house (it measured accurately when we tested it in a team member's house which has almost no electronic equipment but often had strange readings in Forest City houses). It has no memory, so it cannot log data. We used a third party software and a laptop computer to log data which added complexity to the setup and introduced more equipment failure and compatibility issues. We often did not get data or data received had missing data points. Based on continuing problems with the equipment, we switched to the E-Gauge in December, starting with the Hokulani neighborhood. Preliminary results show better data collection with the E-Gauge and these will be included in the next report. Due to safety and liability concerns, a Forest City electrician installed the TED 5000 devices in the breaker panel. The Navy side coordinated the electrician well, but the Marine Corps side seemed to have a communication gap and we resorted to calling one of the electricians ourselves.

A Kill-A-Watt™ EZ P2260 device was used to measure the refrigerator energy. It plugs into the outlet and the refrigerator plugs into the device. We would recommend getting the next model up from this one since it does not store the data once it is unplugged. If there is a power outage, the data are lost. We have been fortunate to not have that happen. It logs total kWh used and the number of hours it has measured. Time of use is not recorded but we did not feel it was necessary for our analysis.

Comfort Level Measurement

In order to determine what comfort levels were achieved in the home, we measured temperature and humidity in seven locations in the house: living room, kitchen, master bedroom, bedroom 2, bedroom 3, master bathroom, attic, and one location outside on the back porch (out of direct sunlight). The temperature in the attic is an indication of the radiant heat the building is being exposed to (except for any homes that happen to have the roof rafters insulated instead of the attic floor).

We used Hobo® U12-012 sensors, made by Onset, to log temperature, humidity, and light. Sensors were configured to record 5-minute averages (vs. the 1-minute averages of the TED power data) over the 4-week period due to a small memory capacity. Temperatures in the different locations were compared. Temperature and humidity combinations were plotted against time. Temperature in the living room and master bedroom were plotted against the AC compressor energy consumption. Since the Hobos were recording data in 5-minute intervals and the TED recorded energy data in 1-minute intervals, the energy data had to be translated into 5-minute data.

The HOBO sensor also recorded light levels, but since we cannot determine whether the light was natural or electric lighting, we have not used it for our analysis. It has been useful in explaining some temperature data in upstairs bedrooms where the temperature rises dramatically around 3:00 PM and there is a corresponding spike in the light reading which indicates the room is receiving direct sunlight on the west side of the home.

Other Data Collected

Data on the make, model, serial number, and condition of the major appliances were collected. The settings on the water heater timer were noted (we have since begun recording data on settings of the water heater and the temperature differential control). Basic construction materials of the house were recorded. Plug loads introduced by the resident were inventoried as well as all the lighting. A basic survey of their energy and water use was asked of the resident.

Occupant Volunteer Selection

Forest City management selected the neighborhoods we would target. We asked that volunteers be selected that had been residing in the home for a year, and were not moving in the month we'd be measuring, and half would be high users and half low users. This did not always prove to be the case. The Navy side had more success in recruiting volunteer families and those families appeared to be more interested in the energy audit process. The Marine Corps side had more difficulty recruiting volunteers and those they did recruit showed less commitment to responding to phone calls or being present in the home for the appointment. The selection covered high, medium, and low users with no particular proportion on the Marine Corps side. Another issue encountered was that the spouse who made the appointment with us sometimes had not informed the other spouse who answered the door when we arrived, so occasionally our appointment was cancelled or postponed for this reason.

We also learned the importance of describing the process over the phone when making the appointment; otherwise they did not realize we would enter each room. For our first installment, some residents thought we were only working outside and they were embarrassed the house was not clean. In future, we need to also stress how much coordination and time commitment we have on this project and it is very wasteful if the resident does not show up for the appointment. We had a lot of "no shows" on the Marine Corps side.

Equipment Installation and Data Acquisition

We introduced ourselves to the occupant and explained the devices we'd be installing. We asked the occupants to answer questions in a survey. While one person conducted the survey, another team member worked with the electrician to install and configure the TED 5000 and tested that it was functioning. A third team member conducted a lighting audit. Once the survey was completed, the first person let the occupant know when we would return in four weeks to collect the sensors and gave them a notice explaining it, then that person moved on to recording data on appliances and plug loads. In all, this process took 45 minutes if nothing went wrong with the TED setup. We allowed one hour per home to account for travel time (eight hours for eight homes). We have since begun to mail a thank you note to the resident as a follow-up to this first visit.

Collection of the equipment four weeks later was much simpler. We learned we could make the appointments and collect the devices in a shorter time period than the installation (four hours for eight homes). The TED data was checked before the device was removed by the electrician. The refrigerator data on the Kill-A-Watt™ EZ P2260 was read before it was unplugged from the outlet. The HOBO sensors were collected for download later. The resident was thanked for their participation. We have yet to send the residents the results of their audit.

APPENDIX B - RESULTS

Summary of Energy Consumption

Overall house energy consumption ranged from 718 to 2,511 kWh per month when extrapolated to a 30-day month (Table B1). Each home had a low baseline energy consumption during quiet hours of the day and a high baseline during the busy times of the day, which ranged from 0.69 to 3.2 kW and from 2.7 to 8.0 kW, respectively. Spikes in energy use were seen as high as 24 kW.

The air conditioning (AC) compressors drew 1.5 to 2.55 kW when they were running. The percentage of time they were running ranged from 25% to 82%, which maintained a mean living room temperature of 74.8 and 68.1 ^{o}F, respectively. The monthly energy consumption of the compressors ranged from 411 to 1,138 kWh (a 727-kWh range or $181 difference at a utility rate of $0.25/kWh).

The water heater drew 4.0 to 5.6 kW when it turned on. Monthly energy consumption for water heating ranged from 10 to 219 kWh (a 109-kWh range or at $27 difference at a utility rate of $0.25/kWh).

The clothes dryers drew 4.5 to 5.95 kW when the heating element came on and 200 to 300 W when it was just tumbling. Monthly energy consumption for dryers ranged from 16 to 279 kWh (a 263 kWh range or $66 difference at a utility rate of $0.25/kWh). The hours of dryer use extrapolated to a 30-day month ranged from 24 to 95 hours for the homes we had a significant amount of data for. Homes with dryer data on shorter durations (2d or 9d) extrapolated to h/mo did not seem a reasonable reflection of monthly use. Dryer data on one home indicated the dryer was used 19 h in 2 d which appears excessive (but extrapolated to 30 d gives an outrageous monthly use of 285 h). Some people do laundry regularly throughout the week and others do it infrequently, resulting in unreliable extrapolation of dryer data collected for a short duration.

