Energy Consumption Data Analysis
Phase II Final Report

Prepared for the

U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability

Under Cooperative Agreement No. DE-FC26-06NT42847
Hawai‘i Distributed Energy Resource Technologies for Energy Security

Subtask 11.3 Deliverable 3

Prepared by

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Submitted by

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June 2012

Acknowledgement: This material is based upon work supported by the United States Department of Energy under Cooperative Agreement Number DE-FC-06NT42847.

UH Watt Watcher Energy Consumption Data Analysis

Phase II Final Report: Air Conditioning Retrofit Study

June 20, 2012




Prepared for:
Forest City Military Communities Hawaii

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Hawaii Natural Energy Institute
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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 improving building design and energy and management. In Phase I of the project, the UH Watt Watcher program teamed with Forest City Military Communities Hawaii to evaluate energy usage in military housing on Oahu. In Phase II, the Watt Watchers monitored homes to understand how much energy could be saved by retrofitting air conditioning systems and improving the thermal envelope of residences.

The Watt Watcher Team monitored homes for approximately five months each. In each home, temperature and humidity were recorded along with energy consumption for the whole house and individual circuits for the air conditioner, the domestic water heater system, the stove, and the clothes dryer. Other appliances and devices were inventoried. A survey was conducted with the resident which provides an anecdotal self-description of the residents' usage patterns.

The major finding in Phase I was the dominance of the air conditioning load in the overall energy consumption**.** That trend continues through Phase II with air conditioning load comprising 57% of the total home energy use.

> *Phase II showed that by slightly modifying the building envelope, replacing the mechanical air conditioning equipment, and sealing the ducts, the average monthly cooling load was reduced 59% from average of 799 kWh to 326 kWh. The control home also experienced a 27% reduction in AC energy due to seasonal change. We therefore give the retrofitted homes a conservative estimate of a seasonally adjusted reduction of 32% for AC energy consumption.*

OBJECTIVES

The objective of Phase II was to inform Forest City of key observations they can use to assist in reducing the cooling load in older Moanalua Terrace homes. Specific objectives include:

- Quantify energy consumption for air conditioning, clothes drying, water heating, stove, refrigerator, and "other" end uses.
- Observe relationships between temperature, comfort and air conditioning energy use.
- Quantify energy savings from retrofits.
- Determine which method of additional insulation provided the most significant reduction.
- Make preliminary recommendations to improve energy consumption:
  - Recommendations to Forest City management
  - Recommendations to residents of Forest City properties

METHODS

Forest City management located six families to volunteer to participate in this study starting in August and September, 2011. All homes were 949 sq ft, one half of a duplex, located in the Moanalua Terrace Phase III or Phase IV neighborhoods, and were built in 1996. All homes had 1997 Carrier 2-ton air conditioners in need of replacement. All homes have R-19 fiberglass batt insulation in the attic, located on the attic floor. Two homes served as controls and were not retrofitted. The four experimental homes all received air conditioning retrofits which included the following:

- Trane 1.5-ton SEER 16 compressor unit model # 4TTB4018E
- Trane 2.0-ton variable speed air handler unit model # TAM7A0A24H21SA
- Thermostat with humidistat – Trane XL803 model # TCONT803AS32DA
- Weatherization strip was added around door in laundry room leading to garage
- Added 3" polystyrene foam core insulation to metal attic hatch door.
- Lined interior of return air plenum with anti-microbial duct board sealed seams with UL 181 mastic and UL 181 tape
- An additional curb was added for ease of access to the air handler unit's filter slot
- Each duct register (10 total per home) was sealed where the ceiling drywall meets the metal in order to mitigate cooling loss back into the attic space
- Checked jumper ducts in attic for leakage

Three of the four retrofitted homes received changes to the thermal envelope (Table 1). One home had an additional layer of R-19 fiberglass batt insulation added to the existing R-19 on the attic floor, increasing insulation to R-38. One home had blown-in cellulose insulation added on top of existing R-19 fiberglass batt insulation on attic floor, increasing insulation to R-38. The last home had no insulation added but a radiant barrier was stapled to the roof rafters in the attic.

Table 1. Thermal envelope treatments and monitoring periods for experimental homes.

