Final Report for Field Evaluation of PATH Technologies

January 2006

Evaluation of an OASys Indirect-Direct Evaporative Cooler Retrofit

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Executive Summary

With funding from HUD's Partnership for Advancing Technology in Housing (PATH) program, Steven Winter Associates (SWA) has conducted a field evaluation of the OASys indirect-direct evaporative cooling system manufactured by Speakman CRS. In dry climates, evaporative cooling offers drastic energy and peak demand reductions compared to conventional air conditioning. Although it is well suited to the Western US, application of this technology has not been wide spread. One of the main barriers to the greater implementation of evaporative cooling systems is their difficulty in meeting occupant comfort requirements on design days when cooling loads are highest. This unacceptable performance during design conditions has prevented the energy benefits of evaporative systems during the entire cooling season from being realized. There is a resulting stigma among homeowners and builders that conventional single stage "swamp" cooler technologies are inferior to AC. Recently the OASys, a (two stage) indirect-direct evaporative cooler (IDEC) has been commercialized by Speakman CRS. In order to boost cooling capacity, the OASys system employs an indirect cooling stage where supply air is lowered without an increase in humidity. Supply air is then further cooled with moisture addition in a traditional direct evaporative cooling stage.

In 2006 Speakman began to manufacture a production OASys model – the first of these new units was retrofitted in a Sacramento area PATH demonstration house. Before the OASys retrofit, the 43-year old house had been cooled exclusively by a 5-ton AC system. The house also included an existing (but no longer functional) roof mounted evaporative cooler. SWA evaluated the drop-in replacement of the existing evaporative cooler with the OASys, interviewing the HVAC contractor and homeowner and installing long term monitoring equipment in order to quantify:

- OASys and AC energy use
- OASys cooling capacity over a range of outdoor conditions
- Indoor house temperature and relative humidity

This evaluation effort was co-funded through the Building America Program and the Sacramento Municipal Utility District (SMUD). Results indicate that (1) The cooling capacity of the OASys is comparable to that of a typical 2-ton AC system and (2) The Energy Efficiency Ratio (EER) of the OASys is roughly 3x greater than that of a SEER 14 AC system.

It is of course somewhat difficult to make a true "apples to apples" comparison of the OASys and an AC system. The explanation of systemic advantages associated with evaporative coolers to an industry that is traditionally only familiar with "tons" and "SEER" is a significant but surmountable market education challenge faced by Speakman CRS. At the same time, there are limitations to the application of the OASys. In the demonstration house, the homeowners tended to prefer to use a back-up 5-ton AC system when outdoor temperature exceeded 100 ^{o}F. These results are of course specific to the comfort preferences of the particular homeowners and the characteristics of the demonstration house. A more efficient building envelope with low-e glazing would have reduced cooling loads and extended the range of outdoor conditions under which the OASys could deliver acceptable comfort.

Overview of Test House

Prior to this PATH evaluation, the 2,150 square foot, 43 year-old evaluation house included an existing rooftop evaporative cooler that was no longer functional (Figure 1). As a result, before the OASys retrofit, the house was cooled exclusively by a 5-ton split AC system. The existing evaporative cooler supplied air to the house via an 18” ID flex duct (enclosed in a 20” OD sheet metal duct). For the OASys retrofit, this ductwork and utility connections associated were taken advantage of, resulting in a straightforward “drop-in” OASys installation. Pressure relief in the house during evaporative cooling is provided by ceiling mounted “Up-dux” barometric dampers. Airflow thru the observably leaky building envelope may also provide a significant amount of pressure relief during evaporative cooling. Conditioned air from the evaporative cooler is supplied to a central hallway diffuser and circulates throughout the house before being exhausted through the Up-dux dampers to a vented attic or directly to the outside thru cracks in the building envelope. Windows in the three bedroom, slab-on-grade, single story house are single pane clear glass. Approximate wall and ceiling insulation levels are R-11 and R-19 respectively. The house is heated with a furnace with supply and return ductwork that is also used by the AC system.

Figure 1. Existing Evaporative Cooler

Figure 2. Ceiling Mounted Up-dux

Evaporative coolers have a much larger market share in older houses than in new construction. As such, the retrofit market is a particularly attractive starting point for the implementation of the next generation of high performance evaporative cooling equipment such as the OASys. Many homeowners with existing roof mounted evaporative coolers eventually replace this equipment with vapor compression air conditioning. By taking advantage of existing utility connections and roof penetrations, the installation of new evaporative equipment is simplified in houses with existing single stage equipment. If in these retrofit applications, it can also be demonstrated that newer two-stage equipment can result in acceptable comfort, it will give homeowners a viable alternative that both costs less to install *and* uses significantly less energy than vapor compression air conditioners.