Refrigerator energy consumption ranged from 40 to 73 kWh for a 30-day month. It was consistently lower in Pa Honua where they had newer refrigerator models than in Monalua Terrace. A 31-kWh difference in energy use (or $8/mo at a utility rate of $0.25/kWh) for this appliance pales in comparison to the 727-kWh (or $181/mo) range in monthly AC energy consumption measured in this phase.

Deficiencies in Energy Consumption Data

The data collected from the TED 5000 was of variable quality (Table 3). We obtained no data from two homes and complete data from two homes. Data from nine homes was incomplete. Hourly data is not useful in determining the operation of appliances.

Table B1. Summary of energy use extrapolated to a 30-day month for data collected from TED 5000 devices installed in Forest City houses in October and November, 2010.

	AC draw kW	Dryer draw kW	DHW[1] draw kW	House kWh/mo	AC kWh/mo	% time AC on	DHW[1] kWh/mo	Dryer kWh/mo	Dryer h/mo	Refrigerator kWh/mo
Monalua Terrace										
M1	2.0	4.7	NA	2,511	1,138	80%	NA	181	44 (only 2d)	71
M2	1.7	5.5	NA	1,356	609	82%	NA	16	7.4 (9d)	69
M3	1.9	5	4	1,870	840	71%	159	73	7.5 (9d)	64
M4	2.0	5.6	NA	2,036	1,050	73%	NA	180	67	71
M5	NA	NA	NA	NA	NA	NA	NA	NA	NA	95
M6	1.5	5.4	4.1	1,517	567	57%	43	80	42	63
M7	2.2	5.3	4.1	1,218	672	44%	126	51	28	60
M8	2.1	4.5	4.2	1,495	586	41%	219	68	24	73
Pa Honua										
P2	1.9	NA	5.6	1,074	411	42%	119	NA	64	47
P3	2.4	NA	5.6	718	342	25%	11	279	285 (only 2d)	40
P4	2.55	4.6	NA	2,217	781	55%	NA	172	95	54
P6	2.49	5.95	4.03	1,959	1,125	74%	10	76	35	47
P5	NA	NA	NA	NA	NA	NA	NA	NA	NA	61

[1]DHW = domestic hot water

Table B2. Quality of energy consumption data from the TED 5000 devices installed in Forest City houses in October and November, 2010.

	Start date	MTU-1 (whole)	MTU-2 (AC)	MTU-3 (DHW[1])	MTU-4 (Dryer)
Monalua Terrace					
M1	10/12/10	OK	OK	none	1.98 days; not same days
M2	10/12/10	OK	every other minute	none	every other minute
M3	10/12/10	cut out days with zeros	more than every 2 min	every other minute	every other minute
M4	10/12/10	OK	OK	none	OK
M5	10/14/10	none	none	none	none
M6	10/14/10	OK	OK	OK	OK
M7	10/14/10	none	OK	OK	OK
M8	10/28/10	OK	OK	OK	OK
Pa Honua					
P2	11/18/10	hourly OK (2 days of min)	hourly OK (2 days of min)	hourly OK (2 days of min)	Missing data points
P3	11/16/10	hourly OK (2 days of min)	hourly OK (2 days of min)	hourly OK (2 days of min)	Missing data, some data 2d
P4	11/16/10	hourly OK (2 days of min)	hourly OK (2 days of min)	none	hourly OK (2 days of min)
P6	11/16/10	hourly OK (2 days of min)	hourly OK (2 days of min)	hourly OK (2 days of min)	hourly OK (2 days of min)
P5	11/16/10	none	none	none	none

[1]DHW = domestic hot water

Energy Consumption per Square Foot by Neighborhood

Monitored homes in Moanalua averaged 1.87kWh/sf, ranging from 1.57 kWh/sf to 2.64 kWh/sf. The homes in Pa Honua used 34% less energy per sf, averaging 1.24kWh/sf with a range of 0.75kWh/sf to 2.34/kWh/sf (Figure B1).

As a percentage of total energy consumption per sf, Pa Honua homes used 43% for air conditioning while Moanalua used 47% (Table B3). While the average ambient temperature for Pa Honua was 1.4 % lower than Moanalua Terrace during their respective monitoring periods, the relative humidity average was 6.6% higher in the Kaneohe-based neighborhood.

The non-AC energy consumption when normalized to kWh/sf, Moanalua Terrace homes consumed 29% more energy than Pa Honua, 1.01 kWh/sf compared to 0.84kWh/sf.

Figure B1. Total and AC electricity consumption per square foot for homes in Moanalua and Pa Honua.

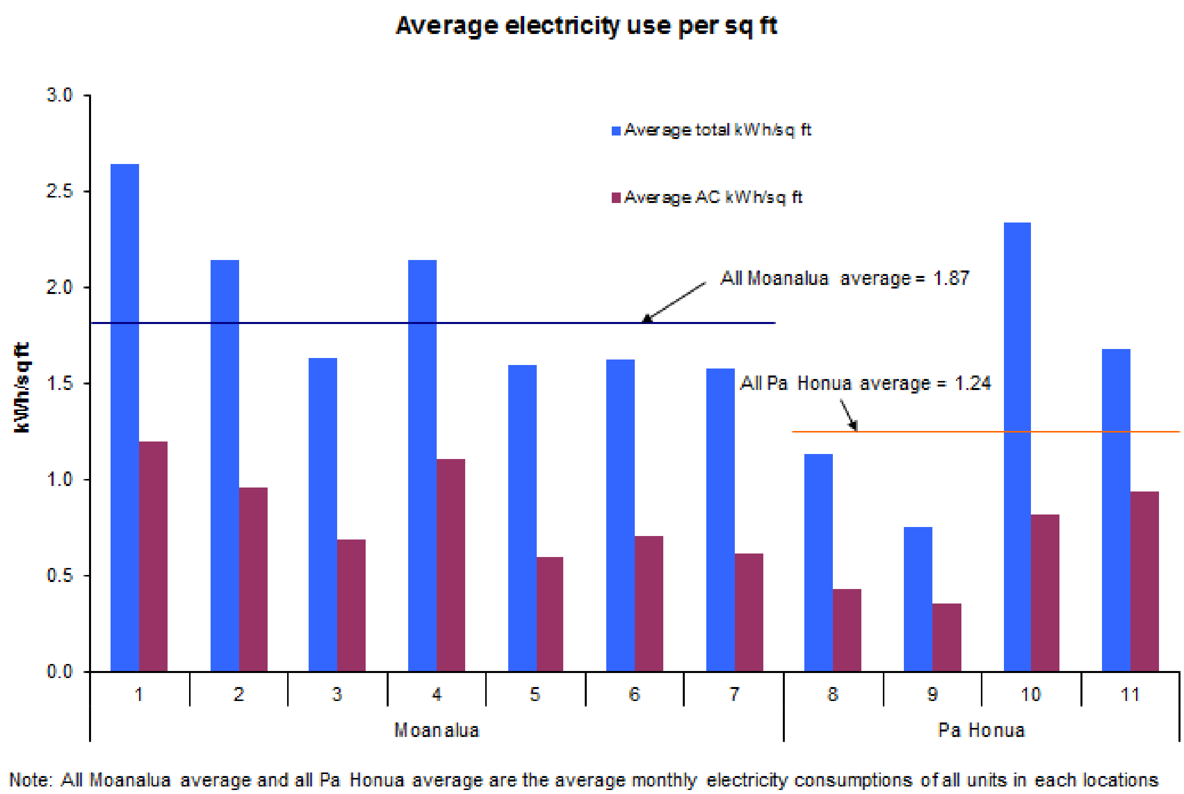


Table B3. Total and AC electricity consumption per square foot for homes in Moanalua and Pa Honua.

