FLORIDA SOLAR ENERGY CENTER®

CONTRACT REPORT

Initial Testing of a Unitary HVAC System Advanced Control Module

FSEC Contract Report Number: FSEC-CR-1980-14

Ranger LVTS V1 Preliminary Laboratory Test Results

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Introduction

Published Ratings for unitary air-conditioners and heat pumps are measured and calculated according to ANSI/AHRI Standards. The Standards evaluate the performance of unitary equipment and then rate that equipment using capacity and energy related performance metrics. These performance metrics accurately report the unitary system capacity and efficiency based on a standardized test procedure, yet lack sufficient information to accurately predict performance of accessorized equipment. For example, the impact of after-market advanced control modules on system performance cannot be evaluated through existing Standards testing.

ASHRAE is investigating a new Standard, identified as Load-Based Method of Test (LBMoT), which allows an HVAC system to be operated in a laboratory environment as if that system were field installed. Using this new test procedure, accessories, such as economizers, heat recovery systems, or even advanced control modules, may be tested in a laboratory environment using an accurate and repeatable test method to identify the improvement in performance specific to the HVAC system accessory.

This method of test will be used to evaluate an advanced control module developed by Ranger Energy Saving Solutions, LLC. Initial laboratory testing was performed to identify protocols necessary to accurately measure the benefit of the advanced control module. The testing protocol and results of these preliminary tests were be conveyed to the funding agency for discussion and approval. The laboratory tests did not provide an accurate and repeatable representation of system performance so an alternate test method was investigated. Additional testing was performed in a pseudo-laboratory environment where two thermostats were tested in a residential home environment to evaluate if field testing would also provide accurate results. Further testing, either laboratory or field based, may be performed to measure improvement in performance over a wide range of operating conditions; 1) if approved by the funding agency, and 2) with commensurate adjustments to the project schedule and funding through a contractual change in scope of work.

BACKGROUND

AHRI Standard 210/240[1] specifies the test and rating requirements necessary to publish ratings of air-, water-, or evaporatively-cooled unitary equipment with capacities up to 65,000 Btu/h (19,000 W). The tests specified in this Standard are used to calculate the AHRI standard rating cooling and/or heating capacity as well as the Energy Efficiency Ratio (EER) or Seasonal Energy Efficiency Ratio (SEER), and/or Heating Seasonal Performance Factor (HSPF). This Standard covers single-speed, multi-speed, and variable-speed compressors and fans. The Standard specifies explicitly how the system is to be tested and the calculations necessary to report a “standard” system rating. Part-load performance is accounted for by testing cyclic operation and, for multi-speed or variable-speed equipment, interpolating the cycling operation to define SEER and HSPF.

The published rating information is meant to allow direct comparison of equipment among different manufacturers or different manufacturing lines. This published rating does not, however, represent the in-situ operating performance when accessories or equipment options are included in the final system configuration. For example, the impact of advanced control algorithms would tend to increase a systems operating efficiency. There are currently no test procedures for unitary equipment which take improved controls into account. This project will endeavor to identify the requisite method of test necessary to accurately measure the performance improvement due to a specific accessory, the advanced control module.

Test Facility

The Florida Solar Energy Center (FSEC) is the largest and most active state-supported renewable energy and energy efficiency research, training and certification institute in the United States. An institute of the University of Central Florida (UCF), FSEC functions as the state's energy research, training and certification center. FSEC is located on a 20-acre research complex on Florida's Space Coast at UCF's Cocoa Campus, 35 miles east of Orlando. Research at FSEC is based on field monitoring, computer simulations and controlled experiments in highly instrumented laboratories. These research efforts are developed in partnership with industry, nonprofit organizations, private sponsors and national laboratories. FSEC annually receives $3 million in operating funds from the University system of Florida and also performs contracted research and training for external sponsors ranging from $5 million to $8 million annually.

The Florida Solar Energy Center (FSEC) has extensively tested small unitary systems for over two decades. FSEC currently operates an environmental test facility capable of testing up to 3.5 tons of cooling capacity with the ability to also test heat pumps in heating mode. The test chamber's outer shell is well insulated reducing external loads imposed on the system under test. The test facility is a dual-chamber (Figures 1 and 2), computer controlled environment using proportional and integral control of electric heaters and moisture generators. Previously tested system types include air-conditioners, heat pumps (air- and evaporatively-cooled), and coil assemblies (both direct-expansion and water-based).

The test chambers are instrumented with chilled-mirror hygrometers for measuring air moisture levels (dew point temperature), an airflow monitoring station, and a steam generator for controlling indoor moisture levels (Figure 3). Thermocouples are used throughout the system under test to measure air and surface temperatures. High accuracy power/energy meters are used to monitor electrical energy to the system under test. Indoor and outdoor conditions are independently controlled using proportional and integral control loops. The control loops can be programmed to meet a specific set point condition (i.e., temperature and relative humidity set point) or programmed to provide a fixed load. The facility has been programmed to operate unattended over long periods of time to expedite system testing (Figure 4).

Figure 1. Test Facility Indoor Chamber

Figure 2. Test Facility Outdoor Chamber

Figure 3. Steam Generator and Airflow Station

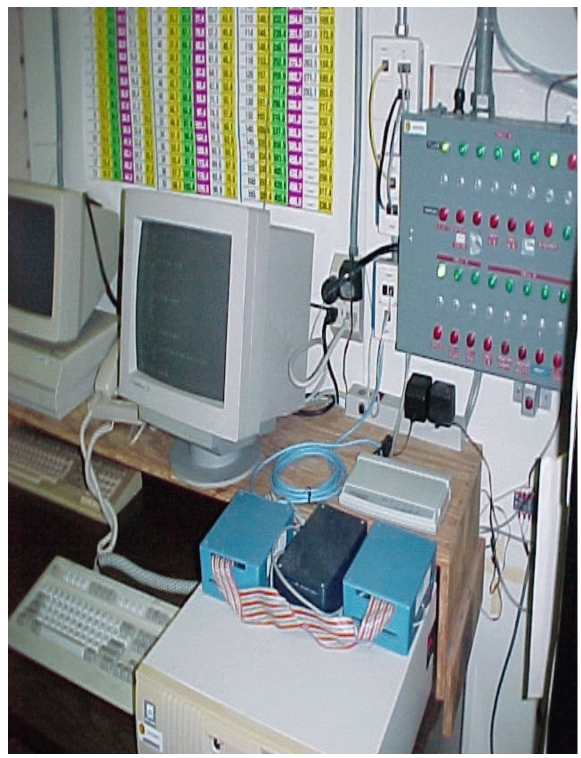

Figure 4. Computer Control Room

Measured data is collected at 15 second intervals and immediately delivered directly to the FSEC server. The data reduction program used at FSEC processes this data and stores the information for immediate use. The computer shown in Figure 4 is able to retrieve that data and graphically display the test results from the beginning of the test through to the most recent scan. This allows visualization of the tests progression and allows for adjustments as necessary to complete the current test. The statistical analysis program also resides on the FSEC server and is used to analyze each test or series of tests to provide a summary of results.