OASys Installation and Operation

After the existing evaporative cooler was removed, the OASys was installed by Madding Air, an HVAC contractor out of Davis, CA. The installation went smoothly even though it was their first experience installing this unit. In their shop, Madding Air fabricated a sheet metal supply air plenum to transition between the OASys outlet and the existing supply air duct. Figure 3 illustrates how the OASys functions on a schematic level. A plug fan draws outdoor air in through an intake located at the top of the unit. The majority of this air (the primary air-stream) is channeled through the dry side of an indirect heat exchanger. A smaller fraction of this air (the secondary air-stream) is evaporatively cooled and flows through the wet side of this indirect heat exchanger before being exhausted through the grille near the bottom of the unit. The indirect cooling stage results in sensible cooling of the primary air stream without moisture addition. After passing through the indirect heat exchanger, the primary air-stream is further cooled in a traditional direct evaporative cooling stage passing through a wetted media before being supplied to the house. A sump is located below both indirect and direct cooling stages. A pump circulates water from this sump to a drip manifold at the top of the indirect and direct cooling stages.

Figure 3. OASys Side View

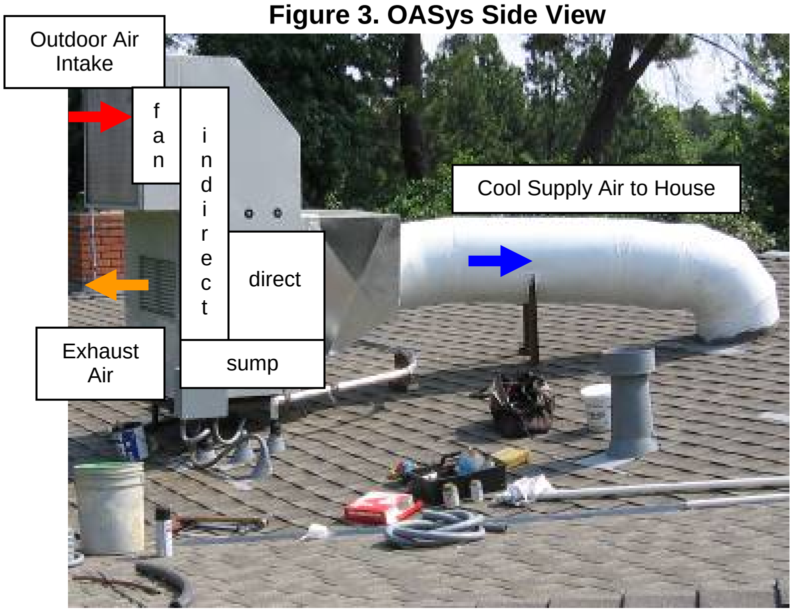


Figure 4. OASys Rear View

The single plug fan is the only driving force for airflow through the unit. Thus the balance between the primary air-stream (supplied to the house) and the secondary air-stream (exhausted to the outside) is dependent on the flow resistances at the two outlets of the unit. More resistance in the supply air ductwork will result in more airflow through the secondary exhaust grille. Conversely, closing down a balancing damper on the secondary exhaust grille (Figure 4), will result in a greater fraction of airflow to the house. This balancing damper therefore allows contractors to make adjustments on-site in response to field conditions. Closing the exhaust grille damper will result in more airflow to the house but also somewhat more humid supply air. Opening the exhaust grille damper will result in less airflow to the house but also somewhat less humid supply air. Water and electrical connections are noted in Figure 4.

An RJ45 cable (Figure 6) is used to connect the OASys unit with an indoor thermostat (Figure 5). This thermostat allows for several different modes of operation. The system can be operated in Auto mode to maintain a user adjustable temperature set-point. In this case, the thermostat internal logic selects the appropriate OASys fan speed (1, 2 or 3). In addition, the system can be operated in continuous evaporative cooling mode or in continuous ventilation cooling mode with a user selected fan speed. Ventilation mode is for use when the outdoor temperature drops below the indoor temperature such as during cool desert nights. In this case, the pump does not operate and the OASys acts like a whole house fan. Night time ventilation cooling can be useful in cooling down the mass of a building in order to reduce next day cooling requirements. In addition, night ventilation provides excellent indoor air quality at a time when a house is most likely to be fully occupied.

