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An Innovative Product's Path to Market.

The influence of laboratory and field evaluations on adoption and implementation

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ABSTRACT

This paper studies the path of a new widget through stages of evaluations. The device is an inexpensive AC modification that successively passed through development tests, field evaluations, and laboratory evaluations on its way to implementation.

The device can produce energy savings in the world's dry climates. This modification extends the indoor fan run time at the end of the compressor cycle. While the potential savings look quite promising, there are also limitations to the application of this technology. The most notable limitation is the duct conduction heat gains for ACs located in hot attics.

The most recent evaluation extended throughout one cooling season. Ten single family homes were monitored with and without the fan control retrofits. All ten sites initially were tested with a device that varied the delay based on the ΔT between supply air and return air. Seven sites later received a device that varied the fan off delay time in proportion to the compressor run time. Fan and compressor run times, energy use, indoor and outdoor temperature and humidity were monitored.

Six of the sites receiving the proportional control demonstrated measureable energy savings. The seventh site produced inconclusive results due to erratic thermostat adjustments. Savings were not observed at the temperature differential controlled sites. The proportional controlled device experienced no installation or operational problems and produced average savings of 16% compared to the pre-retrofit condition.

The purpose of this research was to determine the realization rate of laboratory projected savings in the field with common duct systems in hot ambient conditions.

Introduction

Dry climates like California, the western United States and other climates that exist around the world need air conditioners that maximize indoor temperature reductions for the amount of energy used. Currently available air conditioners are designed to meet national performance standards that are based on "average" cooling season weather conditions across the entire United States. These systems are currently not optimized to maximize indoor temperature reductions under dry ambient conditions. As a result, substantial energy is wasted by unnecessary removal of moisture (latent capacity) provided by air conditioners in dry climates. A portion of the moisture removed can be recovered as temperature reduction (sensible capacity) by re-evaporating it off of the indoor coil at the end of the air conditioner cycle. This is accomplished by keeping the indoor fan on for a period of time after the compressor has turned off.

Dry Climate regions are characterized by low humidity during the summer months, with much of the region also experiencing very hot daytime temperatures which drive high cooling costs and large peaks in electrical demand. Current off the shelf air conditioners are designed to meet national performance standards that are based on "average" cooling season weather conditions across the whole United States. This design gives little or no attention to the performance of air conditioners at dry conditions. As a result, substantial energy is wasted by air conditioners' removal of moisture when it is not needed in dry climates.

All air conditioners do two things to the air:

1) Reduce the air temperature (Sensible Capacity)
2) Remove moisture (Latent Capacity)

Many new air conditioners/furnaces have an available fan time delay, but the amount of time used is not long enough to recover all of the capacity left as moisture on the evaporator coil. The common fan time delay is designed to raise the SEER[1] of the air conditioner. The SEER cycling test is performed with a completely dry evaporator coil. As a result, the short fan time delay only takes advantage of the coil's thermal mass to increase the SEER, but does not take advantage of latent recovery for dry climates.

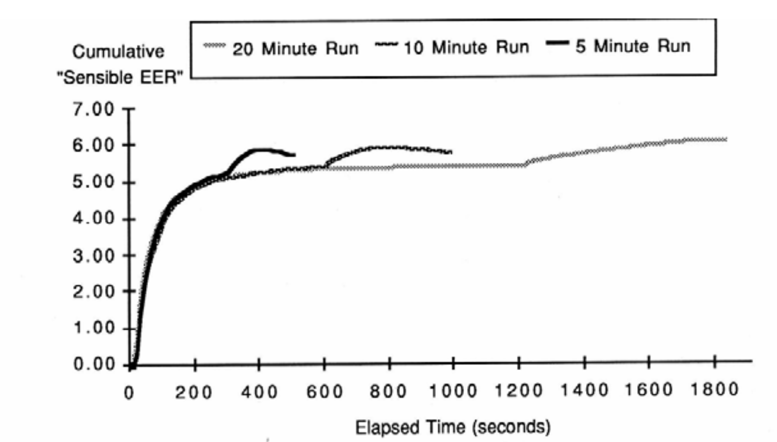
Recovering the latent capacity results in a higher sensible heat ratio and may raise indoor relative humidity slightly. In dry climates, the outdoor moisture content (absolute humidity) is less than the moisture content at indoor design conditions. The inevitable envelope infiltration of outdoor air lowers the indoor relative humidity, reducing or eliminating the need for the air conditioner to dehumidify. These dry climates are represented in Table 1 of ACCA Manual J[2] under the column "Grains Difference 50% RH".