Most facilities are designed and operated to provide stead-state performance information where the unitary system is turned on at some operational speed and the facility maintains tightly controlled conditions. The tests proposed here will require a moderate change in test methodology. Performing a load-based method of test would require that the indoor chamber load devices be programmed to provide a specific duty cycle to impose a fixed sensible and latent load on the system under test. The outdoor chamber load devices would be controlled using proportional and integral control algorithms to maintain a fixed outdoor temperature. The system under test would be allowed to cycle to meet the imposed indoor load. After sufficient time to stabilize, the measured data would be collected over 2 or 3 complete cycles of operation. The tests would be repeated to include impacts of the advanced control module. The indoor and outdoor chamber equipment layout is shown in Figure 5. Note that a cooling system, identified as a chilled water air handler is available for cooling either the indoor or outdoor chamber. The dampers for the air flow through the chilled water coil are typically fixed during a steady-state test, however, in these tests the dampers would revert to the indoor chamber during the compressor off cycle to both maintain a higher outdoor temperature as close to the temperature maintained during the compressor on cycle, and also to provide a cooling/dehumidification load on the indoor chamber while the compressor is off to avoid high moisture levels caused by moisture evaporating off of the cooling coil if the indoor fan continues to operate.

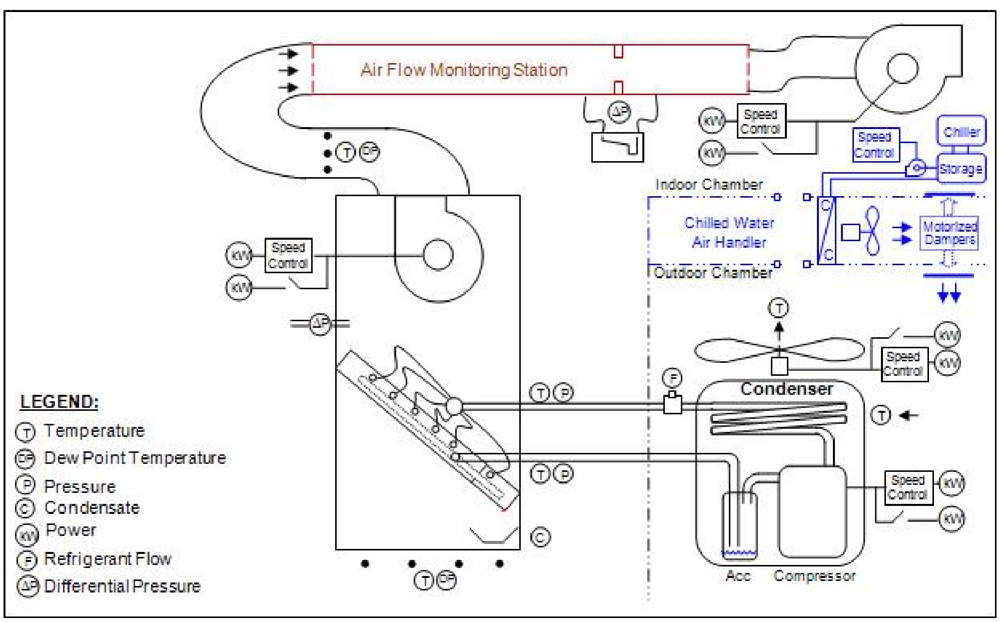

Figure 5. Schematic Diagram of Laboratory Equipment

Test Protocol

Measuring the savings attributed to a control device requires two forms of test. The first being the steady-state performance at a prescribed test condition. The most widely used test condition is that defined in the ANSI/AHRI Standard 210-240, the standard used for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment. The rating condition described in that standard is 80 ºF indoor dry-bulb temperature, 67 ºF indoor wet-bulb temperature (60.4 ºF dew-point temperature), and 95 ºF outdoor dry-bulb temperature. This rating point is referred to as 80/67/95 in the industry. The second form of test is a part-load test where the HVAC system cycles on and off to meet the thermostat temperature set point. Each of these tests will be investigated in an attempt to document the actual performance of the HVAC system when using one of two thermostat types.

Thermostat Selection

The two control devices used during these tests were the Ranger LVTS V1 and Honeywell RTH2510/RTH2410 Series digital thermostat. These controllers are shown in Figure 6 and Figure 7. Each of these are fully programmable with daily temperature scheduling. For these preliminary tests a fixed thermostat set point was selected to determine; 1) the full-load performance of the HVAC system, and 2) the on-off cycling characteristics measured when the HVAC system is operated under part-load conditions (i.e., the load on the HVAC system is less than the maximum available cooling capacity).