	Moanalua							Pa Honua			
	1	2	3	4	5	6	7	8	9	10	11
Average total kWh/sq ft	2.64	2.14	1.64	2.14	1.60	1.62	1.57	1.13	0.75	2.34	1.68
Average AC kWh/sq ft	1.20	0.96	0.69	1.10	0.60	0.71	0.62	0.43	0.36	0.82	0.94

Average total kWh/sq ft of all Moanalua units in October	1.87
Average total kWh/sq ft of all Pa Honua units in November	1.24

Energy Consumption and Indoor Temperatures by Neighborhood

Air conditioning energy accounted for an average of 854 kWh per month or 47% of the 1,812 kWh total monthly consumption in Moanalua, compared to 605 kWh per month or 43% of the 1,401 kWh total monthly average consumption for Pa Honua. Higher energy consumption did not consistently result in cooler temperatures.

The bedrooms in the 2-story homes are located upstairs. In the Moanalua Terrace neighborhood, the bedrooms were consistently warmer than the living room (Figure B2), indicating that the upstairs was not receiving enough of the conditioned air. The temperatures in the bedrooms in the Pa Honua neighborhood were more closely aligned with the living room temperatures (Figure B3).

This preliminary report does not attempt to explain all of the possible interaction of variables that determine comfort in a home. Temperature and humidity are the primary factors. Comfort levels can be reached with higher temperatures when humidity is low enough. In addition, radiant temperatures that result from direct solar gain through the walls, window and ceilings also contribute to the cooling load of a home. Figure B5 illustrates the observed temperatures in the first phase of Moanalua Terrace. These graphs represent average temperature and humidity throughout the entire measurement period and are not reflective of a single actual point in time. These are intended to illustrate the differences between similar homes, on exactly the same days and times. For example, M1 is able to maintain an average of 68 to 69°F in the kitchen and living room, where M5 maintains an average of 84 °F throughout the home. Generally speaking, the kitchens and living rooms are found on the first floor and are cooler than the bedrooms and bathrooms on the second floor. The first floor temperatures range from a mean of 72 to 76 °F, increasing on the second floor to 72 to 80 °F. M5 is the outlier with all rooms with a mean temperature ranging from 83 to 84 °F.

B5 further illustrates the differences in comfort that residents experience, whether by choice or by the performance of equipment. M5 uses approximately half the air conditioning energy per month than M8. However, the temperatures that result from not using the air conditioning result in an 8 – 10°F differential. Further analysis is required to determine precisely the reasons for this difference in consumption and comfort. Is it a conscious effort on the part of resident to minimize cooling, do they prefer warmer conditions, or are there problems with the air conditioning system either in terms of equipment design or maintenance?

Figure B2. Mean living room and master bedroom temperatures over time for the Moanalua Terrace homes.

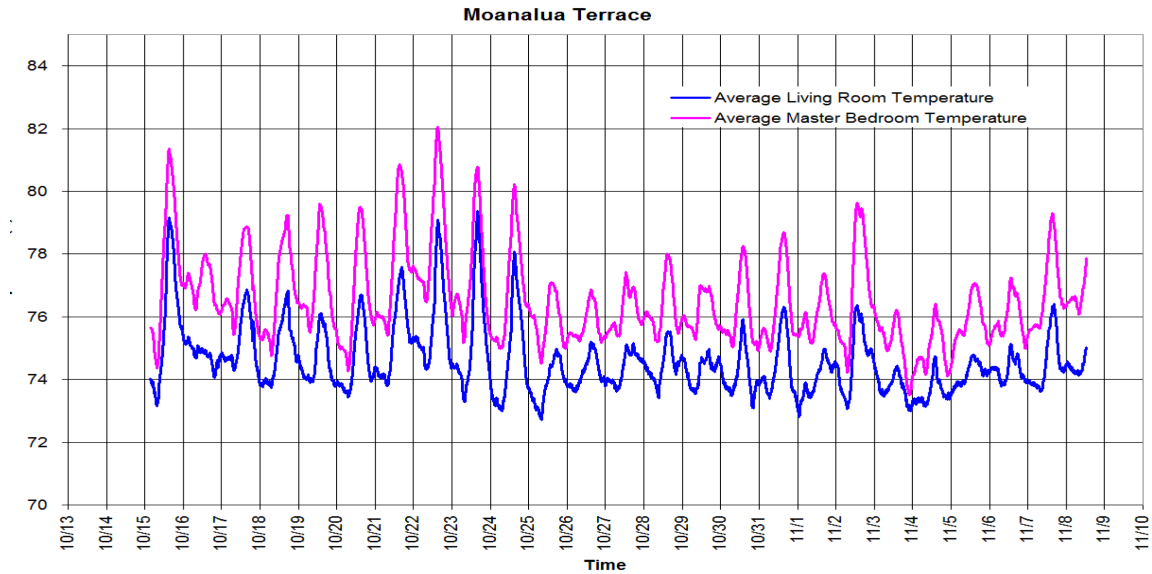


Figure B3. Mean living room and master bedroom temperatures over time for the Pa Honua homes.