Figure 5. OASys Thermostat

Figure 6. RJ45 Cable

Monitoring Equipment Installation

In June, 2006 SWA installed a Campbell Scientific CR10X data logger along with the following sensors to evaluate whole house cooling performance:

OASys Cooling Capacity (Supply Air Duct)

- Humirel Temperature and Relative Humidity Sensor x 3
- Air Monitor Volu-Probe for CFM measurement – used in conjunction with Setra Model 264
- Setra Model 264 Pressure Transducer (0 - 0.10” WC, 0.25% accuracy) to measure duct velocity pressure for calculating supply air CFM

Electricity Use

- Pulse Output WattNode to measure OASys electricity use
- Pulse Output Watt Node to measure AC system electricity use

OASys Water Use

- Omega FTB602 Ultra Low Flow Water Sensor

Outdoor Ambient House Conditions

- Humirel Temperature / RH sensor with radiation shield

Indoor Ambient House Conditions

- HOBO Temperature / RH sensors in three different rooms of the house

This long term monitoring equipment was operational as of June 30, 2006. Data was downloaded weekly from the site via a wireless modem connection. The OASys itself was activated on July 5, 2006 and its performance was monitored through the duration of the 2006 cooling season.

Figure 7. Supply Air Duct Sensors

Figure 8. Electricity Use & Outdoor Temp / RH Sensors

Results & Discussion – OASys Equipment Performance

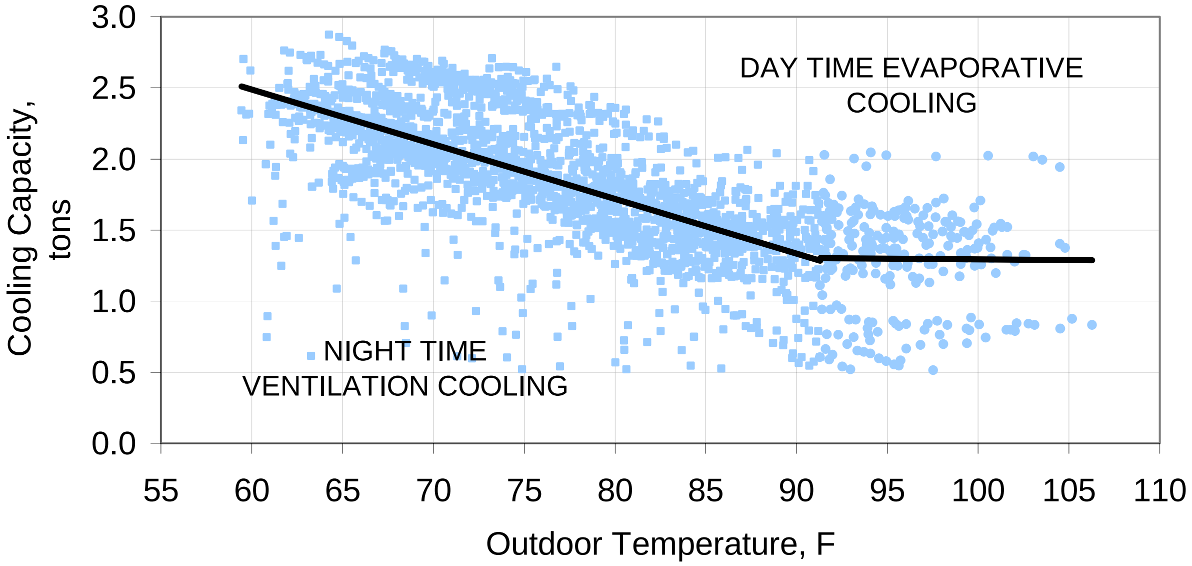
A comparison of the OASys system performance at the three different fan speeds is presented in Table 1. As was discussed in the Installation and Operation section, OASys supply airflow is somewhat dependent on the resistance of supply ductwork and house back pressure. The Table 1 results correspond with the installation in the demonstration house that includes a 20' long, 18" (flex) supply duct (enclosed in a hard duct) with a 90^o elbow. Greater resistance in supply air ductwork will result in less supply airflow to a house with the OASys. Pressure relief in the house is provided by envelope leakage and the four Up-dux barometric dampers that exhaust house air to a vented attic.

Table 1. OASys Performance at Different Fan Speeds

Fan Speed	Electric Demand	Supply Airflow	Supply Plenum Static Pressure	House Pressure (with respect to outdoors)
1	440 Watts	1090 CFM	24 Pa	4 Pa
2	500 Watts	1260 CFM	33 Pa	4.5 Pa
3	650 Watts	1380 CFM	40 Pa	5 Pa

In Figure 9, OASys cooling capacity[1] measurements for July, August and September of 2006 are plotted versus outdoor temperature. This graph thus represents OASys performance over a wide range of conditions and should be useful in understanding how the OASys is likely to perform in other hot and dry climate locations. The range in cooling capacity measured at any one outdoor ambient temperature is primarily due to corresponding differences in outdoor humidity. The cooling capacity data points at lower outdoor ambient temperatures are associated with night ventilation cooling mode.