Increasing the amount of airflow across the evaporator coil will increase the coil's temperature and the sensible heat ratio, but this approach presents challenges for increasing efficiency due to typical restrictive ductwork. Duct modifications can cost in excess of $1000. At less than $100 installed cost, a proportional time delay relay is a more cost effective approach to optimizing an air conditioner for a hot dry climate.

Background

The history of the device begins in 1990. In that year it was reported that: *"Continuing to run the fan at the end of the air conditioner cycle would add sensible cooling. The increase in sensible cooling could be up to 20%. This cooling is done by returning some moisture to the inside air. Additional research is necessary to determine whether this retrofit is effective in climates in PG&E's service territory."* (Proctor 1990, viii)

The 1990 study monitored air conditioner delivered capacity over different cycle lengths and fan off times to investigate the savings potential for fan-off time delays. Results for three of the "forced air signature tests" are shown in Figure 1. The AC signature tests were run on five of the systems before and after the air conditioners were brought to full available airflow and correct refrigerant charge. The potential cooling savings for a 5 minute compressor run time ranged from 10.9% to 19.9% in the pre-repair condition and from 4.1% to 21.1% in the post-repair condition.



[1] Seasonal Energy Efficiency Ratio
[2] Air Conditioning Contractors of America heating and cooling load estimation method

Figure 1. Air Conditioner Signature Test Showing Fan Off Delay Effect on Sensible Efficiency (ibid, 21, fig. 6)

In the following year the tests were expanded to 250 homes. One group of these homes was submetered and had a fan time delay that flipped between 5 minutes and 0 minutes. These homes showed a significant range of energy savings averaging 13%. Two homes showed increases in energy usage. The range of energy savings indicated that a fixed 5 minute delay could not be used universally.

In the following years proposals were made for research funding and pilot tests of the fan time delay for dry climates. For years there was neither the interest nor the funding to pursue this product.

In 2003 the California Energy Commission had renewed interest in air conditioners designed and selected for their performance in hot dry conditions. This interest led to a project to build and test two air conditioners (one package unit, one split unit) followed by field tests of production air conditioners with components specifically chosen to produce high sensible EER as needed for hot dry climates.

Walking Into the Valley of Death[3]

Hot Dry AC Laboratory Tests

The Hot Dry Air Conditioner (HDAC) Project was sponsored by the California Energy Commission PIER Research Program. It included laboratory tests in both steady state and cycling under a variety of indoor and outdoor conditions. Both the split air conditioner and the package air conditioner were run through a series of tests to further investigate the efficacy of the fan time delay. Both units showed significant improvements in sensible EER with the extended time delay. Figure 2 shows the result for the split unit, and Figure 3 shows the result for the package unit.

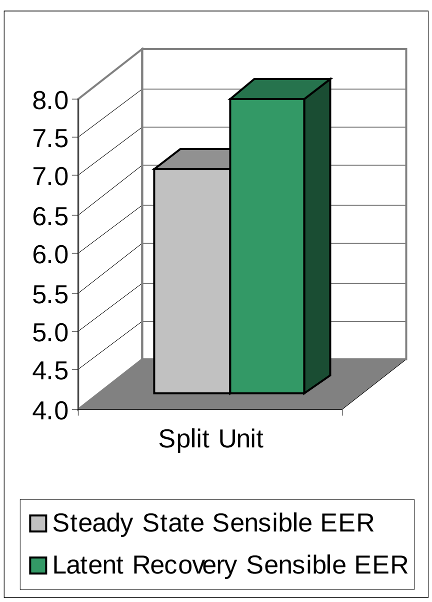


Figure 2. Extended Fan Time Delay Effect on Sensible EER at 115ºF Outside, 80ºF/67ºF Inside (Buntine, Proctor & Knight 2008, 71 fig 52)

[3] The innovation or startup "Valley of Death" is described as the period between technology creation and rising (hopefully sustainable) positive cash flow.