		Before retrofit			After retrofit		
House ID	Treatment	Date start	Date end	# days	Date start	Date end	# days
MT-19	Control	8/29/11	2/23/12	174			
MT-17	Control (family 1)	8/29/11	10/20/11	51			
MT-17	Control (family 2)	11/1/11	1/26/12	85			
MT-18	AC, duct retrofit only	8/29/11	12/9/11	100	12/10/11	2/23/12	73
MT-20	AC retrofit + R-19 blown-in cellulose	9/7/11	11/14/11	67	1/5/12	2/23/12	48
MT-21	AC retrofit + R-19 fiberglass batt	9/23/11	11/6/11	43	11/11/11	1/26/12	75
MT-22	AC retrofit + Radiant barrier	9/23/11	11/7/11	44	11/9/11	2/23/12	104

All experimental homes had their envelopes and ducts tested for air tightness with pressurization tests before and after retrofit. Energy and environmental sensors were installed a minimum of 6 weeks before retrofit to collect baseline data (see Table 1 for monitoring periods). Data was collected for a minimum of 7 weeks after the retrofit. The family in one of the control homes, MT-17, unexpectedly relocated and a new family moved in during the study. The drastic differences in energy habits of the two families rendered this control home minimally useful for the study. All environmental sensors inside the home were removed by the moving company, so most environmental data was lost for MT-17. House MT-20 had the shortest post-retrofit monitoring period because the new air handler froze-up and then the occupants were away for the holidays.

RESULTS

Figures 1 and 2 shows the abundance of energy consumption used for air conditioning compared to other major appliances in the home.

Figure 1. Comparative energy use of major appliances, pre- and post-retrofit.

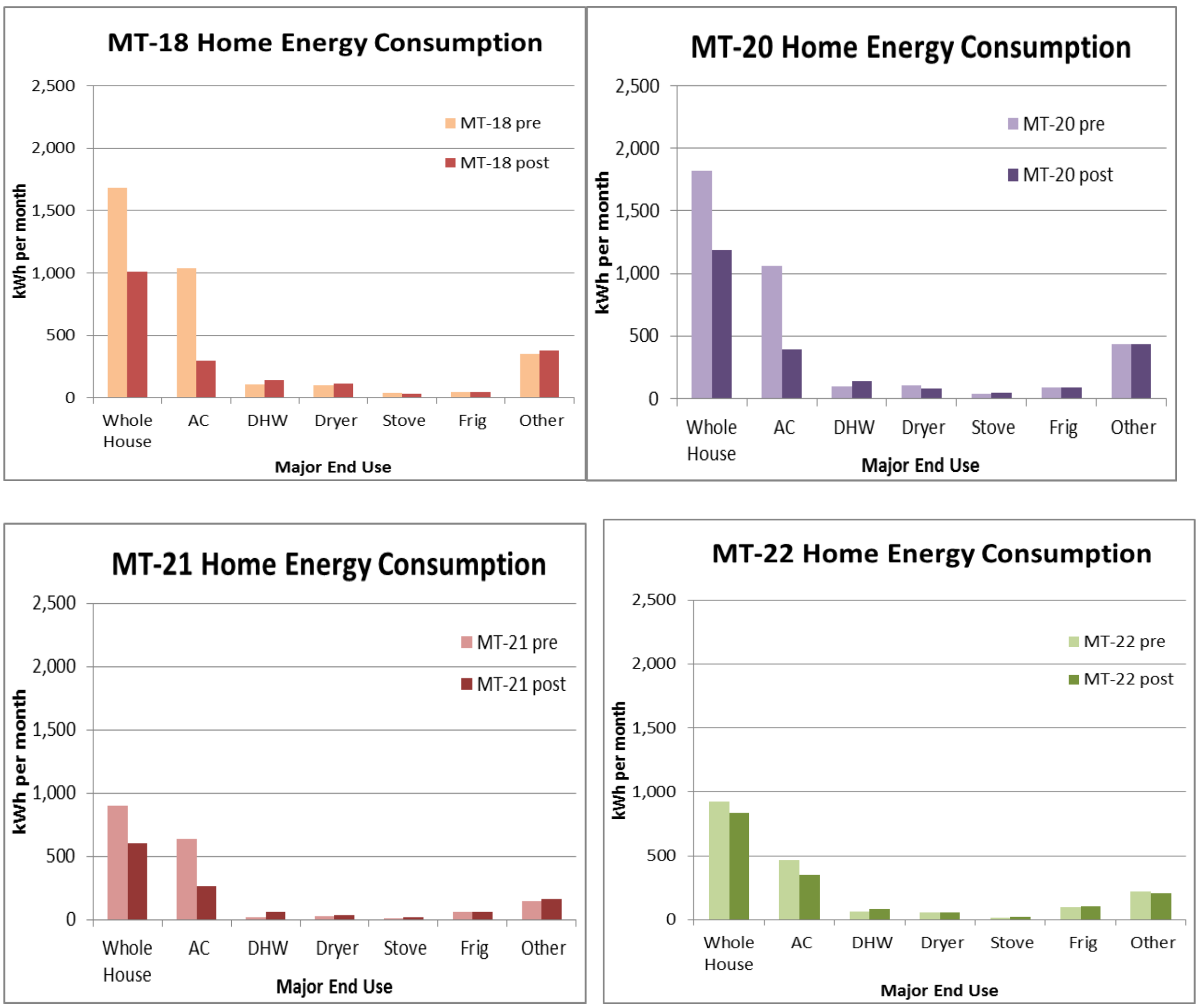
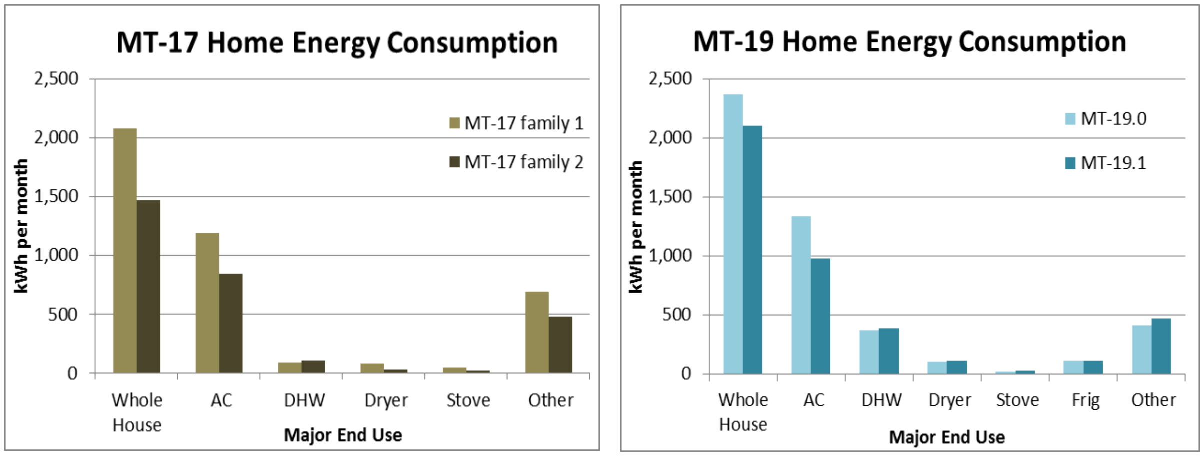