Figure 9. OASys Cooling Capacity vs. Outdoor Ambient Temperature



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[1] Cooling capacity calculated based on an indoor temperature of 80 ^oF, where:
Btu/hr = (80 ^oF – Supply Air Temperature) x Supply Air CFM x 1.08

It is important to note that the OASys cooling tonnage measured is representative of the actual sensible cooling delivered to the house at a particular outdoor temperature. The measurements of OASys cooling capacity are therefore different from what builders and homeowners typically think of when it comes to an AC systems "nominal" tonnage. For instance, AC system nominal tonnage values do not account for:

- <u>Energy losses due to leaky ducts running through hot attics.</u> Typical AC systems include extensive supply and return ducts that allow for the room by room distribution of air throughout the house. In hot and dry climates, the majority of this ductwork is usually located in vented attics. The resulting distribution losses can result in the cooling energy actually delivered to the house ("tons at the register") to be 15% lower than the cooling capacity of the AC equipment (immediately downstream of the indoor coil)[2]. The OASys system includes minimal supply ducting and no return ducts. In addition, the OASys cooling capacity measurements presented in Figure 10 are representative of the conditions near the end of the supply duct and therefore very nearly indicate the actual cooling delivered to the house.
- <u>The decrease in AC system cooling capacity at higher outdoor temperatures.</u> AC equipment SEER rating tests are performed at mild outdoor conditions (82 ^{o}F). As a result, the cooling capacities that are reflected in AC equipment model numbers do not account for the degradation in performance at more extreme outdoor temperatures that are often typical in hot and dry climates. According to Carrier's published data for one nominal "2-ton" SEER 14 system, cooling capacity is 8% lower at 105 ^{o}F than at 85 ^{o}F.
- <u>The ratio of sensible cooling capacity to latent cooling capacity.</u> In dry climates, sensible capacity is most critical since dehumidification needs tend to be minimal. It is sensible capacity that actually lowers the temperature of a house and determines the run time of AC equipment. With typical AC systems, 70 – 75% of the cooling delivered is sensible (the balance is latent capacity).[3] With the OASys, 100% of the cooling delivered is sensible.

The above described *system* effects can combine to result in a significant degradation in the cooling capacity of typical AC equipment and should be taken into account when comparing AC nominal ratings to the OASys performance results. For instance, a nominal 2-ton AC system that loses 8% of its nominal cooling capacity during extreme outdoor conditions, loses another 15% of energy due to duct distribution losses and has a sensible heat ratio of 0.70 will only result in the delivery of 1.1 tons of sensible cooling to the house (a net 55% decrease in cooling compared to the nominal 2-ton rating!). For comparative purposes, Figure 10 includes Carrier's published performance data for a 2-ton SEER 14 split AC system presented alongside the OASys results[4]. In this figure, Carrier's published equipment data for total cooling capacity and sensible cooling

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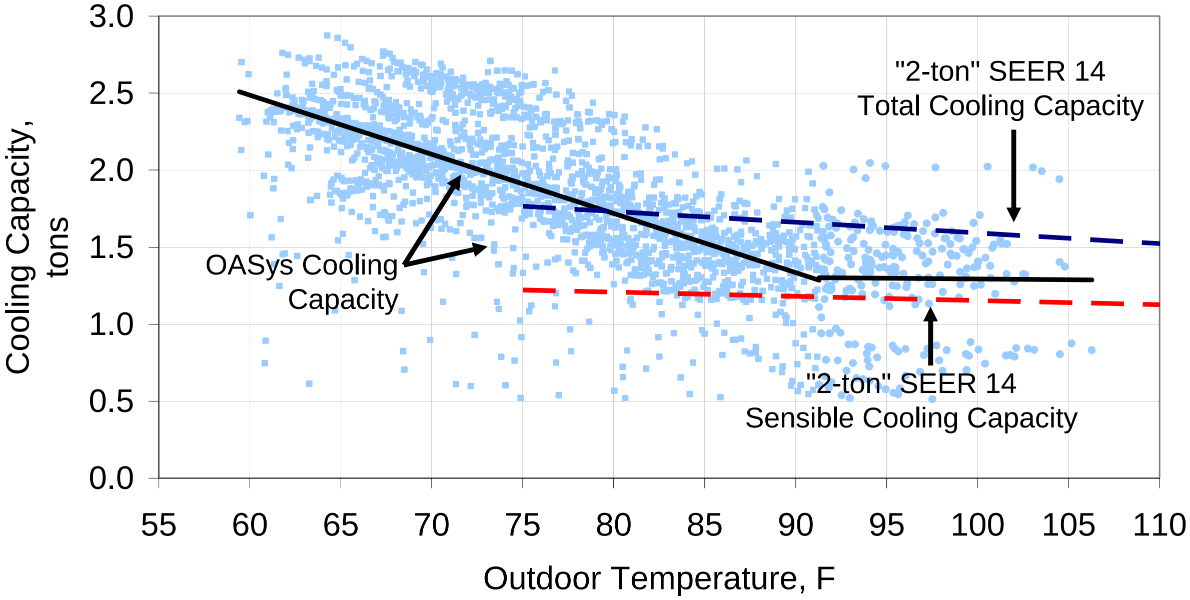
[2] Building America Research Benchmark Definition 12/29/2004 for single story houses with attic ducts