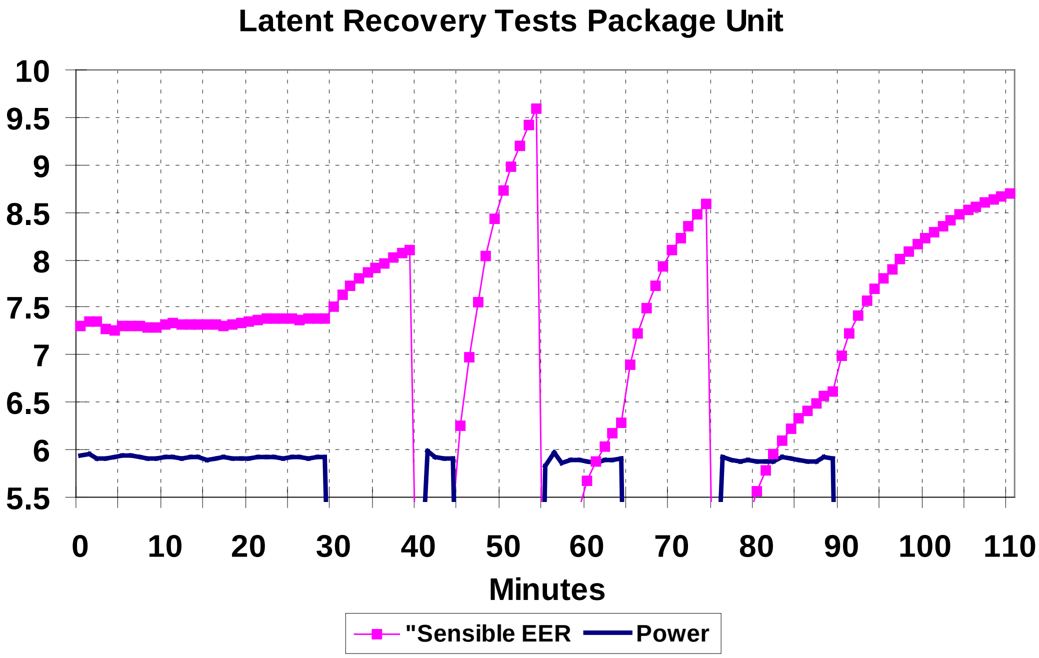


Figure 3. Cumulative Sensible EER for Package Unit with Latent Recovery Fan Time Delay for Compressor Run Times from 5 Minutes to 30 Minutes (Buntine, Proctor & Knight 2008, 66 fig 48)

As elapsed time proceeds (X axis) the unit is running at steady state with a sensible EER of 7.4. At 30 minutes the compressor shuts off (the watt draw drops from 5.9 kW to the indoor fan only power). From the 30 minute mark, the indoor fan continues to run for 10 minutes evaporating water off the coil and delivering sensible capacity. At the end of the "tail" the overall sensible EER has risen to 8.1.

At the 40 minute mark, the compressor comes on and runs for 5 minutes. At the end of that 5 minute compressor cycle, the cumulative sensible EER is less than 6. From the 45 minute mark, the indoor fan continues to run for 10 minutes delivering sensible capacity. At the end of the "tail" the over sensible EER has risen to 9.6.

At the 55 minute mark, the compressor comes on and runs for 10 minutes. At the end of that 10 minute compressor cycle, the cumulative sensible EER is delivering sensible capacity. At the end of the "tail" the overall sensible EER has risen to 8.6. It is evident that the longer compressor on cycle would require a longer "tail" to approach the efficiency achieved by the 5 minute compressor on cycle within a 10 minute "tail."

At the 75 minute mark, the compressor comes on and runs for 15 minutes. At the end of that 15 minute compressor cycle, the cumulative sensible EER is 6.6. From the 90 minute mark, the indoor fan continues to run for 20 minutes delivering sensible capacity. At the end of the "tail," the overall sensible EER has risen 8.7.

Hot Dry AC Field Tests

The design of the PIER project anticipated a number of the differences between standard laboratory tests and field conditions. The PIER project tested the proof of concept HDACs at the duct airflow restrictions common to the field, at temperatures approached or achieved at peak conditions, and under both moderate and dry indoor conditions. Nevertheless laboratory testing does not cover the full range of conditions experienced in the field, including occupant behavior, duct system performance, thermostat effects, and most importantly – air conditioner cycling. Based on the laboratory test success, a number of manufacturers were approached to provide air conditioners that would approach the HDAC performance by selection of existing components or modifications to their existing equipment. A total of seven air conditioners were tested with a pre/post experimental design. Newly installed and checked SEER 13 air conditioners were monitored for half a season and the specially selected equipment was monitored for the remainder of the season.

As part of this field test eight air conditioners were tested with methods of converting the latent capacity present as water on the coil at the end of the compressor cycle into useful sensible capacity. The two methods to recover the latent cooling capacity were investigated in this study: compressor pause and extended tail (blower off time delay). Either of these methods could be applied in the unit from the manufacturer or as a retrofit.