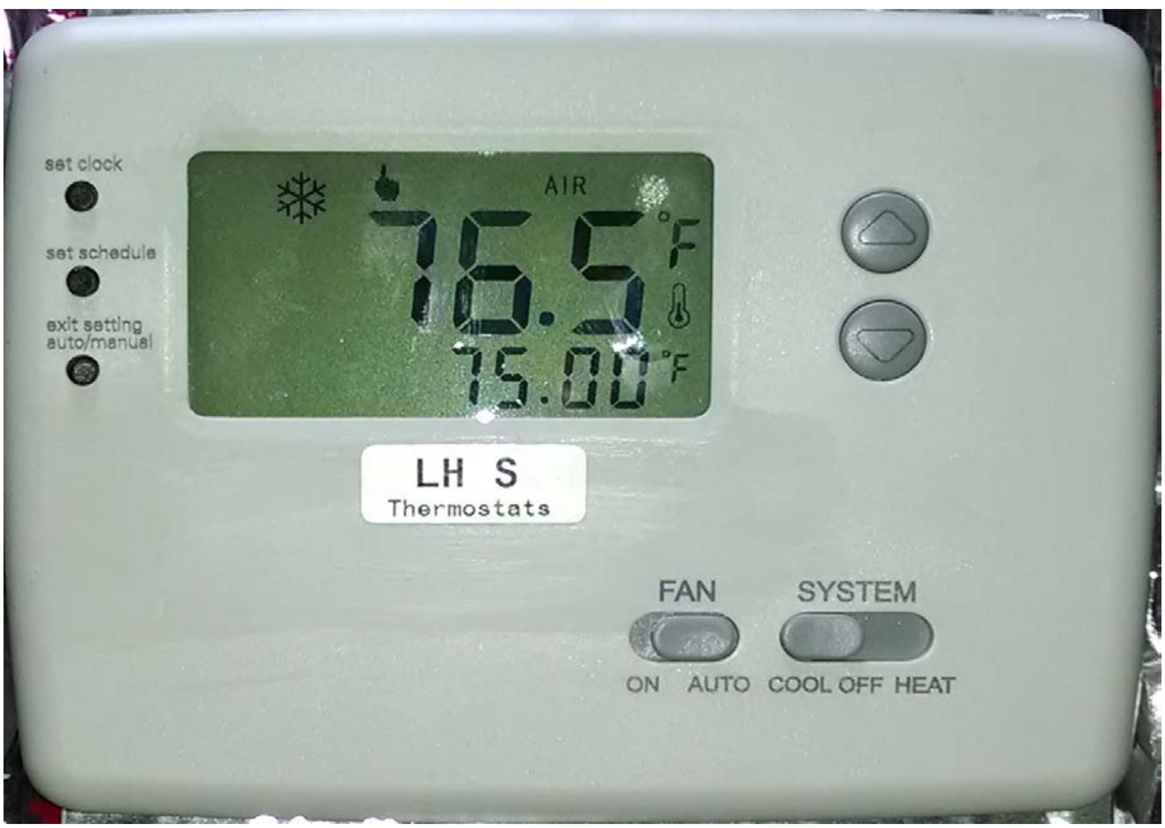

Figure 6. LVTS V1 Digital Thermostat

Figure 7. Honeywell Digital Thermostat

Preliminary Laboratory Test Results

The first test performed was to measure the performance of the HVAC system with the Ranger LVTS V1 digital thermostat installed. The test condition was the ANSI/AHRI Standard Rating conditions of 80 ºF dry-bulb and 67 ºF wet-bulb (60.4 ºF dew point) indoor temperatures and a 95 ºF outdoor dry-bulb temperature. The test was conducted over a 3 hour period where the LVTS V1 digital thermostat was allowed to operate as programmed by the manufacturer. The figure shows that the LVTS V1 thermostat interrupts the operation of the HVAC system at 30 minute intervals and holds off compressor operation for a period of 5 minutes. Note the location of the vertical dotted line in this and subsequent figures. The data presented below each sub-figure is averaged beginning at this vertical dotted line and ends either at the next vertical dotted line or the end of the figure. The second, third, and fourth sub-figure also shows the measured average performance of the HVAC system.

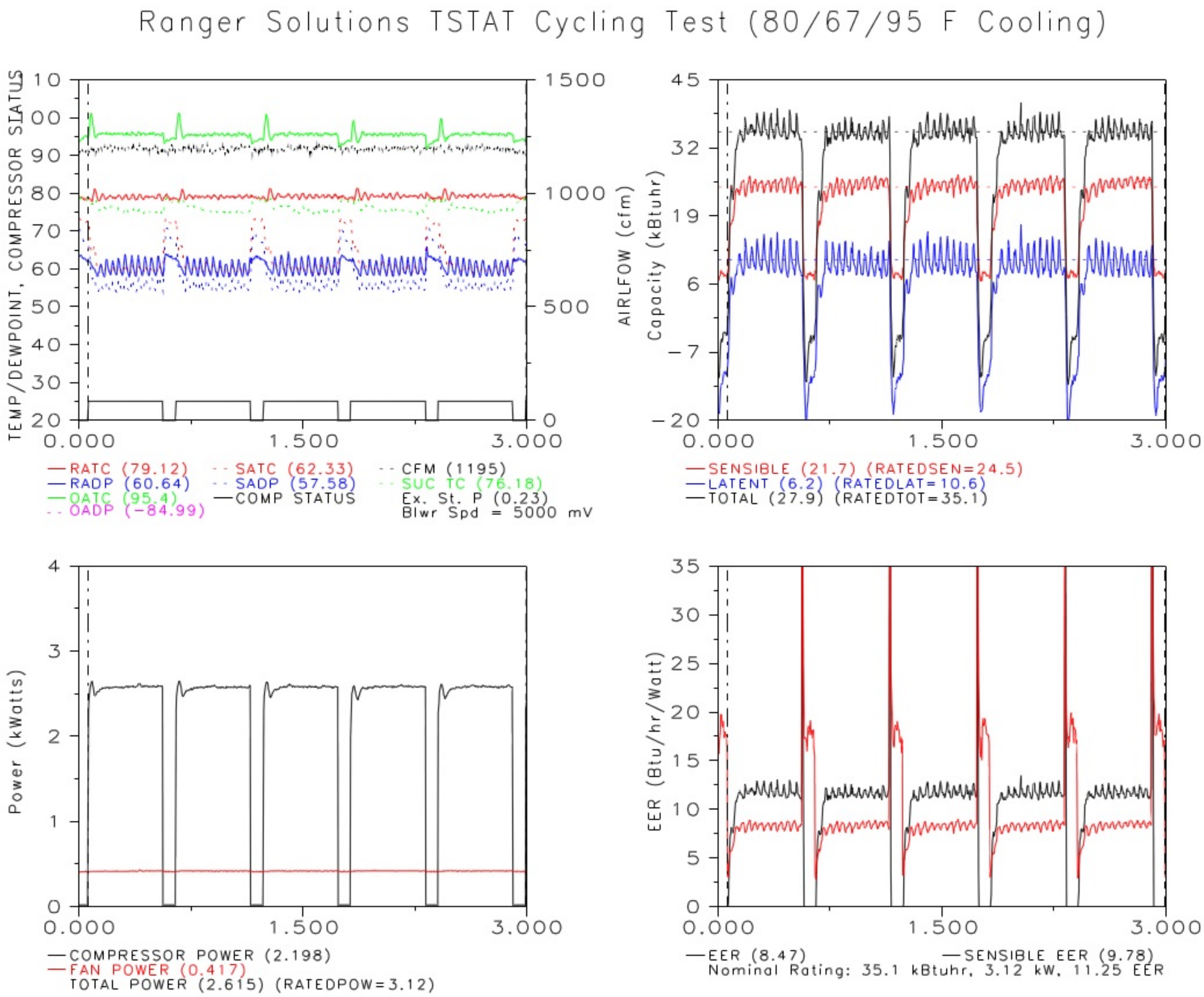

Figure 8. Initial Tests of the LVTS V1 Digital Thermostat at Full-Load Operating Conditions: 80/67/95.