Figure 2. Comparative energy use of major appliances for control homes, MT-17 family 1 and then family 2, and MT-19 for just 1 family but split over time to show seasonal change.



Figures 3a and 3b 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 4a and 4b). 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 5 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 different the 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 is most likely due 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.

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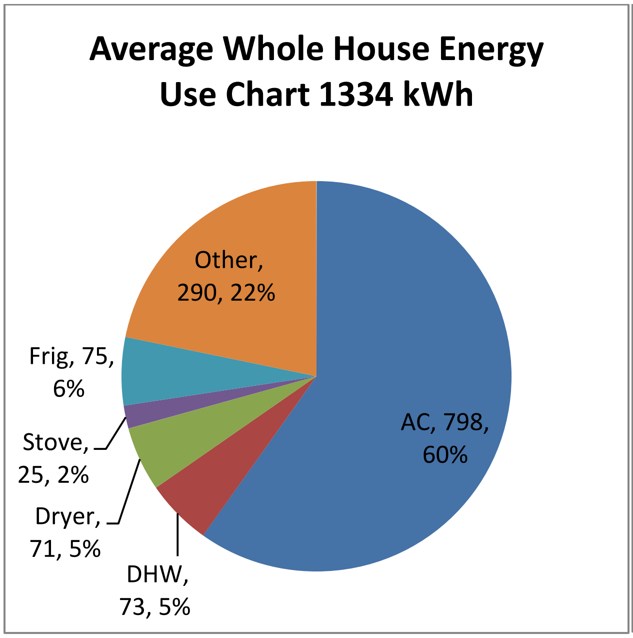
[1] http://beopt.nrel.gov/

Figure 3a and 3b. Average total energy use for retrofit houses pre- and post-retrofit.