Compressor Pause. In Compressor Pause Mode (CPM) the compressor is cycled at regular intervals to reduce the amount of water that drains off of the coil. For example, the compressor will run for 6 minutes and the fan will continue to run for 5 minutes to evaporate the condensate left on the coil. This cycle repeats until the cooling demand is met. The compressor is stopped before the energy (in the water) on the evaporator coil is lost down the drain. The fan portion of the cycle then recovers the sensible capacity by evaporating the condensate. The Standard Unit at one location was tested with CPM. The unit showed a 0.5 point Sensible EER improvement. The unit was run in CPM on some of the hottest days of the season and, due to the close sizing of the air conditioner, it was not able to meet the cooling demand during the peak hours. In cases where the unit is "correctly sized" there needs to be an automatic override of CPM if it is to be used.

Extended Tail (Fan Off Time Delay). At each site, tail lengths (blower off delays) and tail blower speeds were tested to improve the sensible efficiency by evaporating the water from the evaporator coil at the end of the compressor cycle. The data acquisition system recorded the efficiency of each partial cycle including the instantaneous efficiency just before the fan stopped. When the compressor is off the efficiency can be quite high since there is far less electrical energy being expended. The end of fan cycle (EOC) efficiency is a measure of the remaining potential from continuing to run the fan.

Figure 4 displays the end of fan cycle efficiency for the standard unit at one location with an ECM motor using a 5 minute low speed tail. Note that the EOC sensible efficiency is greater than 10.

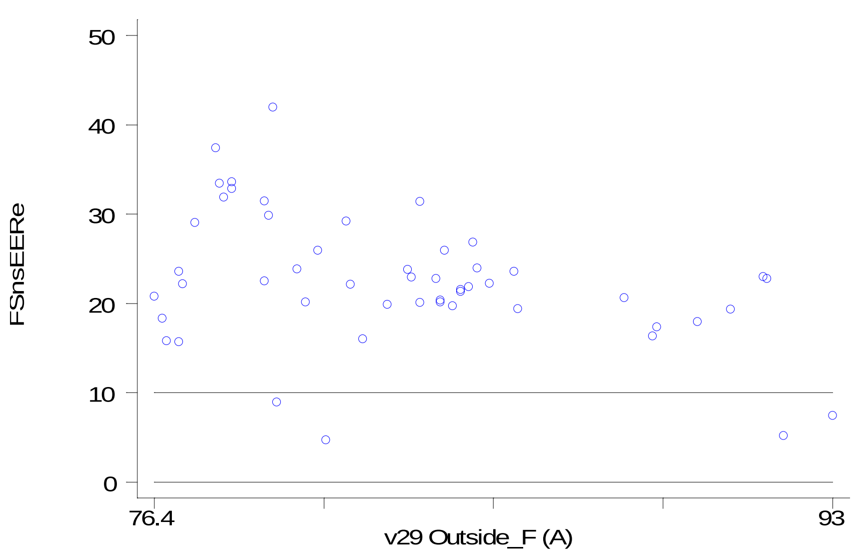


Figure 4. End of Fan Cycle Sensible EER vs. Outside Temperature (PG&E ETP 2007, 22 fig 4)

The results varied among the 8 units with some units seeing large improvements in Sensible EERs when extended tails were implemented and others seeing decreases in Sensible EERs if tail lengths were too long. These efficiencies were measured at the units based on the difference between supply and return plenum temperatures and the airflow.

These tests showed that the length of the fan off delay could be as much as 5 minutes for units with PSC fan motors if the compressor cycle length was at least 9 minutes long. Figure 5 shows that the EOC Sensible EER exceeds 7 for a 5 minute tail for the vast majority of the recorded cycles.