To compare this operation to a standard thermostat, a portion of this test was averaged during the compressor on time period which would simulate a standard thermostat where compressor operation would not be interrupted during normal operation. In the following figure, the fourth compressor on cycle was used to provide this information. Note the double vertical dotted lines where the data is averaged over a single compressor on time period.

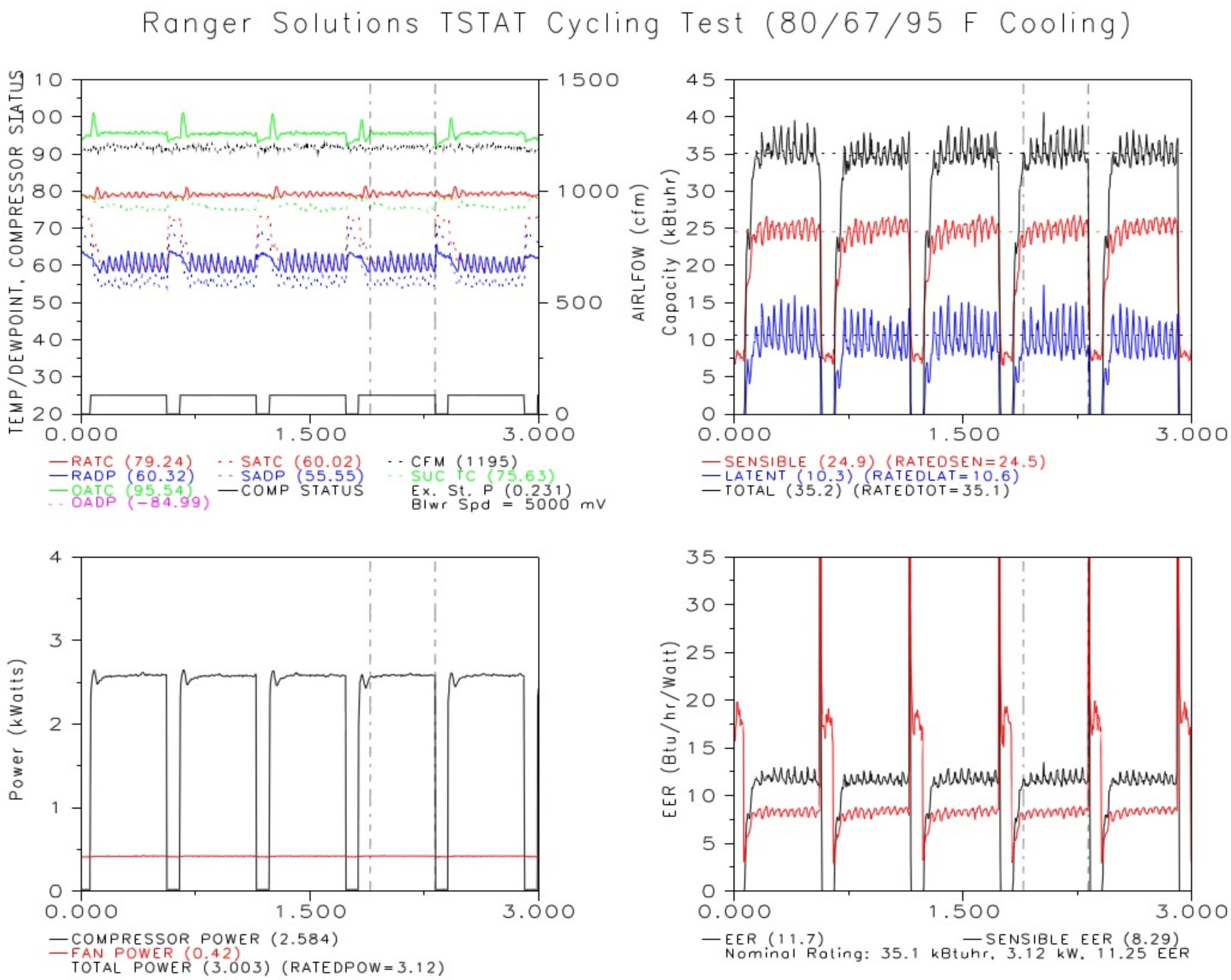

Figure 9. Initial Measurement of the Full-Load Operating Performance of the HVAC System.

In each of these figures, the results show that the control algorithm in the LVTS V1 thermostat disengages the compressor for a pre-programmed period of time at specific intervals. The results of this test are shown in Table 1. The measured data show that compressor power decreases by approximately 15 % and the fan power drops slightly due to a reduction in the amount of moisture on the cooling coil during the compressor off cycle (i.e., moisture evaporation reduced the coil pressure drop). As expected, the cooling capacity of the system is also reduced since the compressor was interrupted during normal operation. The total and sensible capacity were reduced by 20.7 and 12.9 %, respectively. The latent capacity (moisture) was impacted to a greater degree since during the compressor off cycle moisture is evaporated back into the supply air stream. For this reason, the latent capacity was reduced by 39.8%.

Table 1. Preliminary Results of Steady-State Performance at ANSI/AHRI Standard Rating Conditions

Test	Average Power (kW)			Avg. Capacity (kBtu/hr)		
	Comp	Fan	Total	Total	Sensible	Latent
Steady-State	2.585	0.42	3.003	35.2	24.9	10.3
LVTS V1	2.198	0.417	2.615	27.9	21.7	6.2
% Difference	**-14.97**	**-0.71**	**-12.92**	**-20.70**	**-12.85**	**-39.81**

The steady-state tests performed did not include the impact of the fan overrun strategy inherently included in the model LVTS V1 thermostat. To measure this operational aspect an additional test was performed to assess the part-load performance of the HVAC system as if this system were field installed. The environmental load centers were fixed at a specific duty cycle to emulate a fixed load on the system under test. The LVTS V1 digital thermostat was adjusted to provide a similar average indoor temperature during the measurement period. A target indoor temperature set point of 77 F was used for each of the following tests.