[3] The California Energy Commission is currently funding a research project to develop an AC system that is tailored to hot and dry climates. A primary design goal of this project is to maximize equipment sensible cooling capacity. www.hdac-des-pier.com/.

[4] Carrier Published Performance Ratings for 38TRA 024340 condenser with MVP040-14 furnace @ 800 CFM supply airflow and return air conditions of 80 ^{o}F DB / 67 ^{o}F WB.

capacity at different outdoor temperatures has been reduced by 15% to account for duct losses that occur in real houses. From Figure 10, it is clear that the OASys typically provides more sensible cooling capacity but less total cooling capacity than the nominal 2-ton split AC system when outdoor temperatures are greater than 80 ^{o}F. In night ventilation cooling mode when outdoor temperature is less than 80 ^{o}F, the OASys cooling capacity is greater than even the total cooling capacity provided by the nominal 2-ton split AC system.

Figure 10. OASys & 2-ton SEER 14 Cooling Capacity vs. Outdoor Ambient Temperature



AC systems field performance can also suffer as a result of improper refrigerant charge level and low air handler airflow when the indoor fan is not matched correctly with the ductwork. The OASys of course does not use any refrigerant and requires minimal ductwork, thereby eliminating the potential for charging problems and minimizing the potential for low airflow issues.

In Figure 11, OASys Energy Efficiency Ratio (EER)[5] measurements for July, August and September of 2006 are plotted versus outdoor temperature. These results are compared to Carrier's published EER ratings for a nominal 2-ton SEER 14 split AC system (downgraded by 15% for attic duct losses to reflect effective field performance). As is also the case with AC equipment, OASys efficiency decrease as outdoor temperature increases. Average measurements of OASys EER during day time evaporative cooling are more than 3x greater than the performance of the SEER 14 AC equipment at corresponding outdoor temperatures.

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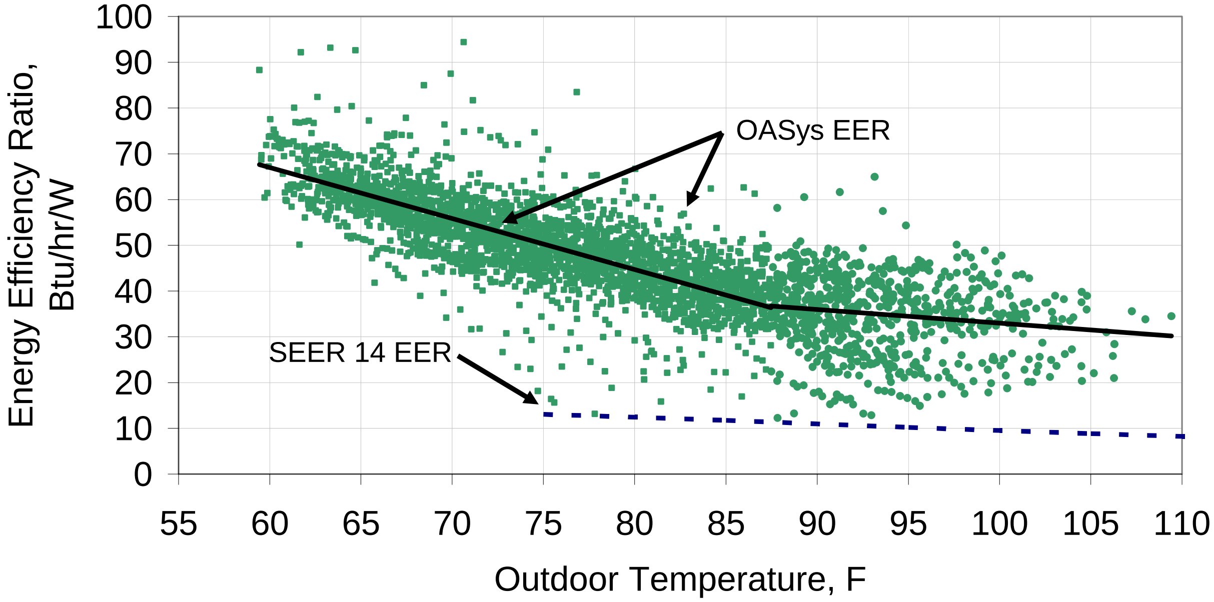
[5] EER = Cooling Capacity based on 80 ^{o}F indoor temperature (Btu/hr) / Electric Demand (W)