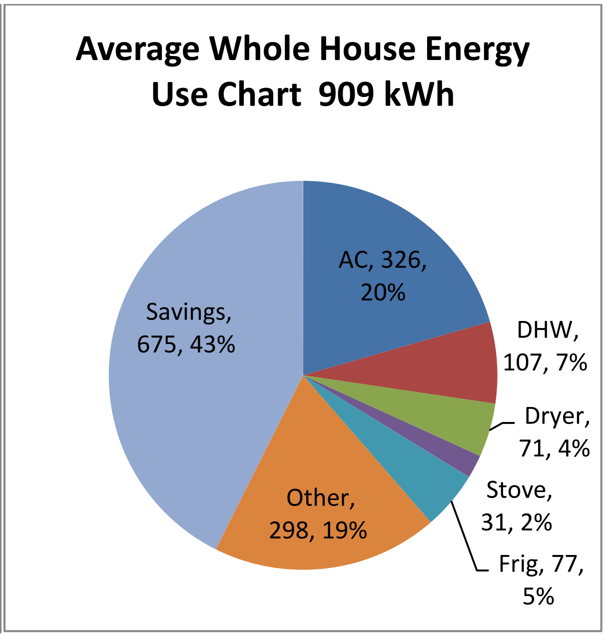
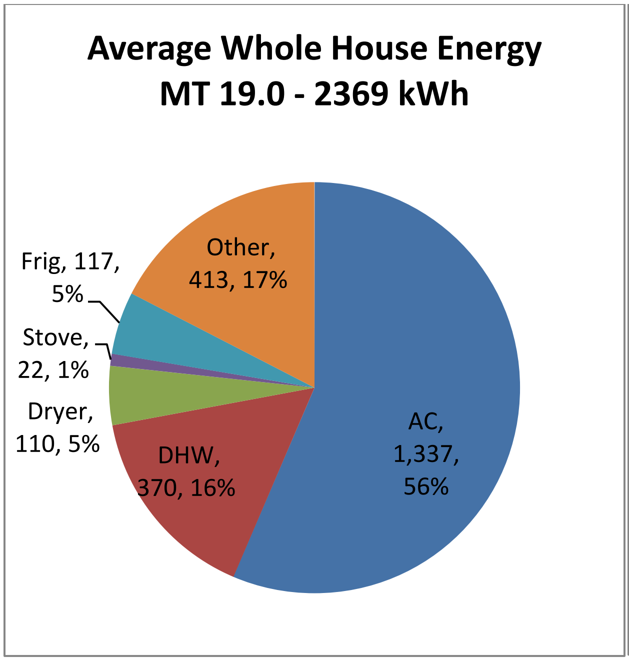


Figure 4a and 4b. Average total energy use for the control house before and after Nov 11, 2012.