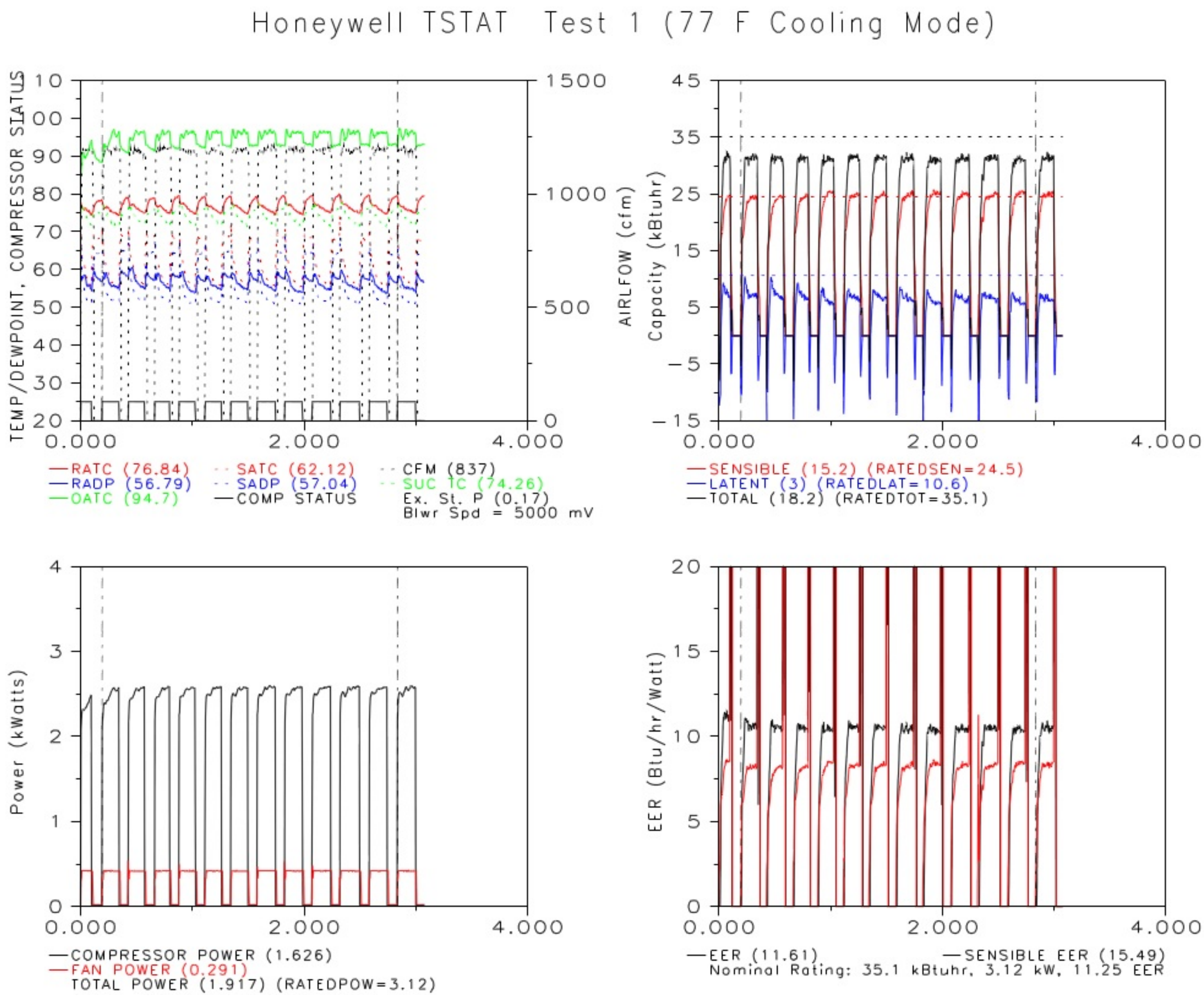

Figure 10. Part-Load Performance using the Honeywell Thermostat

Note in Figure 10 that the fan and compressor turned off at the same time during the compressor off cycle. This operational characteristic is common when fan overrun is not used. Also note the variation in indoor moisture levels (blue line) and outdoor temperature (green line). Given that this environmental change is designed for steady-state operation, controlling the conditions within each chamber is very difficult and can impact the results. This test was repeated for the

Ranger LVTS thermostat, as shown in Figure 11, to compare results and investigate whether this particular method of test is appropriate for accurately measuring system performance.