Figure 11. OASys & SEER 14 System EER vs. Outdoor Ambient Temperature



Results & Discussion – Whole House Comfort Performance

Ultimately, comfort is the most important performance aspect of any cooling system. The Sacramento house provided a unique opportunity to evaluate the comfort performance of the OASys in that the homeowners always had the option of operating their existing 5-ton AC system. While the homeowners were very enthusiastic about the OASys, there were instances during the summer when they chose to operate the AC system instead. As has been previously discussed, the envelope of the 43 year old house includes single pane windows and minimal wall and ceiling insulation. These house characteristics combined with record heat wave conditions during parts of the summer allowed for an opportunity to push the OASys to the limit and evaluate its performance under worst case conditions.

Figure 12 presents the indoor temperature (orange) and relative humidity (blue) conditions in the house during a typical summer week along with outdoor temperature (red). The electric demand due to the AC (black) and the OASys (green) are also noted on a separate scale on the right side of the graph. During this week, the OASys was operated in both day time evaporative cooling and night ventilation cooling modes. Over the course of this seven day period, the homeowners only operated the AC for a few hours during the evening of 8/3 when the outdoor ambient temperature reached 100 ^{o}F (close to the ASHRAE design temperature of 101 ^{o}F for Sacramento). During the six afternoon periods when the OASys alone was used for cooling, indoor temperatures did not exceed 76 ^{o}F. Corresponding relative humidity was between 60% and 70% RH.