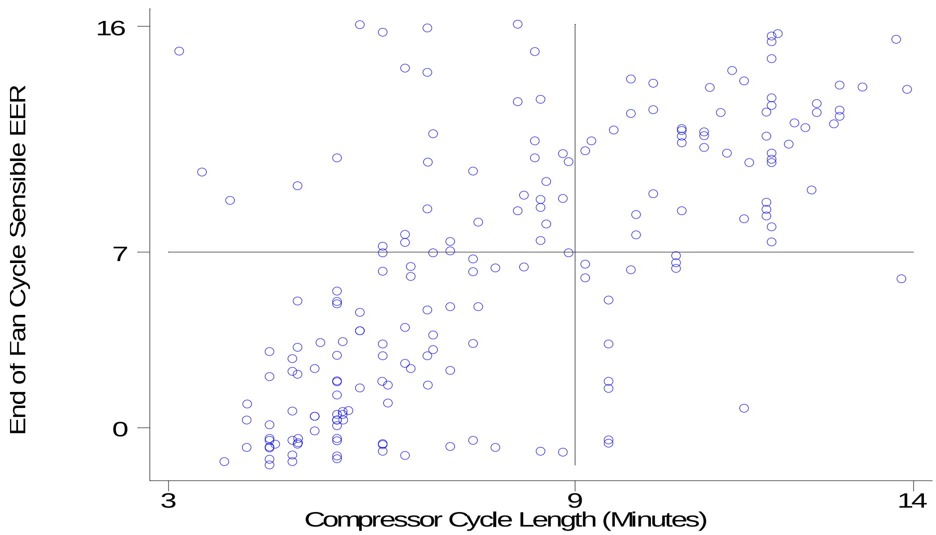


Figure 5. End of Fan Cycle Sensible EER vs. Compressor Cycle Length (PG&E ETP 2007, 23 fig 5)

Based on the PIER field test an algorithm was developed that related the fan run time to the compressor run time (an indicator of evaporator coil moisture loading).

First Full Scale Implementation

In 2006, Pacific Gas and Electric Company was interested in new innovative products. Given the low cost of this measure and available energy savings it was a natural add on to their existing residential air conditioner charge and airflow program. One manufacturer of time delay relays had an existing relay that could be programmed in the factory to follow the algorithm that related the fan run time to the compressor run time.

Implementation of the program revealed how unexpected challenges can occur with products. Initially the product consisted solely of the time delay relay with the proprietary algorithm. The technicians had to use standard wire and wire connectors to complete the installation. This approach produced problems. The technicians miswired an unacceptable number of units. To address this issue the relays were repackaged with a manufactured wiring harness with wires of the appropriate colors for proper installation.

A second challenge appeared – certain digital thermostats bleed a small current through the fan signal at all times. The solid state relay saw that bleed as a fan signal and ran continuously. To address this issue the relay was changed to include a small electromechanical relay that did not activate from the bleed current. Simultaneously monitoring of the measure was continued at three field sites to further define the limits of the measure. (PG&E ETP 2008)

Intertek Laboratory Tests

In the winter of 2009 various time delay lengths were tested at the psychometric test facility in Plano Texas. This facility is regularly used by air conditioning manufacturers to certify their units to AHRI. The facility consists of a climate controlled indoor room and a climate controlled outdoor room. The facility has the ability to cover a wide range of climate conditions from very hot summer conditions to very cold winter conditions. These tests were sponsored by the California Investor Owned Utilities in support of codes and standards.

The test results produced more clarity concerning the interactions of airflow, compressor run times and fan delay times. There were three series of tests covering variations in the evaporator airflow. Each series followed the standard SEER cycling test sequence: compressor on 6 minutes, compressor off 24 minutes, compressor on 6 minutes, compressor off 24 minutes, etc. repeating for five cycles. The five cycles had increasingly longer fan delays as shown in Table 1.

Table 1. Fan Off Delays During SEER Type Cycling Test

Cycle	**First**	**Second**	**Third**	**Fourth**	**Fifth**
Fan Off Time	0 sec	105 sec	200 sec	300 sec	610 sec

The outdoor and indoor conditions were different from the standard SEER cycling test in order to produce more realistic answers. The outdoor temperature was set at 95°F (SEER is at 82°F). The indoor conditions were held at 80°F dry bulb, 67°F wet bulb (50% Rh). These conditions produce a wet coil as is common in normal operation even in dry climates. The standard SEER test is run with a totally dry indoor coil, which is artificially accomplished by indoor conditions of 80°F dry bulb, 57°F wet bulb.

The results are summarized in the following subsections.

Effect of Airflow on Sensible EER[4]. Generally latent capacity is reduced and sensible capacity is increased at higher airflows. These tests confirmed what prior tests have shown. Higher airflow produced higher sensible capacity. The downside of higher airflows has always been the increase in fan watt draw necessary to obtain the higher airflows. These tests showed that, within the tested range of airflow, the Sensible EER increased in spite of the higher fan watt draws. Figure 6 shows the increased Sensible EER due to airflow in two identical tests with a 100 second fan delay.

[4] Sensible EER is the product of the steady-state Energy Efficiency Ratio (EER) and the Sensible Heat Ratio (SHR).