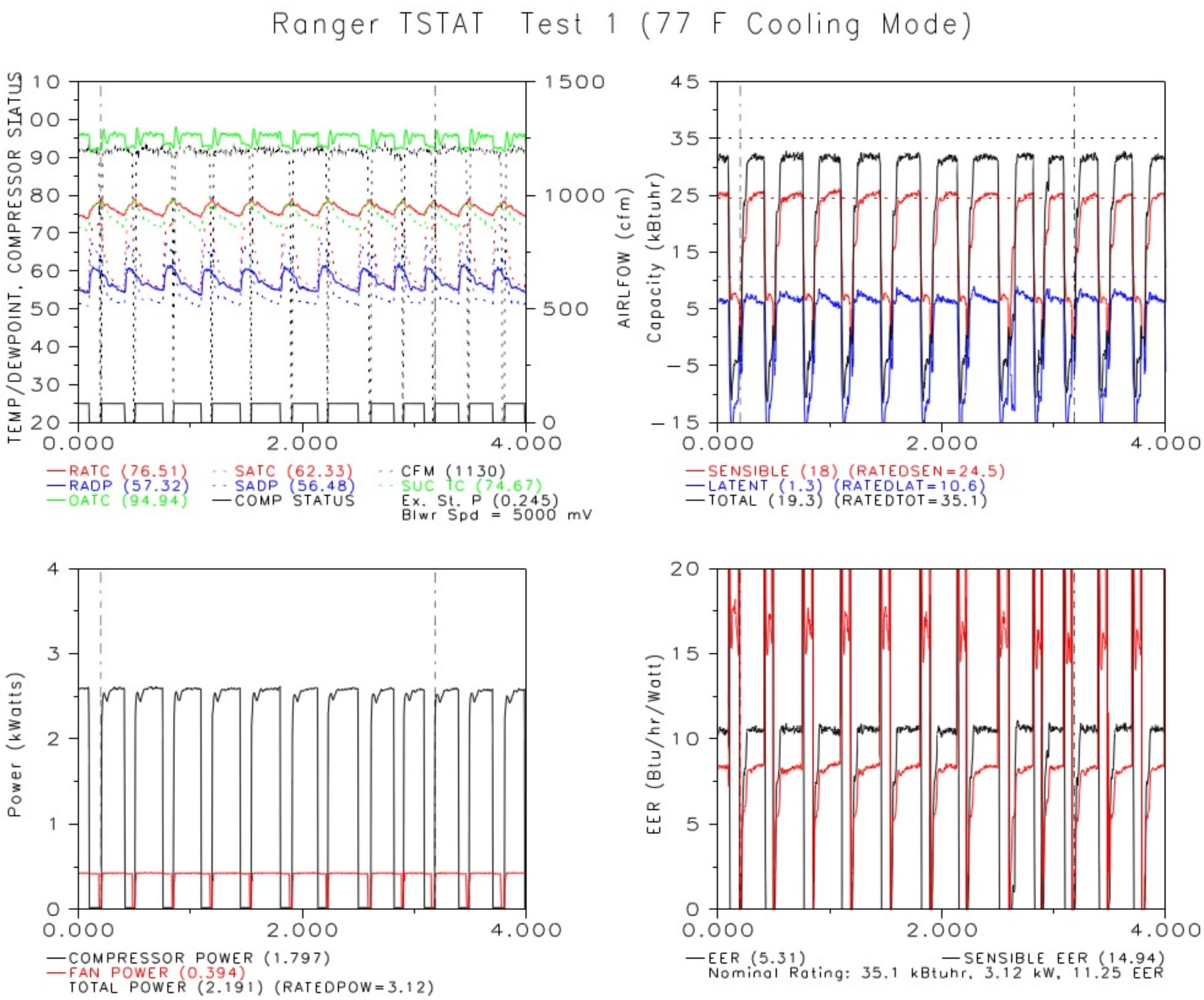

Figure 11. Part-Load performance using the Ranger LVTS Thermostat

Comparing the average power and cooling capacity for each of these tests in Table 2 shows an increase in energy use for the LVTS thermostat. To investigate why this result occurred, a review of the test chamber test protocol is warranted. For these tests, a cooling system is used to offset the condenser heat rejected to the outdoor chamber (see description for Figure 5). This cooling was re-routed to the indoor chamber during the compressor off-cycle to mitigate moisture excursions from set point. Since the cooling provided to the indoor chamber during the compressor off cycle is proportional to the off cycle timing of each thermostat, this additional load on the system is not constant for each thermostat since the off cycle operation is also not constant. Additionally, the size of the environmental chamber is small compared to a typical application where extreme changes in operating conditions would not occur. Clearly, this test does not provide a fair comparison since the loads on the two systems were not the same.

Table 2. Preliminary Results of Part-Load Performance of Tested Thermostats						
Test	Average Power (kW)			Avg. Capacity (kBtu/hr)		
	Comp	Fan	Total	Total	Sensible	Latent
Honeywell	1.626	0.291	1.917	18.2	15.2	3.0
LVTS V1	1.797	0.394	2.191	19.3	18.0	1.3
% Difference	**+10.52**	**+35.40**	**+14.29**	**+6.04**	**+18.42**	**-56.67**

The preliminary results of lab testing were inconclusive since the loads applied to each system under test were not identical during testing. For this reason, an alternate test method was warranted.

Side-by-Side Testing in a Residential Home Setting

Additional testing was performed in two side-by-side residential homes used to determine energy savings for retrofit studies. These homes are constructed identically, however, retrofit studies have already commenced and one of the homes includes carpeting. The additional carpeting in one home versus the other causes a difference in the interior cooling load. This difference was noticed while measuring energy data during the time where the Honeywell and Ranger LVTS thermostats were installed and tested in these residences.

Figure 12. Flexible Residential Test Facility at FSEC

The testing schedule for these homes is quite intensive, however, there was a period of 10 days where preparatory work was performed to ready for the next phase of testing. During this time period the Honeywell and Ranger LVTS thermostats were installed in the East and West home, respectively. Initial data was collected to investigate the potential for energy savings directly attributable to the Ranger LVTS algorithmic programming as shown in Figure 13. Each thermostat was set at 77 °F and allowed to stabilize for one day to allow building materials to adjust to the new indoor conditions.

Testing began on June 6, 2014 at 10:30 AM when the thermostats were installed. On the following day, at 9:30 AM, the Ranger LVTS thermostat temperature calibration was adjusted to bring the two homes to nearly the same temperature by adjusting the Ranger LVTS operating temperature upward by 1.2 °F. This calibration was not performed to align the thermostat temperature reading to the actual temperature, but to align the indoor temperatures to the same operating point. The measured data was averaged over the time period from June 7, 2014 at 11:00 AM through June 10, 2014 at 10:45 AM as shown in the figure.