Figure 12. Cooling Equipment Operation & Whole House Comfort – Typical Week

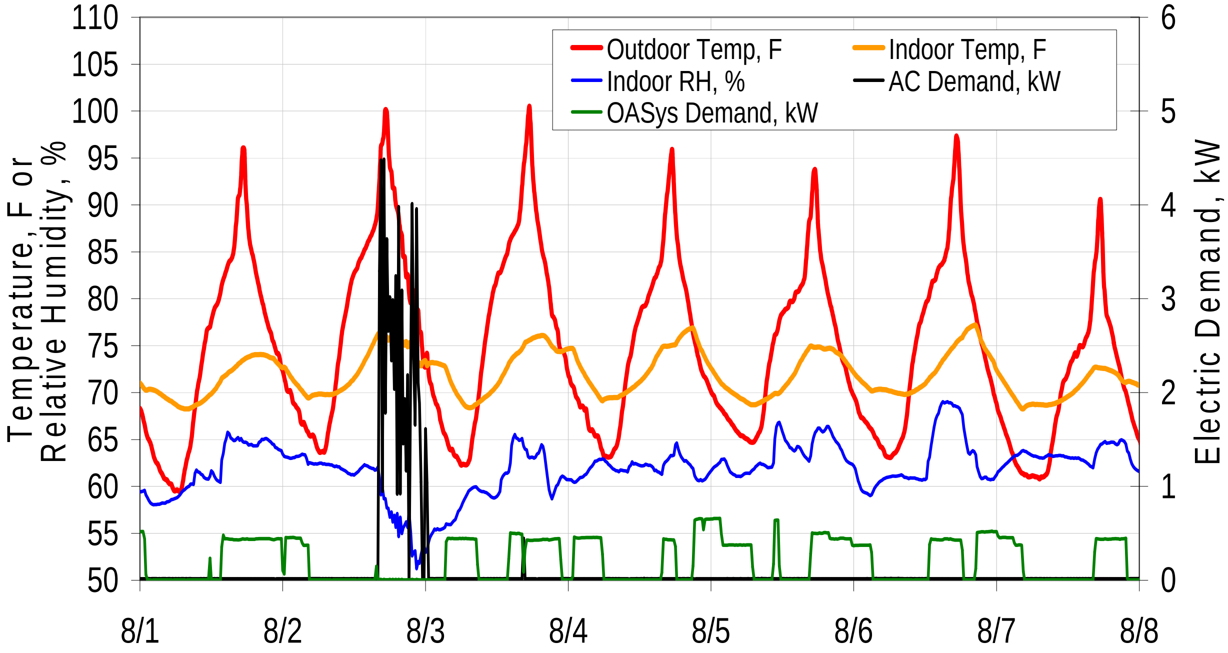
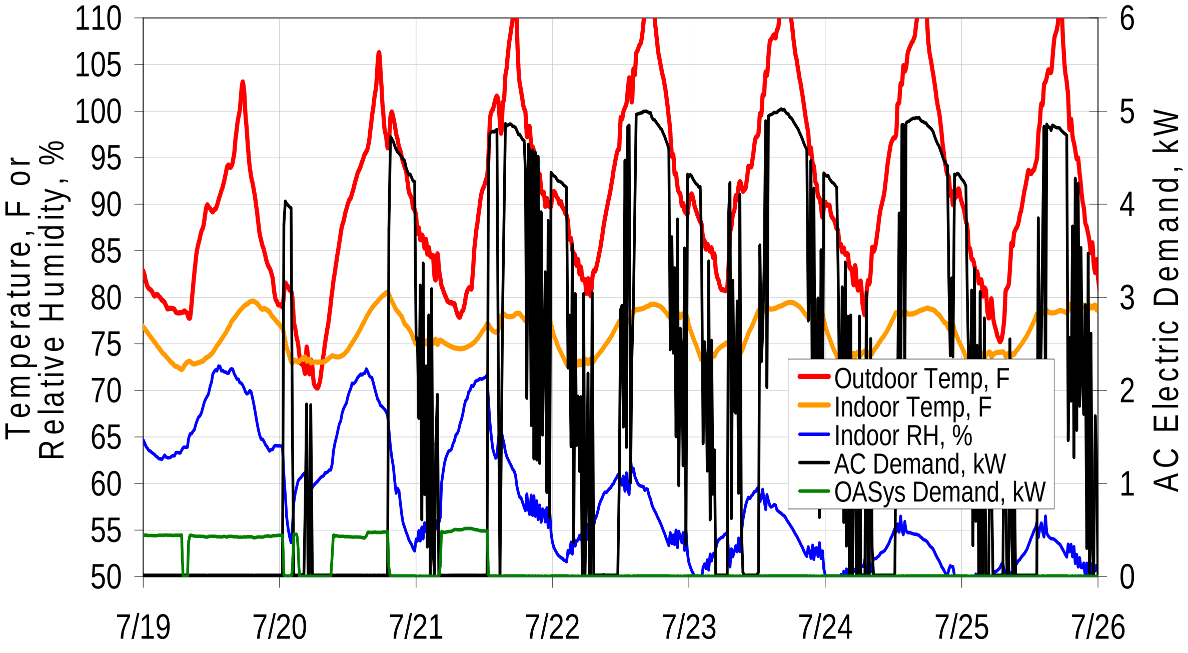


Figure 13 is identical to Figure 12 except that it focuses on the most extreme period in the summer, representing record heat wave conditions with afternoon temperatures exceeding the Sacramento design temperature on every day.

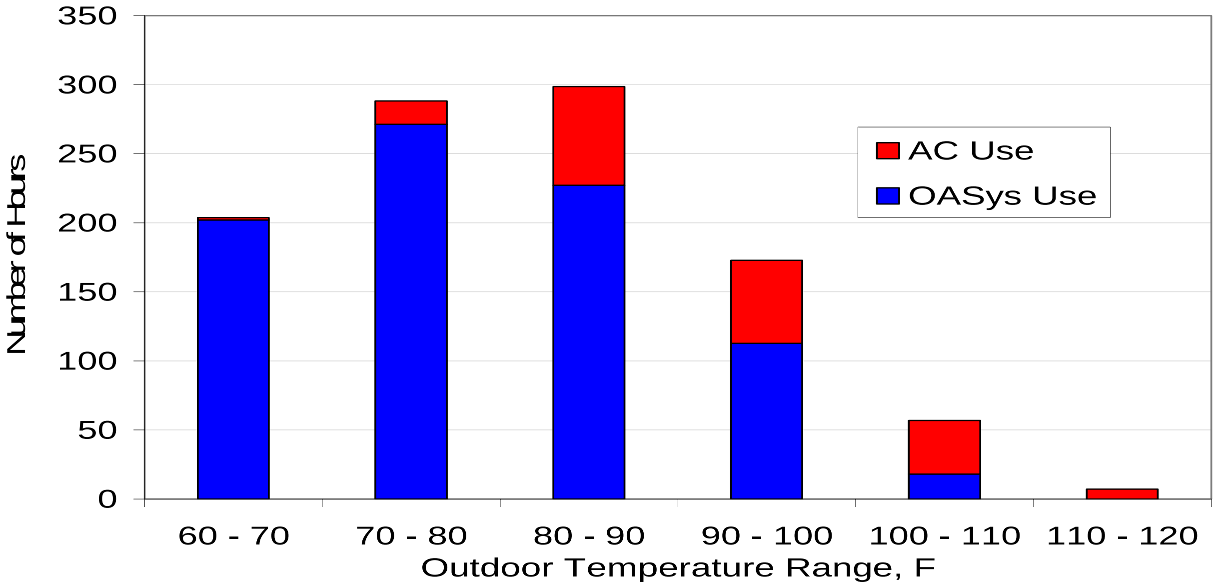
Figure 13. Cooling Equipment Operation & Whole House Comfort – Extreme Week