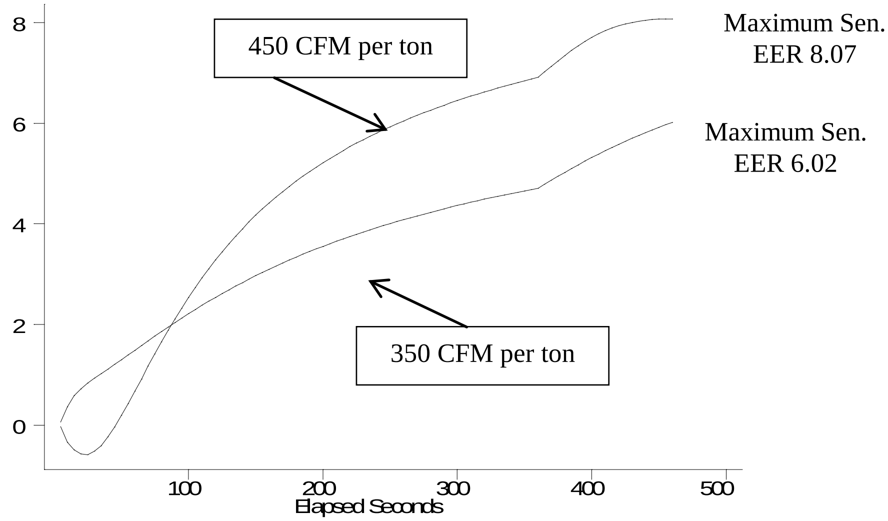


Figure 6. Airflow Effect on Sensible EER with a PSC Fan Motor (CUSC 2010, 24 figure 17)

In Figure 6 the Sensible EER for the 450 CFM scenario is higher during the compressor part of the cycle. The higher efficiency is due to a larger sensible capacity. When the higher airflows are accomplished, there is less moisture on the coil at the end of the cycle (less latent storage) and the length of the fan delay is limited by the amount of moisture on the coil.

When the performance of the unit is limited by the combination of the duct system and the equipment to 350 CFM per ton or less, as is most common in field studies, there is more moisture on the coil and the fan delay can be lengthened to achieve higher Sensible EER.

Low Fan Speed during the Fan Delay. It has been proposed that lowering the fan speed during the fan delay combined with an electrically commutated motor would produce even higher Sensible EERs due to the low watt draw of the BPM. This hypothesis was investigated with multiple tests. Figure 7 compares two otherwise identical tests--one with the fan speed at 350 CFM per ton and one with 216 CFM per ton during the time delay. As is evidenced there, in spite of the lower watt draw of the motor at the lower speed, the sensible EER is better for any reasonable length fan delay.

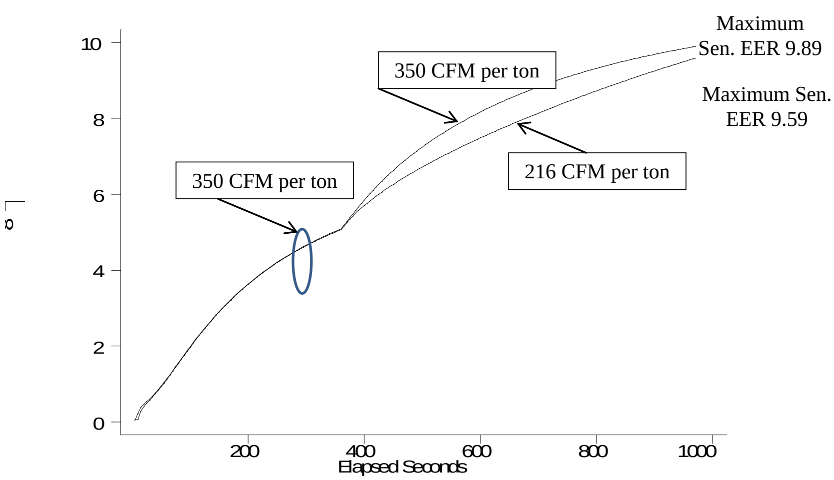


Figure 7. Cumulative Sensible EER for BPM Fan Motor Unit with 350 and 216 CFM per ton Airflows during Time Delay (CUSC 2010, 25 figure 18)

Effect of Duct System Efficiency on Sensible EER Delivery. The lab tests indicate that a long fan delay would be advantageous to produce higher Sensible EERs at the unit, particularly with a BPM motor. This appearance may be correct for units that have no duct system or have very high distribution efficiencies. However, real ducted systems have conduction heat gains and leakage losses (duct losses). These losses are important to take into account in determining the fan delay length. Duct losses modify the Sensible EER results substantially. Figure 8 shows the results for a PSC motor and 350 CFM per ton with and without duct losses[5].