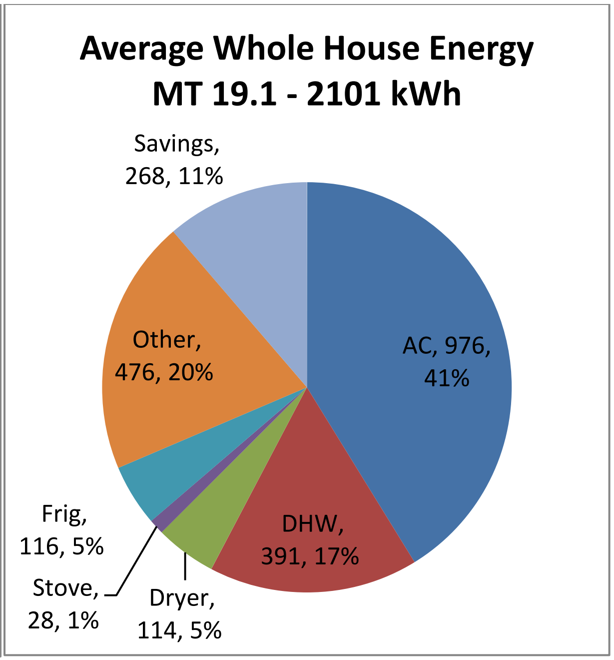
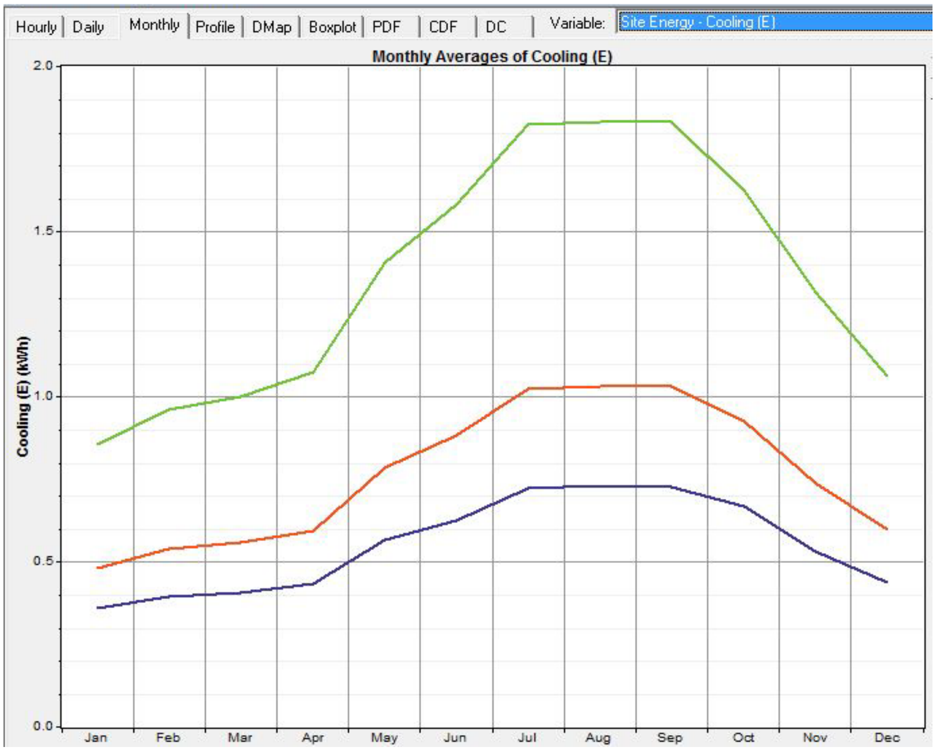


Figure 5. Energy simulation graphical output from BEOpt showing energy use over the year of a house before retrofit (green line), a retrofitted house (red line), a hypothetical retrofitted house with a deeper retrofit.



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 2). 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 2. 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

Figure 6 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 7). 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 6. Energy consumed by AC (kWh/mo) vs percent time temperature-humidity index exceeded 70.