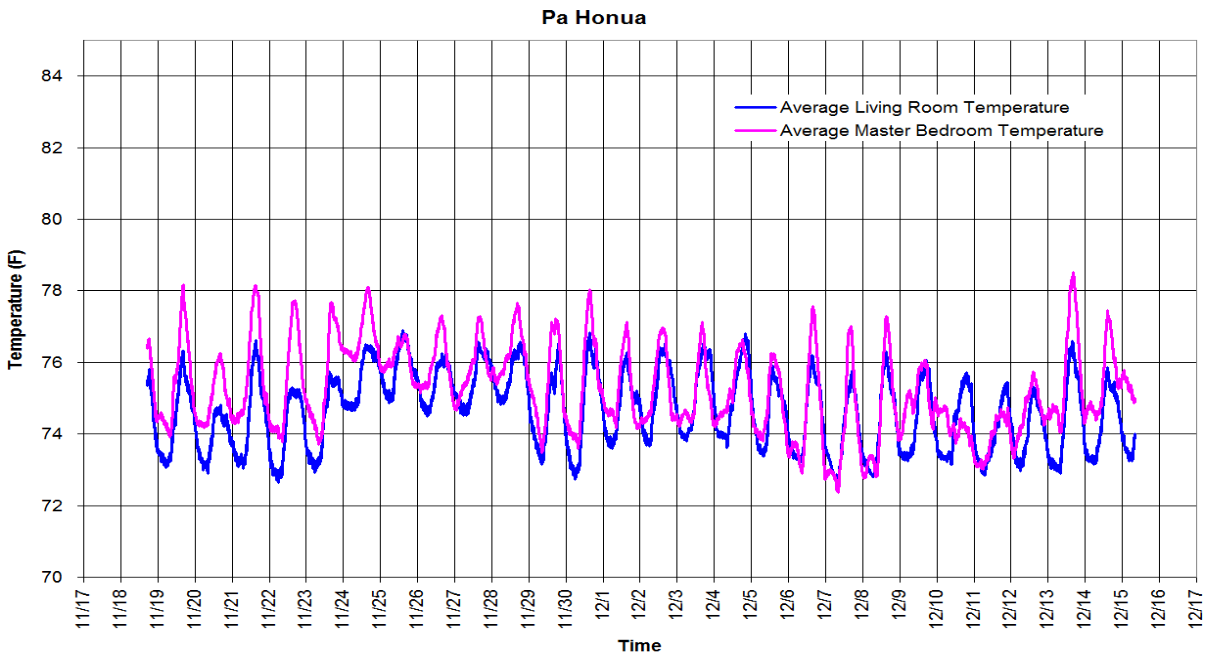
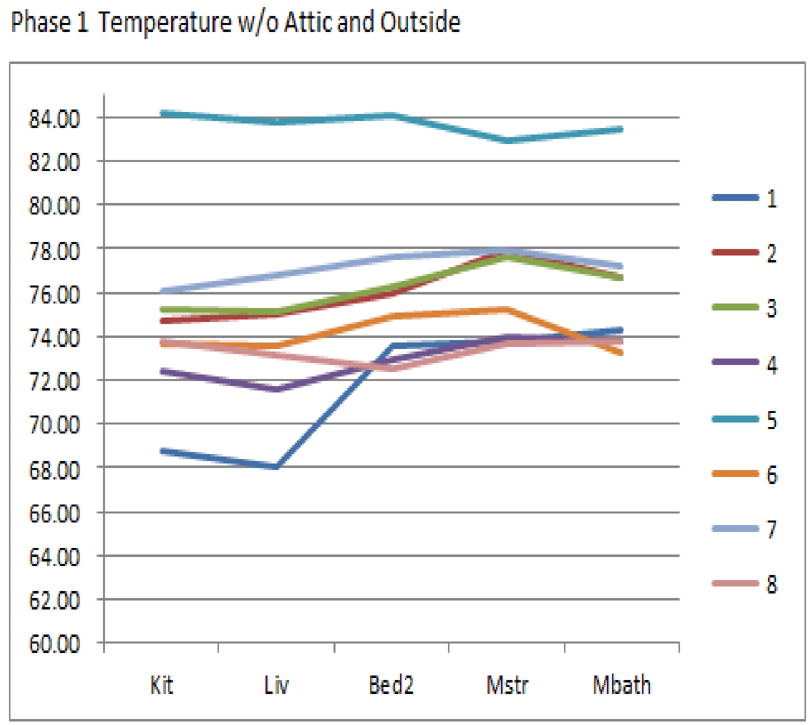


Figure B4. Mean monthly temperatures of rooms in eight homes in the Moanalua Terrace neighborhood.



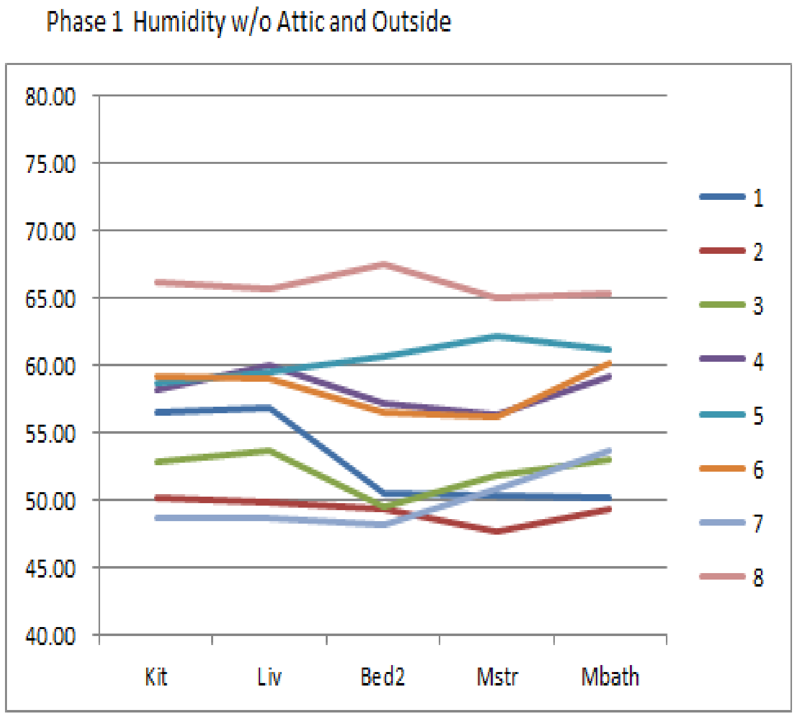


Figure B5. Temperatures in the living room and master bedroom of two homes in Moanalua Terrace neighborhood.