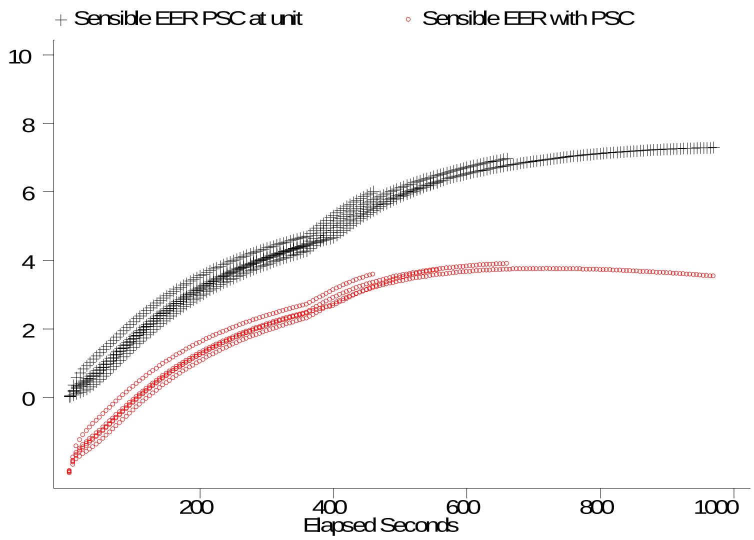


Figure 8. Cumulative Sensible EER for PSC Unit with 350 CFM per ton (CUSC 2010, 26 figure 19)

The upper lines show the Sensible EER without any duct losses. In a system without ducts or without duct losses, the peak Sensible EER of 7.30 BTU/watt hr. occurs with the longest fan time delay (610 seconds). The lower lines show the Sensible EER with duct losses. With duct loss, the peak occurs with a shorter time delay and is limited to 3.89 BTU/watt hr.

The duct losses have a similar effect on the unit's Sensible EER when it is fitted with a BPM motor. These results are shown in Figure 9. Without duct losses the peak Sensible EER (9.89 BTU/watt hr.) occurs with the longest fan delay. With duct losses the peak Sensible EER (5.23 BTU/watt hr.) in Figure 9 occurs at a 525 second time delay.

[5] The duct losses are calculated as proportional to the temperature difference between the supply temperature and 120ºF. At full capacity the duct losses are calculated at 20%.

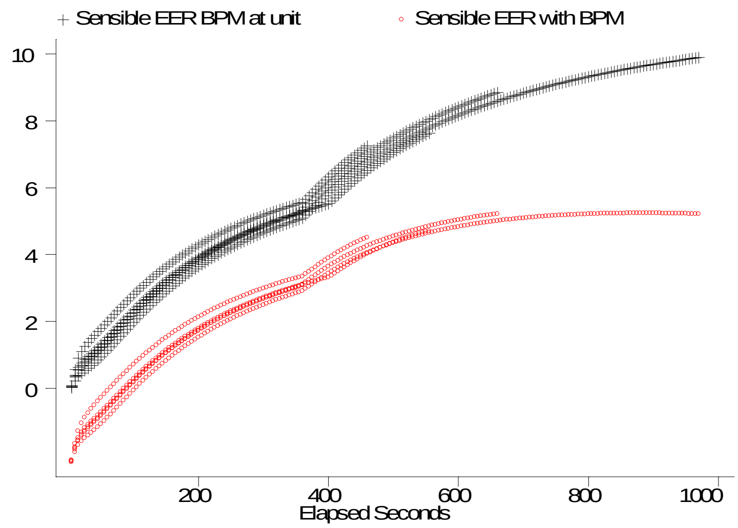


Figure 9. Cumulative Sensible EER for BPM Unit with 350 CFM per ton (CUSC 2010, 27 figure 20)

2010 Field Evaluation

In the summer of 2010, ten single family residential houses in California were monitored with and without fan control retrofits. The sites included package and split air conditioners of various vintages from 1975 to 2009. Duct leakage ranged from 74 CFM to 868 CFM at 25 Pascals.

Each site was initially configured with the temperature dependent time delay control and monitored in a flip-flop methodology with extended fan delay control toggled every four days. An average of 9 weeks of data per site was collected with temperature dependent fan delay control. The temperature dependent control did not produce reliable energy savings, possibly due to supply duct leakage and the placement of the supply temperature sensor. At this point three of the participants dropped out of the test.

Seven sites were then configured with the proportional time controlled device that was being used in the utility energy efficiency program described in the First Full Scale Implementation section above. Data were analyzed by temperature-hour bins to produce a comparison at similar temperature conditions and time of day.

A number of one-time measurements were taken at the time of time delay installation, data collection, and project conclusion. Evaporator airflow and indoor blower motor watt draws were recorded at various settings to verify the air conditioner was operating the same throughout the monitoring periods.