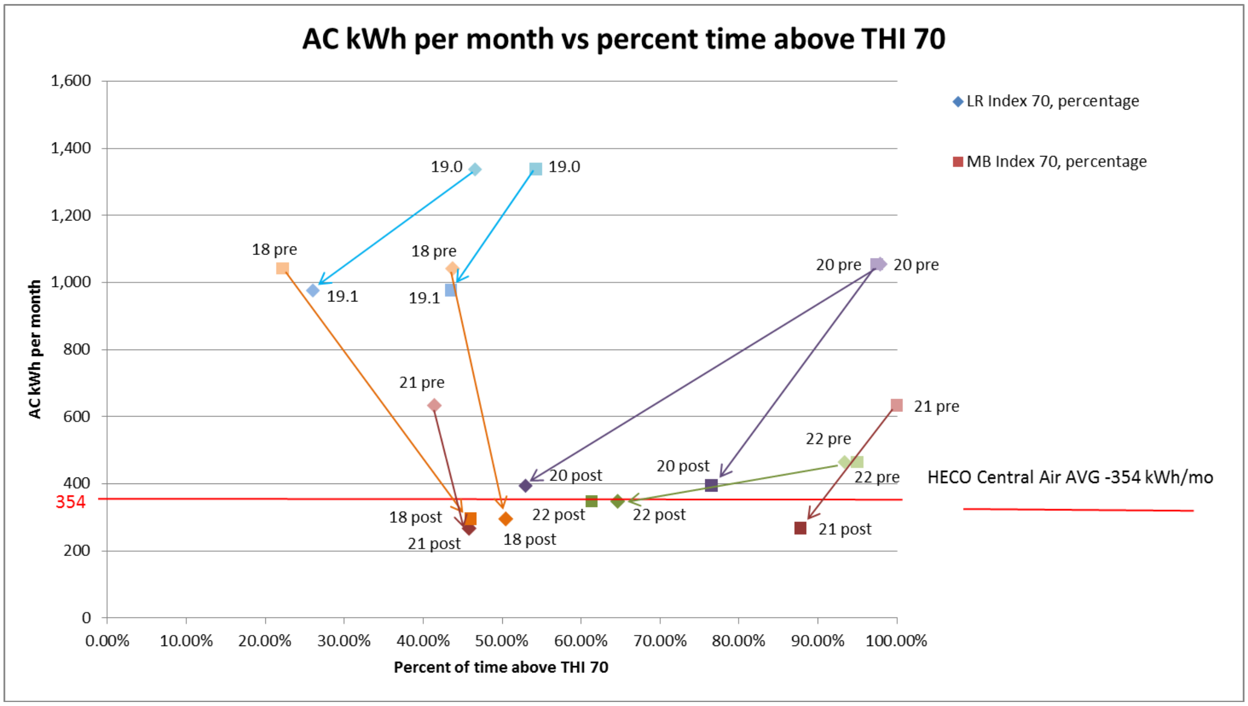


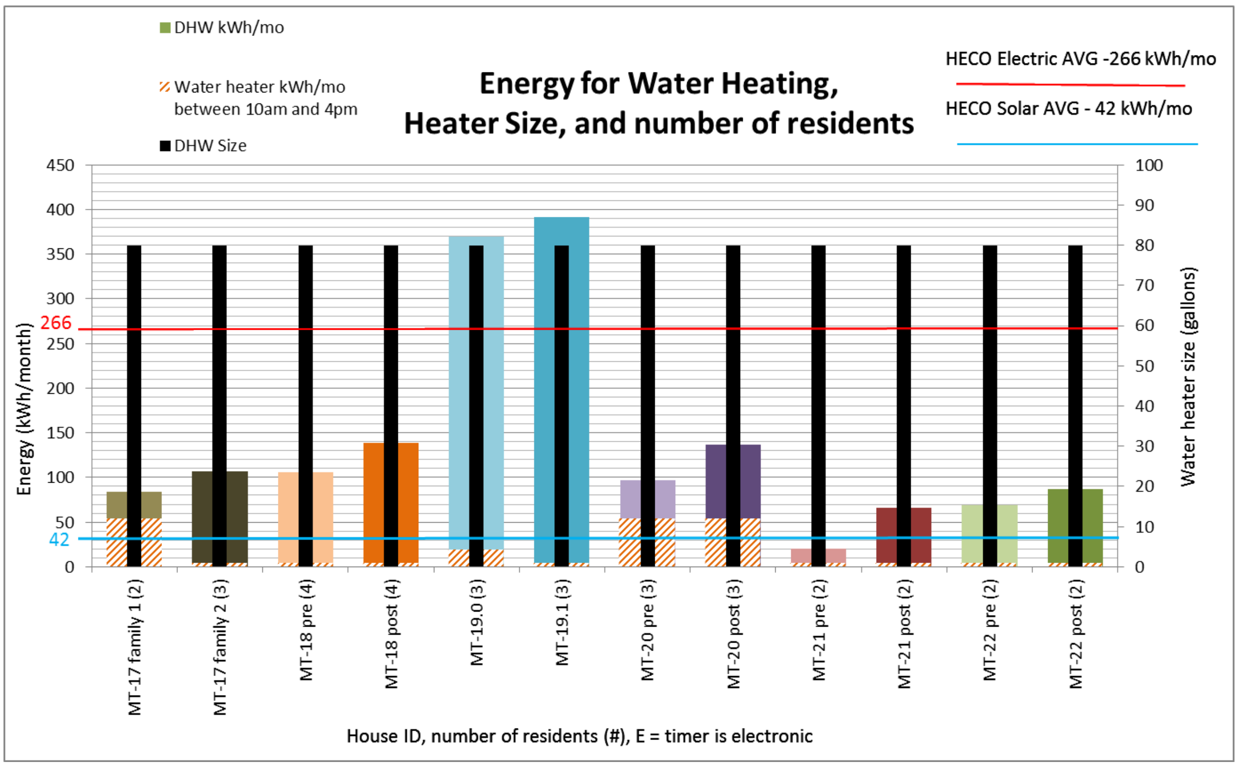
Figure 7. Results of pressurization tests for houses and ducts.

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.

Figure 8. Comparison of energy for water heating, heater size, and number of residents in the home.