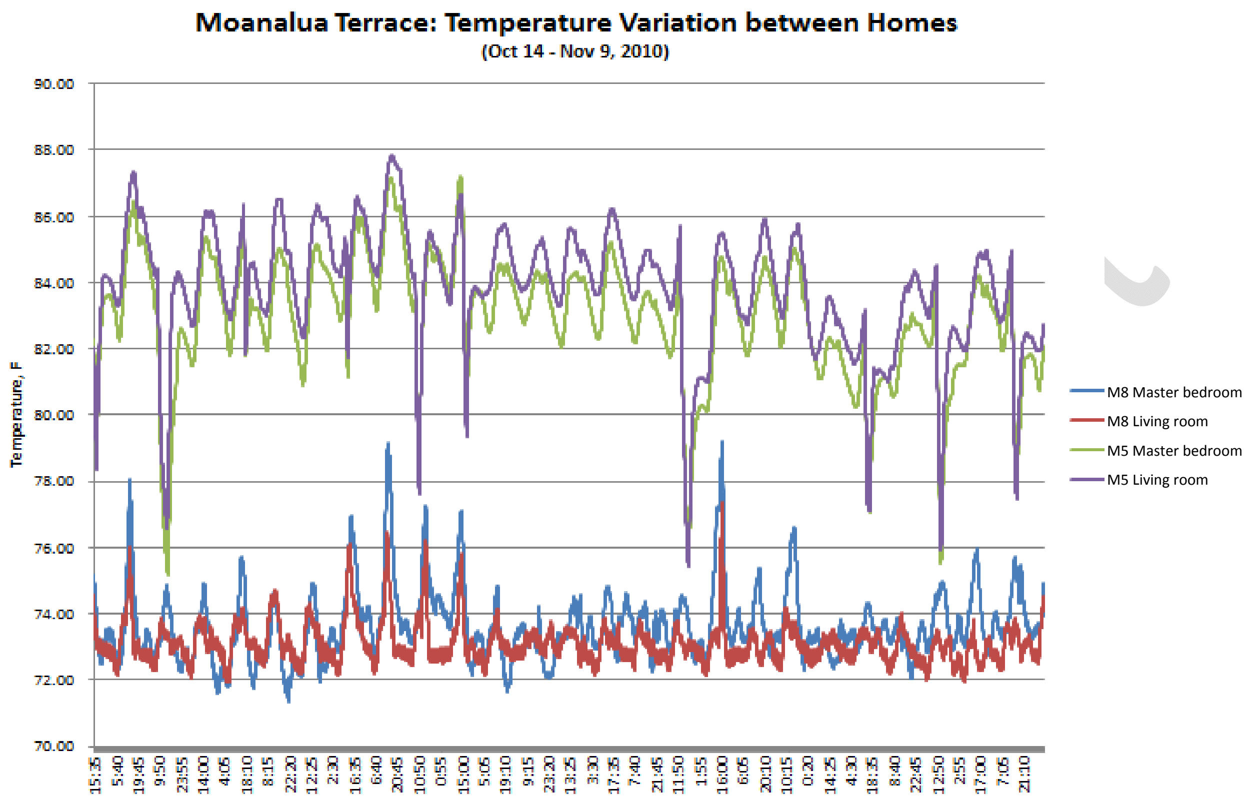
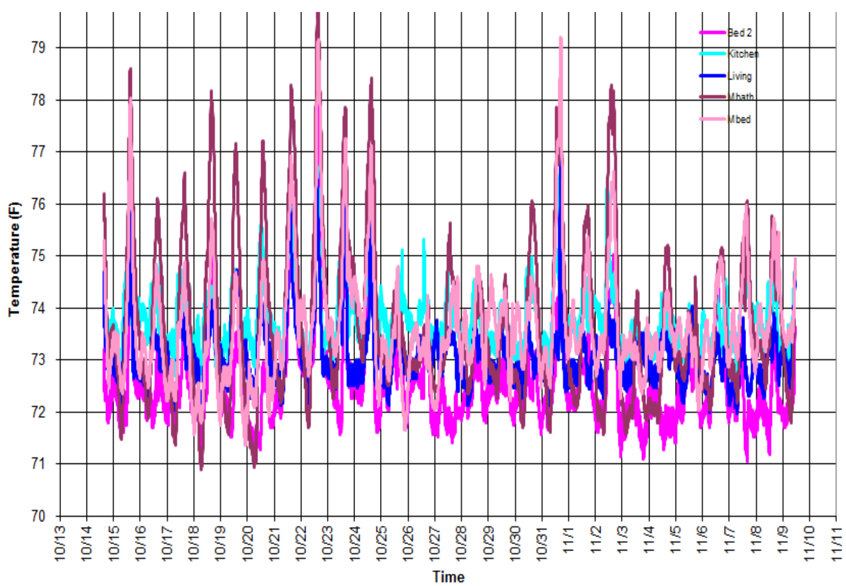


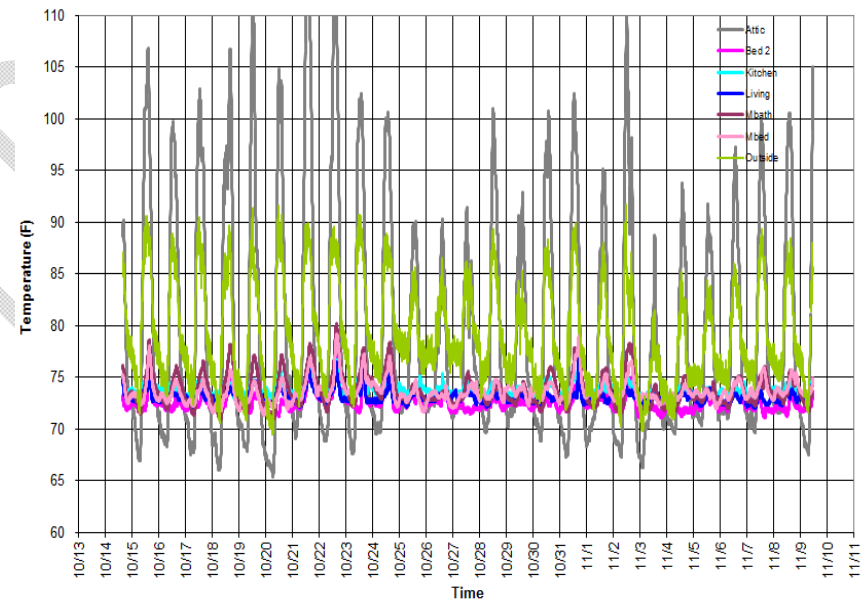
Figure B6 illustrates the temperature changes over time in a typical home in the Moanaloa Terrace neighborhood over time. Attic temperature can easily exceed 110°F. This radiant heat can cross at thermal bridges such as steel beams and areas where attic insulation has been shifted (e.g. by security system installers) or were never properly installed initially (e.g. the corners of the attic).