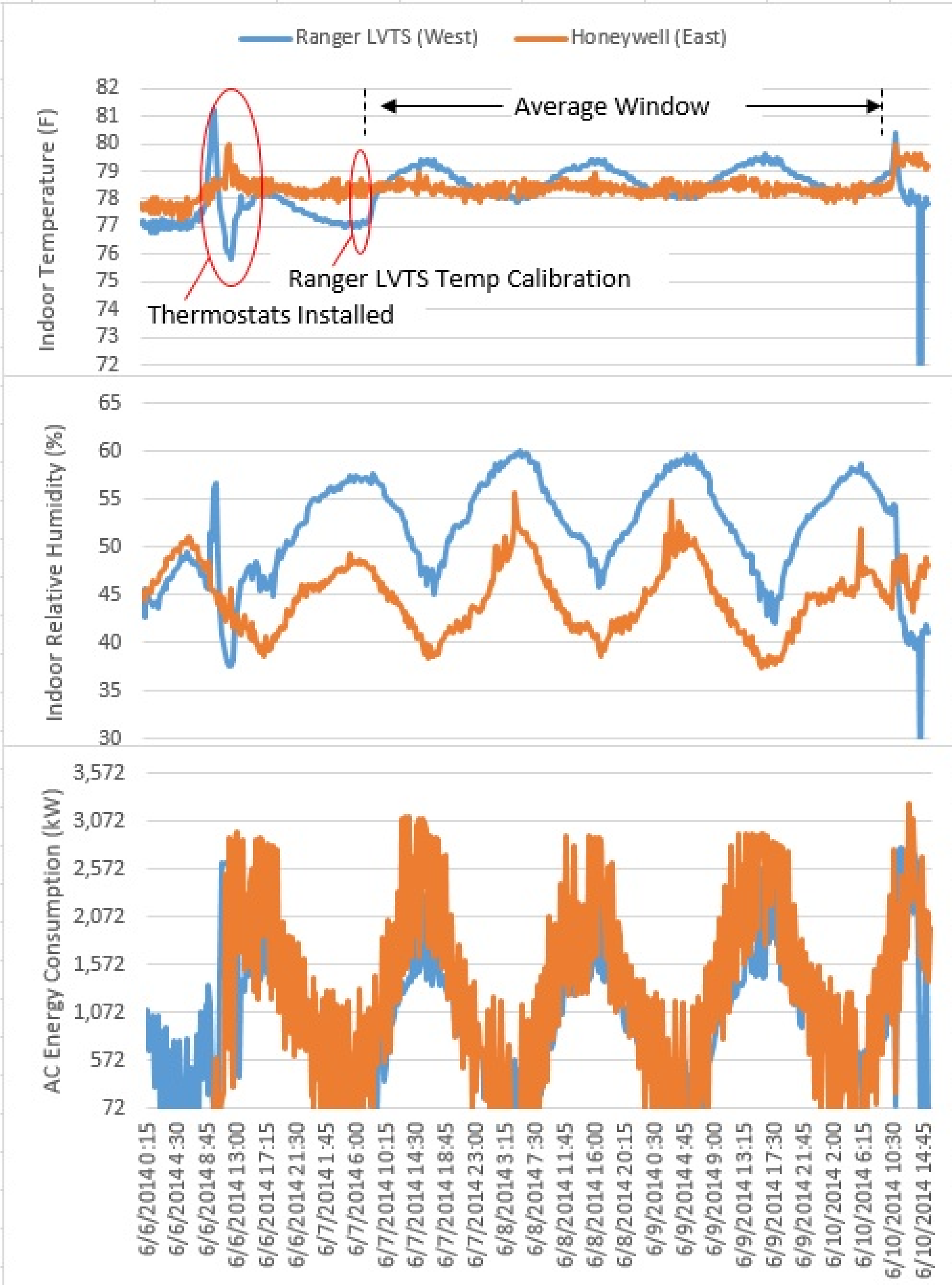

Figure 13. Initial Data Collection in a Residential Setting

Of interest in this data set is that the Ranger LVTS operating temperature was slightly higher than that of the Honeywell. In addition, the Honeywell thermostat was installed in the home with previously installed carpeting while the home where the Ranger LVTS thermostat was installed did not have carpeting. Additionally, the lack of carpeting in the test home with the Ranger LVTS creates a difference in cooling loads between these two homes and thereby causes a difference in performance. Whether the lack of carpeting increased or decreased cooling loads in that home is will be determined in future tests of retrofit measures.

The homes operated for the following 3 days to collect comparative performance data. The data shown in Figure 13 is summarized in Table 3 below.

Table 3. Summary of Initial Data Collected in Side-by-Side Test Homes

Thermostat	Average Condition			
	Indoor Temperature (°F)	Indoor Relative Humidity (%)	Air-conditioner Power (kW)	Condensate Removal Rate (lb/hr)
Honeywell	78.38	44.26	1298.9	1.38
LVTS V1	78.70	53.44	997.8	0.83
Difference	**+ 0.32**	**+ 9.18**	**-301.1**	**- 0.55**

Although the average indoor temperature in the home where the Ranger LVTS operated was slightly higher, thereby giving a slight advantage to the Ranger LVTS thermostat via an expected lower energy consumption, the fact that the Honeywell home had carpeting would eliminate most or all of that advantage if the carpeting reduced cooling loads during these tests. Alternately, if carpeting increased cooling loads during these tests, these results would be misleading.

Regardless of the differences in home furnishings and operating conditions, the Ranger LVTS thermostat showed an average reduction in power of 301 Watts or 23%. Given that the Ranger LVTS thermostat uses fan overrun as one of the mechanisms for savings, it is interesting to note that the average indoor relative humidity was 9.2 % RH higher and the average condensate removal rate was 0.55 lb/hr lower than that measured using the Honeywell thermostat. This result is expected given the use of latent recovery as a means to offset cooling loads.

One other characteristic difference in the temperature profiles for each thermostat tested is that the Ranger LVTS thermostat shows a diurnal temperature profile while the Honeywell maintains a more stable operating temperature profile. The manufacturer later pointed out that using the heat pump setting for a straight-cool air conditioner could cause this behavior and recommended that the thermostat switch be changed from HP to normal which means the test had to be repeated to verify that the operational temperature profile was corrected and to collect additional performance data to compare to that already collected.

This test procedure was performed relatively quickly to determine the efficacy of using existing homes as a test bed for measuring energy savings for thermostats and there was still several days available to perform another test. For the next test, the thermostat switch was moved from HP to Normal. In addition, an investigation into another enhancement to the thermostat algorithm could be performed. It was determined that the performance data collected during the next test would be measured at a lower indoor operating temperature to highlight the manufacturer’s enhancement. The thermostat’s would also be moved to the adjacent home to see if the impact of carpeting could be measured along with the improvement in AC performance due to the thermostat control algorithm.

The first step was to change the thermostat locations. Notice in Figure 14 that the Honeywell thermostat is now located in the West house and the graphic trace representing the Honeywell thermostat is now blue. Similarly, the Ranger LVTS is now located in the East house and is represented by the orange trace. Also note that the diurnal indoor temperature profile has somewhat moderated due to the setting change suggested by the manufacturer. The final step was to reduce the indoor operating temperature set point to 72 °F which occurred on June 7, 2014 at 4:15 PM.