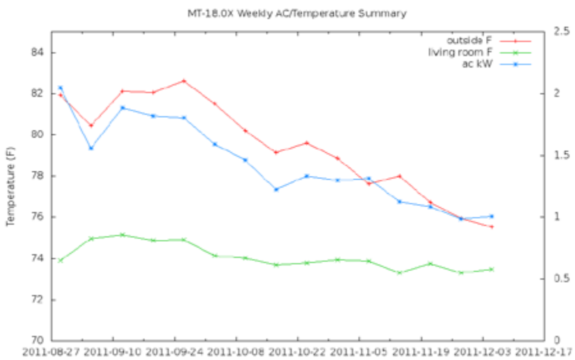
RECOMMENDATIONS TO FOREST CITY MANAGMENT

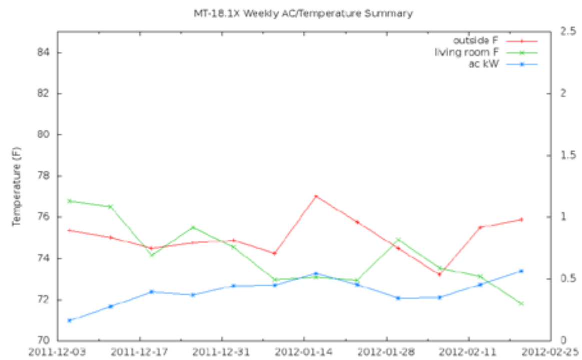
- Roll-out the AC and duct retrofits as soon as possible.
- Test ducts after retrofit, there should not be more than 90 CFM leakage to the outside. The calculation: 400 CFM per ton of AC compressor capacity = 1.5 * 400 = 600 CFM. Tolerance level for retrofit is 15% of 600 = 90 CFM.
- Have a third party 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 – bargain for a better deal on cost. 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.

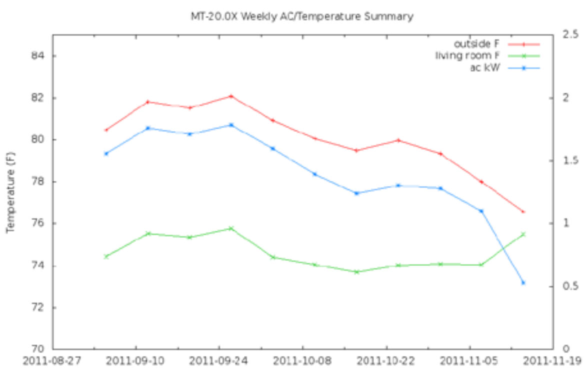
RECOMMENDATIONS TO FOREST CITY RESIDENTS

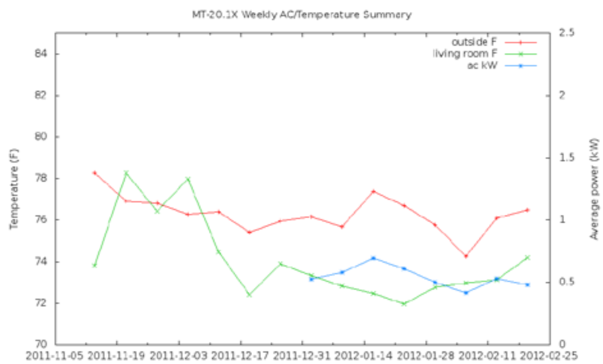
- Setting your thermostat to "auto" instead of "on" can save you $12/month on your monthly energy bill (60 kWh).
- Program your thermostat to turn the AC off or maintain a warmer temperature when you are not home.
- Set the hot water heater timer to meet your personal showering schedule.
- To test if 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).

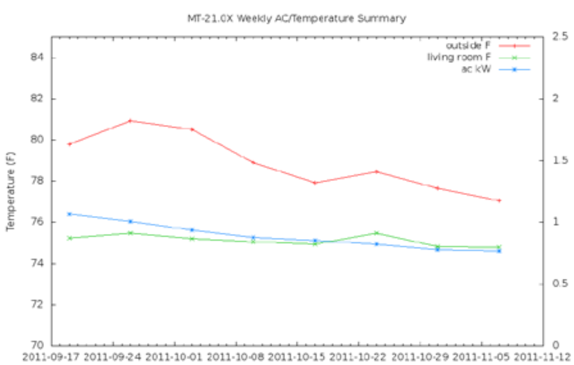
APPENDIX A
Indoor and Outdoor Temperature Vs AC Energy Graphs