Figure B6. Temperature and humidity data from M8 which illustrate: a) indoor temperatures; b) all temperatures including attic and outdoor; c) temperature and humidity in living room (first floor) and master bedroom (second floor); d) relative humidity

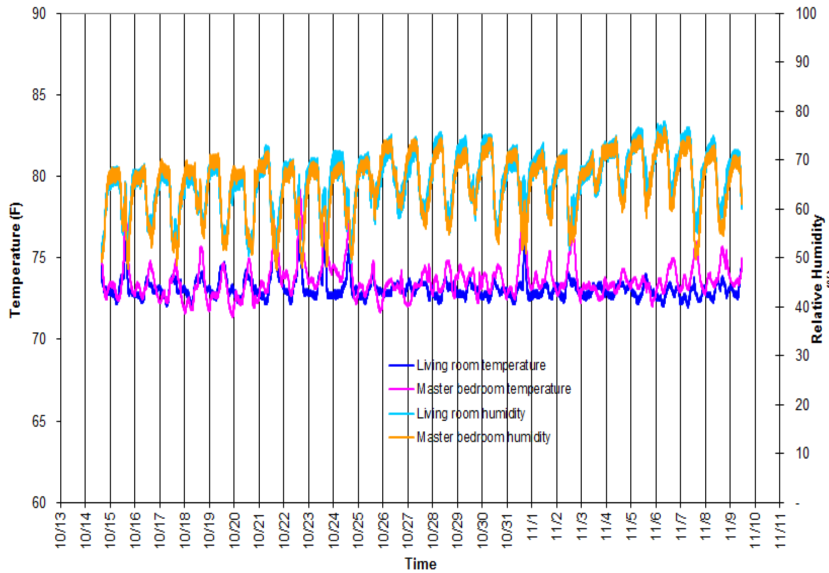
a) Indoor temperatures only



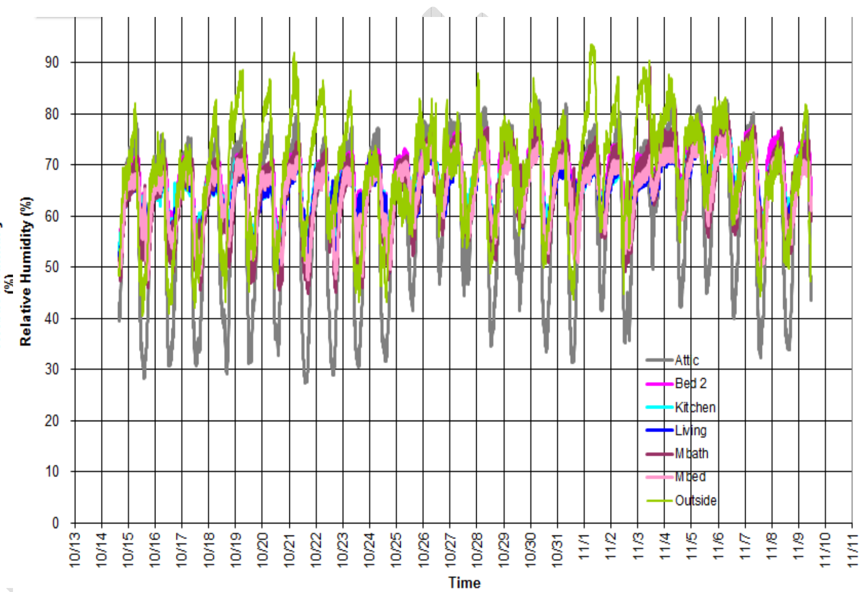
b) All temperatures, including attic and outdoor



c) Temperature vs. humidity in two rooms



d) Relative humidity readings

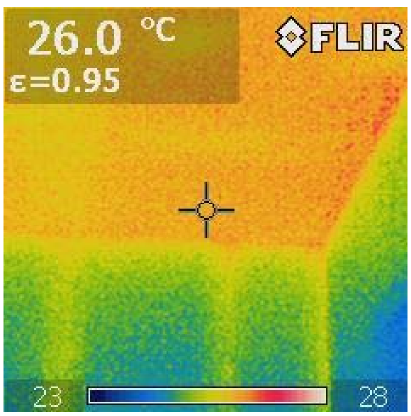


Infrared Observations

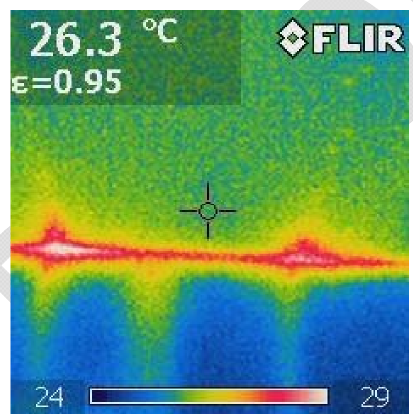
Much of the perception of warmth comes in the form of radiant heat from the walls, ceiling and other surfaces, including furniture. A room air temperature reading does not capture the true impact of the elevated temperature of a wall, window or ceiling. The following thermographic infrared images show pathways that heat will enter a home. Figure B7-a shows heat being transmitted through the wall studs and B7-b through ceiling plate. Figure B7-c shows heat being transmitted through ceiling joists and B8-d through the ceiling directly in areas where the attic insulation has been moved but not replaced. It is also clear in figure B7-c the radiant energy transmitted by the glass in a window.

Figure B7. Thermography images from Pa Honua houses.

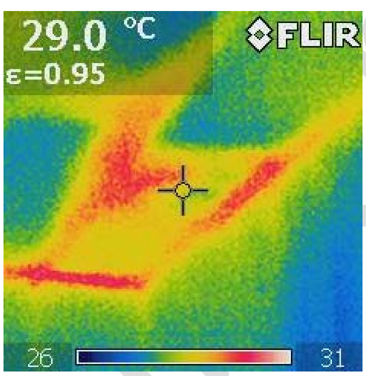
a) wall studs; ceiling



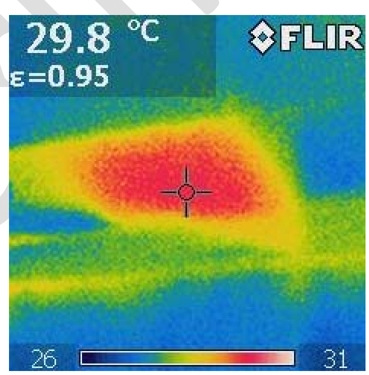
b) ceiling plate; soffit areas not insulated