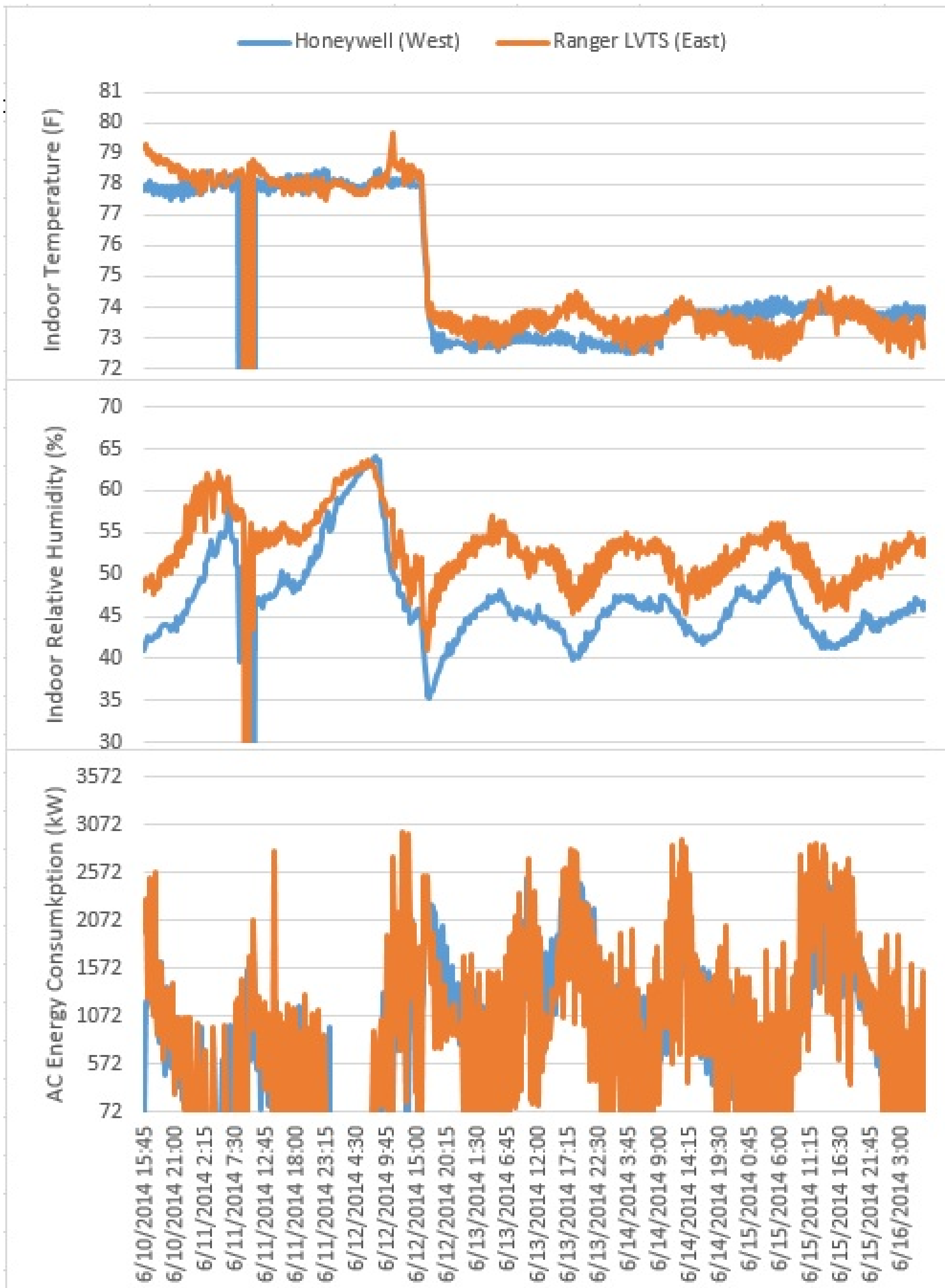

Figure 14. Final Data Collection in a Residential Setting

The homes were allowed to operate at this setting for one day. It was apparent that the indoor operating temperature in the home with the Honeywell thermostat was about 0.5 to 1.0 °F lower than the home with the Ranger LVTS thermostat (see indoor temperature data during June 12-13 in Figure 14). For this reason, the Honeywell temperature set point was increased 1 °F (since there are only integer representations of temperature on this thermostat) on June 14, 2014 at 9:30 AM.

Averaging this new set of data provides the following results. The data set including all collected data occurred from June 13, 2014 at 7:15 AM to June 16, 2014 at 7:00 AM. The data set after the Honeywell thermostat set point temperature was adjusted upward from 72 °F to 73 °F occurred from June 14, 2014 12:00 PM to June 16, 2014 at 7:00 AM.

Table 4. Summary of Final Data Collected in Side-by-Side Test Homes

Time Period	Thermostat	Average Condition			
		Indoor Temperature (°F)	Indoor Relative Humidity (%)	Air-conditioner Power (kW)	Condensate Removal Rate (lb/hr)
6/13/2014 at 7:15 AM to end	Honeywell	73.48	44.94	1157.1	1.37
	LVTS V1	73.49	51.41	1159.8	1.21
	Difference	**+ 0.01**	**+ 6.47**	**+ 2.7**	**- 0.16**
6/14/2014 at 12:00 PM to end	Honeywell	73.86	44.94	1032.8	1.19
	LVTS V1	73.46	51.24	1132.6	1.16
	Difference	**- 0.40**	**+ 6.30**	**+ 99.8**	**- 0.03**

Clearly, the same trend in energy savings was not realized in this final test. Each AC system operated at nearly the same average energy use with a slightly higher energy consumption for the Ranger LVTS thermostat at the end of the available test period. There are several possible reasons for these findings. First, the homes were in different stages of retrofit and had not yet been validated as to the actual energy use attributed to these retrofits. Second, there were at times activity in one of the homes while the other home may not have had the same level of activity. Third, the accelerated attempt to collect measured performance data over a very short period of time may have introduced lagging effects that take a much longer period of time to converge (i.e., large changes in temperature or relative humidity may impact material sensible and latent heat storage).

Although this test is one of the most reasonable methodologies available for testing this type of advanced control module, these tests were completed in a very short period of time and a longer test period is presumably needed to accurately measure differences in energy use. In addition, the use of a single home with alternating use of each thermostat should provide a more fair comparison of the expected energy use with each thermostat.

Conclusions and Recommendations

Testing an AC system in an environmental lab is typically performed at steady-state conditions while these tests are intended to measure the actual operating efficiencies of a system operating at part-load conditions. Laboratory testing did not prove fruitful given the complexities associated with testing a cycling AC system. For example, the abrupt change in cooling capacity when the compressor turns off causes rapid changes in environmental temperature and moisture levels that are difficult to control. The change in temperature and moisture levels during a laboratory test procedure should replicate what actually happens in the field and the measured performance during these preliminary tests did not accurately reflect expected field performance.

For these reasons, the following recommendations should provide a more meaningful representation of energy savings for this specific technology:

- Select a residential home to measure the energy use corresponding to each thermostat for an extended period of time.
- Alternate each thermostat's operation, in the same home, for 1- or 2-week periods where each thermostat will operating at similar outdoor conditions.
- Include periods of time where the thermostat is operating at a reasonable indoor temperature (e.g., 76 °F) and periods of time where the indoor operating temperature is at some lower set point temperature (e.g., 73 °F).
- Include a period of time where outdoor conditions are changing, for example summer through spring or winter through fall, to measure performance over a wide range of outdoor temperatures.
- Accumulate measured data as daily averages or summations and compare a sufficiently large data set to provide a statistical representation of the energy consumed with each thermostat. The daily energy use should be compared to average outdoor temperature as well as the average daily temperature difference (i.e., Temperature difference = Outdoor temperature – Indoor temperature).