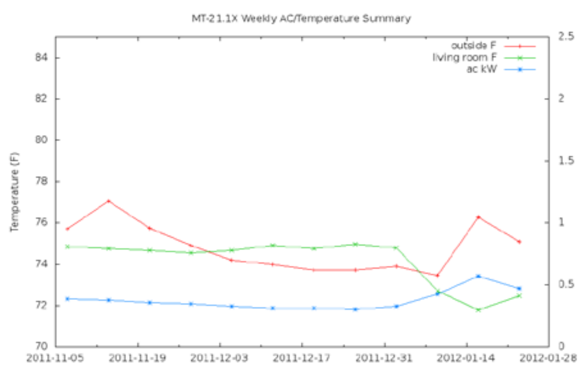


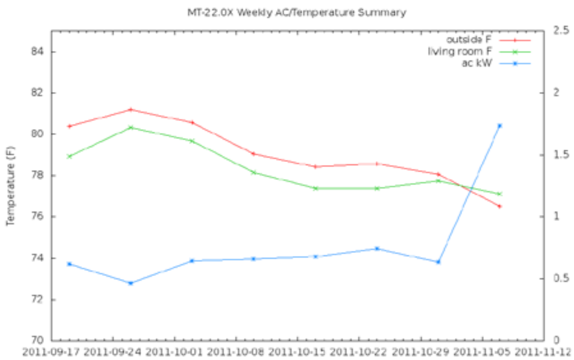


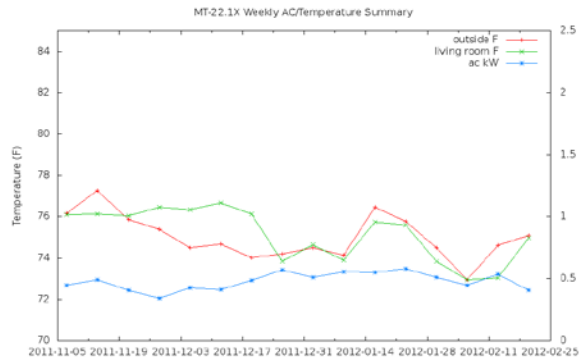









MT-22.0X Weekly AC/Temperature Summary
outside F
living room F
ac kW
Temperature (F)
Average power (kW)
2011-09-17
2011-09-24
2011-10-01
2011-10-08
2011-10-15
2011-10-22
2011-10-29
2011-11-05
2011-11-12


MT-22.1X Weekly AC/Temperature Summary
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living room F
ac kW
Temperature (F)
Average power (kW)
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2011-11-19
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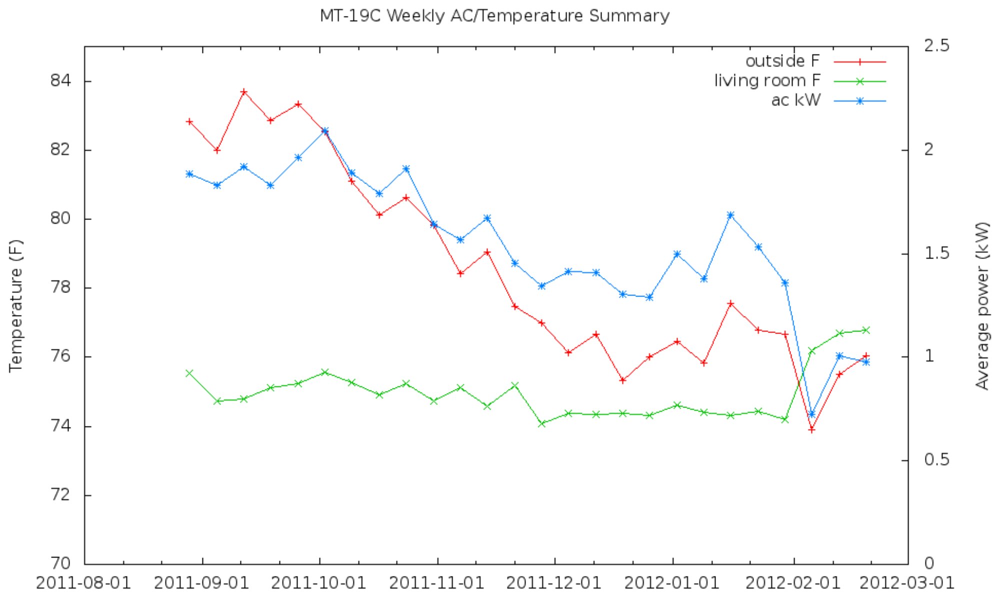
2012-02-11
2012-02-25


MT-19C Weekly AC/Temperature Summary
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living room F
ac kW
Temperature (F)
Average power (kW)
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2011-09-01
2011-10-01
2011-11-01
2011-12-01
2012-01-01
2012-02-01
2012-03-01