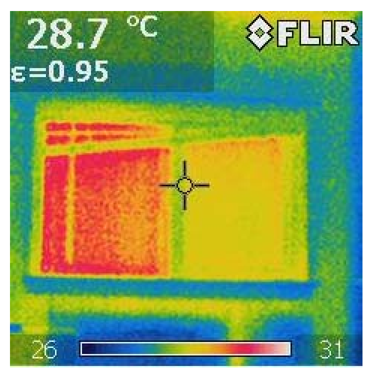
c) ceiling joists



d) ceiling; attic insulation missing



e) window

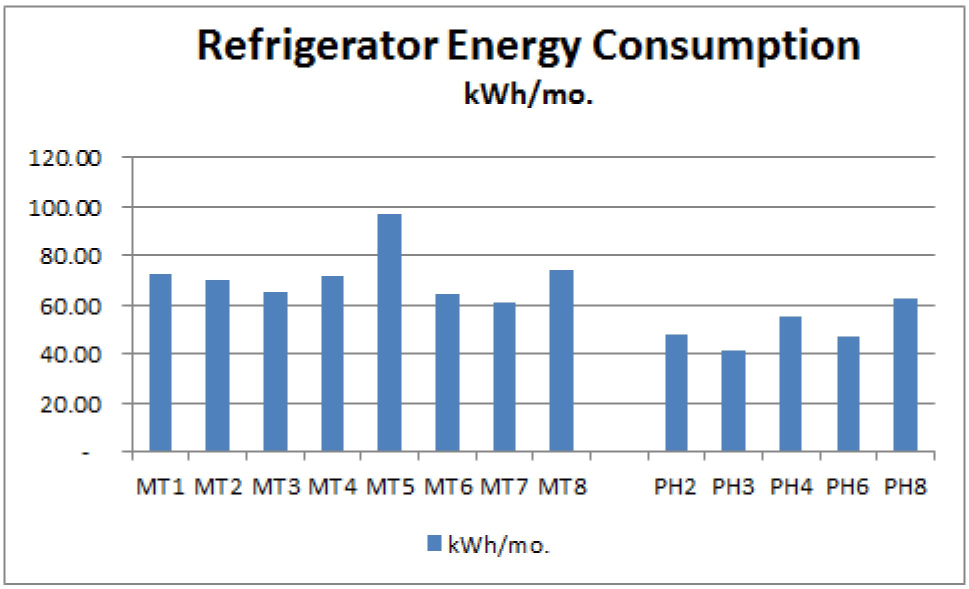


Refrigerators

The energy consumption from refrigerators is largely a function of size, configuration and year of manufacture. Generally speaking, refrigerators grew increasingly efficient over time with periodic increases in federal efficiency standards. The first standards went into effect in 1993, with stricter standards taking effect July 1, 2001.

Moanalua Terrace homes were constructed in 1993 and 1996, under the older standards, all furnished with refrigerators manufactured between 1995 and 1998. These refrigerators used on average 30% more energy than the Pa Honua sample, which were all manufactured after July 1, 2001 (Figure B8).

Figure B8. Energy consumption of refrigerators in Moanalua Terrace and Pa Honua neighborhoods.

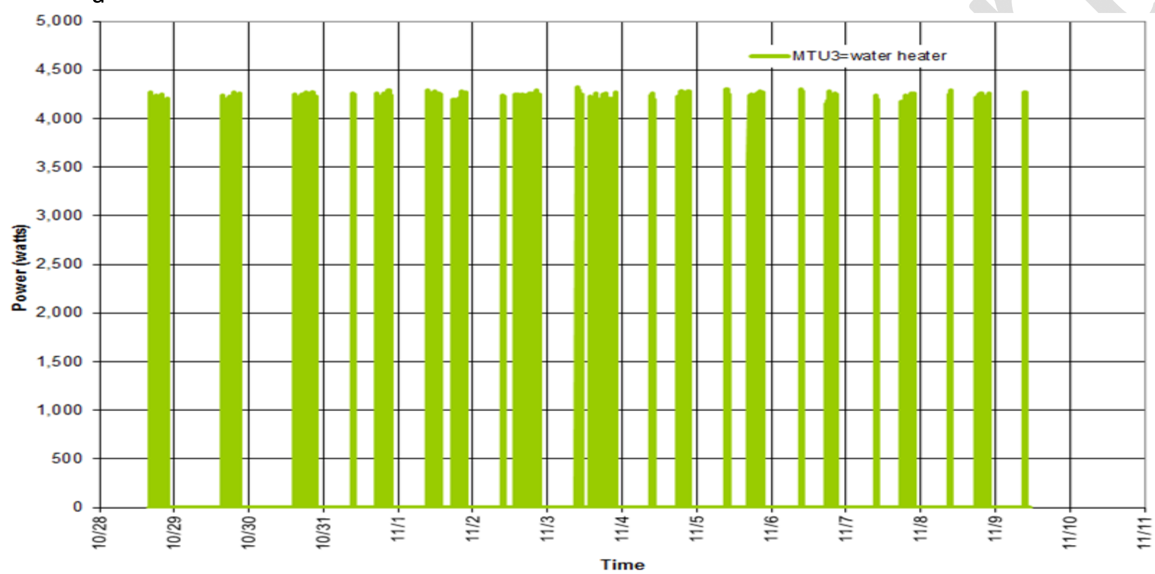


Water heating

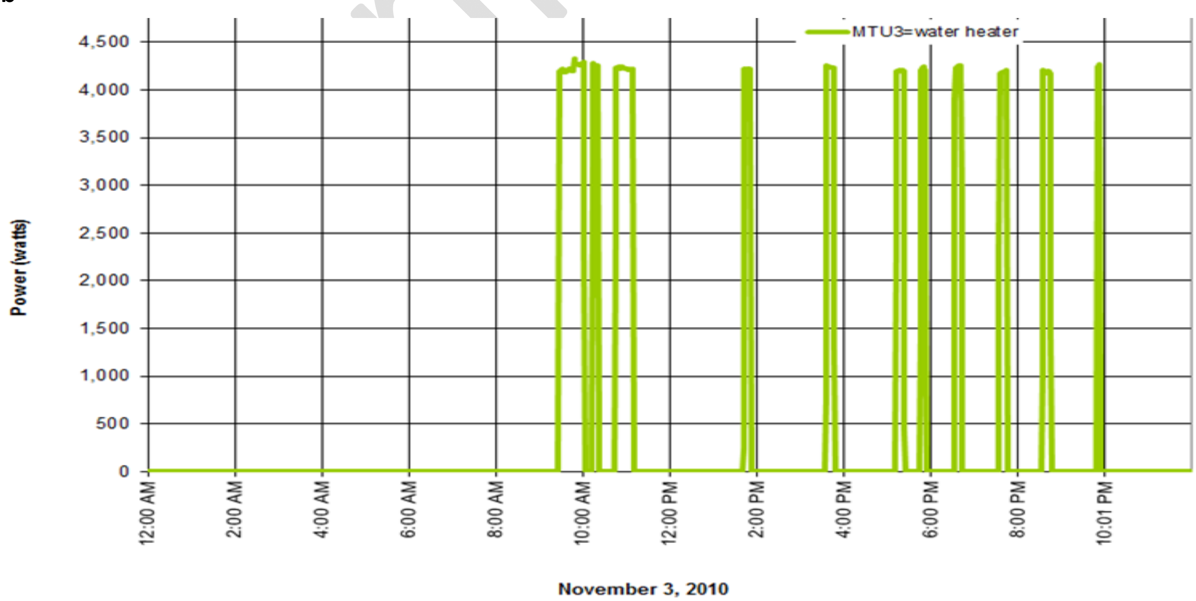
The monthly water heater profile for M8 is illustrated in Figure B9-a. The water heating element draws 4,200 W of power when it turns on. The primary source of hot water for the homes is solar using an 80-gal hot water storage tank. Figure B10-b indicates frequent cycling of the heating element in one day. The element is shown to energize 5 times during the period of 8 am to 4pm when the element should be set to “off” by the timer. This is indicative that for this home the pins that limit the solar timer to specific hours a day (4am to 8 am and 4pm to 8pm) are not set properly if at all.