During the *coolest* day of this extreme period (7/19), outdoor temperature reached 103 ^{o}F and indoor conditions were both warm and humid. As a result, the homeowners turned the AC ON during the early morning of 7/20 in order to improve comfort in the house. On 7/20, the homeowners operated the OASys throughout the day. During this period, indoor conditions with the OASys were again warm and humid and by 7:00 PM the homeowners turned the AC ON in order to improve comfort. On 7/21 the, OASys was operated until 12:30 PM and then the AC was turned ON. The homeowner continued to exclusively rely on the AC for the rest of the heat wave. During the hottest days of this heat wave, continuous operation of the 5-ton AC system barely kept the house temperature below 80 ^{o}F. Another indication of the severity of this heat wave is that there were only a few hours during the entire period in which night time outdoor temperature dropped below indoor temperature, resulting in no potential for night ventilation cooling.

Figures 12 and 13 represent snapshots of the cooling system operational choices made by the homeowners during two particular weeks in the summer. By presenting the frequency of OASys and AC operation over different outdoor temperature ranges during the entire summer, Figure 14 provides a broader view of the homeowner comfort preferences. In this bar chart, the numbers of hours with significant OASys operation are indicated in blue for the different temperature outdoor temperature ranges. The corresponding hours of significant AC operation are indicated in red[6]. This analysis was performed over a period starting on July 5 (when the OASys was installed) and ending on September 30. From this figure, it is clear that when outdoor temperature was below 100 ^{o}F, the homeowners preferred the OASys while when outdoor temperature was above 100 ^{o}F, they preferred the AC system.

Figure 14. Homeowner Comfort Preferences
Frequency of OASys and AC Operation Over Different Outdoor Temperature Ranges



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[6] A period of “significant” AC use was defined as a 15-minute interval with an average AC electric demand greater than 500 Watts. A period of “significant” OASys use is defined as a period with an average OASys electric demand greater than 100 Watts.

Conclusions

The drop-in installation of the OASys unit in a Sacramento house with existing rooftop evaporative cooler connections went smoothly. Monitoring results collected from this house were used to quantify OASys performance. In addition, SWA conducted an analysis in order to compare OASys performance with that of a typical AC system. The results of this analysis indicate that the cooling capacity of the OASys is comparable to that of a typical 2-ton AC system and that the Energy Efficiency Ratio (EER) of the OASys is roughly 3x greater than that of a SEER 14 AC system. It is of course somewhat difficult to make a true “apples to apples” comparison of the OASys and an AC system. By continually introducing 1000 – 1400 CFM of outdoor air into the house, the OASys can result in superior indoor air quality than an AC system. In addition, the actual field efficiency of AC systems is often lower than published ratings due to improper refrigerant charge and low air handler airflow when the indoor fan is not matched correctly with ductwork. The OASys does not use any refrigerant and requires minimal ductwork, thereby eliminating the potential for charging problems and minimizing the potential for low airflow issues. The explanation of these systemic performance advantages associated with evaporative coolers to an industry that is traditionally only familiar with “tons” and “SEER” is a significant but surmountable market education challenge faced by Speakman CRS.

There are also limitations to the application of the OASys. In the 2,150 square foot, 43 year old demonstration house with single pane glazing, the homeowners tended to prefer to use a back-up 5-ton AC system when outdoor temperature exceeded 100 ^{o}F. These results are of course specific to the comfort preferences of the particular homeowners and the characteristics of the demonstration house. However in a house that requires a 5-ton AC system, it is clearly unrealistic to expect the OASys to maintain comfort throughout the summer. A more efficient building envelope with low-e glazing would have reduced cooling loads and extended the range of outdoor conditions under which the OASys could deliver acceptable comfort.