The average time of the installation of the proportional time delay relay control was about 15 minutes. Most of that time was verifying that the ETD was functioning properly. All occupants agreed to have the proportional time delay relay remain installed on their air conditioners at the time of project conclusion.

The primary performance measure was the change in electrical energy consumption. Pre/post consumption was compared by outdoor temperature and hour of day. Measured outdoor temperature data were grouped into 5 degree temperature bins. The hours of the day were grouped into 2-hour bins. Average total watt hours by temperature 2-hour bin were calculated with and without the ETD functioning. Watt hours included the compressor, condenser fan motor, and evaporator fan motor run times and watt draws. Bins were weighted by the number of data points in each temperature bin. Bins were excluded from the analysis that had less than 1.6% the total amount of data points in that bin or had no comparable data between monitoring periods.

Energy savings from the enhanced time delay control can be seen in Table 2 below. These values are the weighted temperature bin average energy savings over the whole monitoring period.

Table 2. Air Conditioner Energy Savings with Proportional Time Delay Control During Monitoring Period

Site	Energy Savings
Stockton #1	14%
Fresno #1	14%
Clovis #1	9%
Clovis #2	25%
Lemoore	14%
Tracy	18%
Bakersfield	N/A*
Average	**16%**

* Results indicated that the thermostat was not on one temperature set point or program during monitoring. The resulting air conditioner run times were too inconsistent to produce a meaningful comparison.

Energy savings were not found using the temperature dependent time delay control. Multiple revisions over 3 week periods were made during monitoring, however no electrical energy savings could be found. Nine of the sites exhibited longer than expected fan tail delays due to varying air conditioner conditions with micro controller programming set points. During these longer fan tail delays, capacity was still being supplied to the conditioned space for the duct run monitored.

Independent Assessment Report

The California Energy Commission commissioned an independent assessment report on the proportional time delay. The assessment concludes that: “Results from this demonstration, supported by extensive laboratory testing, confirmed energy savings averaging 16%”. (SDSU 2011)

Continued Implementation

Given the short time involved in installation and the low cost of the device, HVAC contractors are hesitant to make a special trip to a customer’s home for implementation. When this device is combined with other items – such as a tune up or duct sealing, it provides high incremental value to the customer and for the utility under utility programs. Where utility residential HVAC programs have been eliminated or severely curtailed it is difficult to implement the installation of this device. One high volume utility program is using this device coupled with other AC measures.

Conclusions

The enhanced time delay relay is a device that can provide notable incremental energy savings to customers and utilities. It is not a “game changer” that produces 50% cooling savings, but it does produce good savings at a low price. Most importantly it can be applied to millions of air conditioners in a very short time period.

The path to market within utility programs for an innovative energy efficiency device is highly dependent on the political situation between utilities and regulators. Laboratory and field tests are helpful, but the path is not clear and open even with extensive laboratory and field testing.

The path to market through the general HVAC industry for an innovative device of low cost and unknown to the general public is even more difficult. The average HVAC contractor has a business plan that does not include introducing low cost innovative products to their customers.

The walk through the innovation "Valley of Death" is often viewed as a need for capitol and utility programs are sometimes suggested as a method of producing a sustainable market. The history of this innovation illustrates some of the challenges associated with using the utility program pathway.

References

Buntine, Chris., Proctor, John., and Bob Knight 2008. *2007 Energy Performance of Hot Dry Air Conditioning Systems*. California Energy Commission, PIER Building End-Use Energy Efficiency Program. CEC-500-2008-056.

[CUSC] California Utilities Statewide Codes and Standards Program 2010. *Residential Refrigerant Charge Testing and Related Issues, 2013 California Building Energy Efficiency Standards Measure Template.*

[PG&E ETP] Pacific Gas and Electric Company Emerging Technologies Program 2008. *Hot Dry Climate Air Conditioner Pilot Field Test Phase II.* Emerging Technologies Application Assessment Report #0724.

[PG&E ETP] Pacific Gas and Electric Company Emerging Technologies Program 2007. *Hot Dry Climate Air Conditioner Pilot Field Test.* Emerging Technologies Application Assessment Report #0603.

Proctor, John 1990. *Pacific Gas and Electric Appliance Doctor Pilot Project Final Report.* San Rafael, CA: Proctor Engineering Group, Ltd.

[SDSU] San Diego State University Research Foundation 2011. *Proportional Time Delay Relay for Air Conditioner Latent Capacity Recovery.* California Energy Commission Public Interest Research Program.