Figure B9. Water heater energy consumption for M8 over a) three weeks and b) one day.

a



b

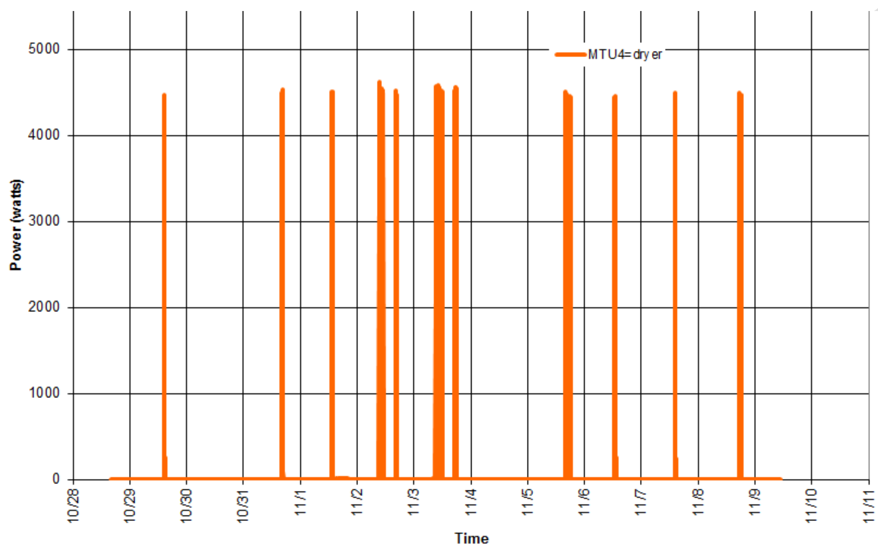


Clothes Dryer

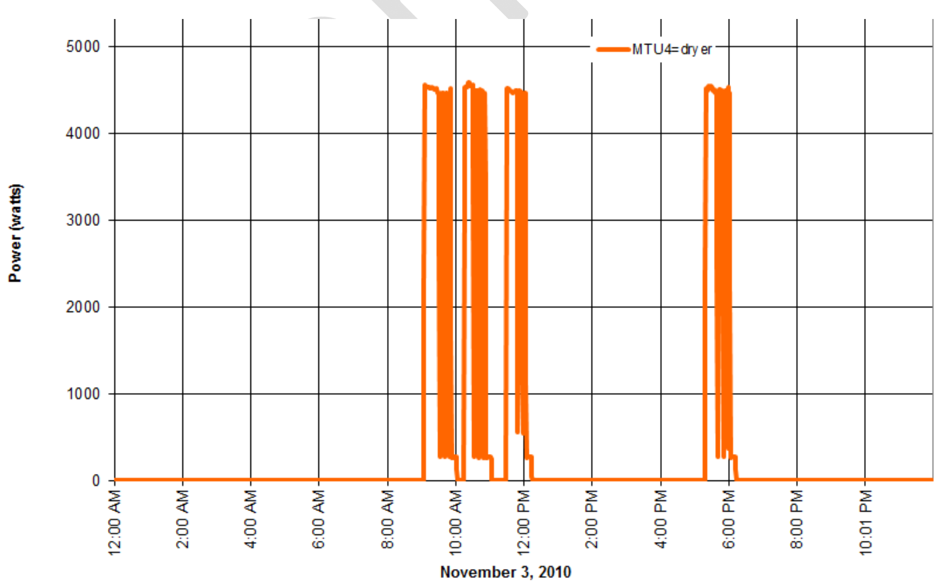
The clothes dryer is the third high power draw appliance in the home, drawing approximately 4,500W. Use of the dryer is purely a function of personal preference of the resident. In Figure B10-a, it appears there are approximately 11 loads over course of a month for M8. Upon closer examination of a single day, Figure B10-b shows 4 cycles of drying.

Figure B10. Energy consumption of the clothes dryer in M8 over a) three weeks and b) one day.

a.



b.



APPENDIX C - DATA SHEETS

Occupant Survey

1. Number of stories to the home 1, 2, or 3

2. Including yourself, how many people live in the home on a full-time basis?

	0	1	2	3	4
Children 0-10					
Children 11-18					
Adults 18+					

3. At what temperature do you normally set your thermostat for air conditioning?

   68-70 ___

   71-73 ___

   74-76 ___

   77-80 ___

   Other, please specify: _______________________________

4. If you set your temperature higher at night or while out of the house, to what temperature do you set it?

   68-70 ___

   71-73 ___

   74-76 ___

   77-80 ___

   Other, please specify: _______________________________

5. Is the air conditioner in operation…

   ___ All of the time

   ___ Most of the time

   ___ Some of the time

   ___ During hot spells only

   Other, please specify: ______________________________

6. Do you open and close your windows for fresh air and ventilation?

   __ Yes

   __ Sometimes

   __ Never

7. If and when you open the windows for fresh air and ventilation, do you…

   ___ Always turn off the AC

   ___ Sometimes leave the AC on because cooling is needed in certain rooms

   ___ Always leave the AC on

8. Information regarding household water use:

Approximately how many showers are taken each week?

Average length of each shower?

How many baths are taken each week?

9. Information regarding refrigerators and freezers:

Do you used a 2nd refrigerator or freezer?

10. Approximately how many loads per week do you run your dishwasher?

11. Are they full loads or partial loads?

12. Approximately how many times power week do you hand-wash your dishes?

13. Approximately how many burner-minutes per day do you use your range? (Example: 2 burners for 15 minutes = 30 burner minutes).

14. Approximately how many hours per week do you use your oven?

15. Approximately how many minutes per day do you use your microwave oven?

16. Laundry profile in your home:

	0	1-2	3-4	5-6	7-8	9-10
Total loads/week						
Cold water loads						
Warm water loads						
Hot water loads						

17. Approximately how many loads per week do you run in your clothes dryer?

Small loads/week _______

Large loads/week________

We also ask if they happen to have any problems with the appliances:

AC work okay?

Get enough hot water?

Dryer work okay?