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Commercial High Efficiency Air Conditioners – Savings Persistence

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Abstract

Proctor Engineering Group established a time series estimate for condenser and evaporator coil fouling rates for commercial air conditioning units. This was derived from available research. Laboratory testing was used to modify the estimated fouling rates and establish a profile for coil fouling. Both high efficiency and standard efficiency coils were tested in a controlled laboratory environment and subjected to continuous fouling. The efficiency of the air conditioner was monitored at various intervals to document the effects of coil fouling on efficiency.

The units were tested to determine the efficiency impact of the fouling. Efficiency measurements were made at various steps during the testing. Tests were run to establish the baseline efficiency, efficiency with the evaporator fouled, and with both the evaporator coil and the condenser coil fouled. The coils were then removed and the standard efficiency coils installed. The proper measured charge was reinstalled and the testing repeated.

The data collected provided a profile for each set of coils: the efficiency at a baseline and the efficiency with the various amounts of coil blockage. The results from these tests were compared to other research conducted on the effects of air flow reduction on air conditioning systems.

The results of the testing showed that the high efficiency coils start with and maintain a higher efficiency than standard efficiency coils. The slower degradation rate will increase the life of the equipment and use less energy over the operational lifetime. The study also suggested changes in the servicing requirements of the systems.

Executive Summary

This report presents the results of research conducted on the performance of commercial direct expansion air conditioners (Comm. DX AC). It was one of the measures evaluated in the larger DSM effort. The larger study, *Persistence 3A: An Assessment of Technical Degradation Factors: Commercial Air Conditioners and Energy Management Systems* (*Persistence 3A*), sponsored by the California DSM Measurement Advisory Committee (CADMAC) Persistence Subcommittee, is the third project to examine the relative technical degradation of demand side management (DSM) measures compared to standard efficiency equipment.

Research Question

The primary research question is: “Are the efficiencies gained by increasing the number of rows in an air conditioning coil sustainable over time?”

High efficiency commercial package air conditioners can attain efficiency gains through a variety of means: changing to a scroll compressor, changing the metering device, changing motors, adding face area, and adding rows of coils. In *Persistence 1* no relative degradation was likely from the above means except for adding rows to the coils. Due to this, the TDF was determined to have a high degree of uncertainty. There are no technical data available that assist in establishing the differential rate of fouling or efficiency loss.

Research Methodology

Proctor Engineering Group established a time series estimate for condenser and evaporator coil fouling rates. This was derived from available research. Laboratory testing was used to modify the estimated fouling rates and establish a profile for coil fouling. Both high efficiency and standard efficiency coils were tested in a controlled laboratory environment and subjected to continuous fouling. The efficiency of the air conditioner was monitored at various intervals to document the effects of coil fouling on efficiency.

Research Study Results

All of the coils exhibited the same basic fouling behavior. The predominate site of coil fouling was on the face of the coil. The reduction in efficiency was due to the reduction in air flow across the coil. The reduction in air flow on the evaporator coil tended to reduce capacity more than efficiency. The opposite was true for air flow reductions on the condenser coil.

When the air flow was reduced slightly, there was a commensurate reduction in efficiency. As the fouling reached critical proportions, the rate of air flow reduction was greatly accelerated and the efficiency and capacity dropped accordingly. Air flow was reduced 35% on the high efficiency coil with a 2% drop in EER. When air flow was reduced 35% the standard coil had under a 6% drop in EER. The majority (4.6%) of that reduction required less than 10% of the total fouling time.

Due to the length of time required in the fouling process, it was difficult to control for the amount of contaminants reaching the coils. Physical investigation of the coils and evaluation of the fouling profiles were used to confirm that the number of rows in the coil did not have an impact on the fouling rate.

The efficiencies of both systems were insensitive to low and moderate amounts of air flow reduction due to fouling. However, the high efficiency coils were less susceptible to efficiency loss due to high reductions in air flow.

The condenser fouling data shows that fouling of the condenser coils has a much more dramatic effect on the efficiency. This is particularly true for the standard condenser coil. Although condenser coils have a better chance of being cleaned, fouling them has a more damaging effect on the efficiency and increases the power use of the equipment. A 35% reduction in air flow resulted in a drop in the EER of 24% for the standard unit and 19% for the high efficiency unit. The power use increased 18% and 13% respectively. The data indicate that efficiencies gained by increasing the number of coils are sustainable for many years, depending on the speed of fouling. Once the coils have achieved a significant drop in air flow, significant degradation of operating efficiency will occur. An estimation of the degradation times is provided for general reference.

The long term energy cost savings justify the initial extra expense to produce the units with more coils.

1 INTRODUCTION

This study, *Persistence 3A: An Assessment of Technical Degradation Factors: Commercial Air Conditioners and Energy Management Systems* (*Persistence 3A*), is a continuation of the work performed by Proctor Engineering Group (PEG) in the first two Statewide Measure Performance Studies (*Persistence 1*, PEG 1996 & *Persistence 2*, PEG 1998).

1.1. Project Research Objectives

The persistence studies are part of a multi-faceted approach to estimating the persistence of energy savings from demand side management (DSM) programs in California. These studies focused on one aspect of the persistence of savings -- technical degradation. The general research question that these studies are designed to help answer is:

How will DSM program savings be affected over time by changes in the technical performance of efficient measures compared to the technical performance of the standard measures they replace?

Other aspects of savings persistence such as measure life, measure retention, and market effects are being examined through a number of other studies and projects.

The primary study result is a set of Technical Degradation Factors (TDFs). The TDFs are a series of yearly numbers which when multiplied by the first year savings yield an estimate of the energy savings in years subsequent to the first year. Specifically the TDF is defined as: “A scalar to account for time and use related change in the energy savings of a high efficiency measure or practice relative to a standard efficiency measure or practice." (CADMAC 12/17/97) The base level of performance is the period covered by the first year impact evaluation. The TDF is the ratio of savings in subsequent years to savings in the first year.

This calculation is independent of measure life as determined in the California evaluation protocols. The TDF is calculated for a 20 year period to allow for its independence from changes in the estimates of measure life.

Changes in energy usage that are due to operating conditions, product design or human interaction are included within the scope of the project. The performance of most efficient and baseline measures depend upon installation, and operation & maintenance (O&M) practices. These factors were included within the studies to the extent that they were found to influence relative changes in measure performance over time. The immediate impacts of any initial installation defects are assumed to be accounted for in first year impact studies.

1.2. Background

The primary research question is: "Are the efficiencies gained by increasing the number of rows in an air conditioning coil sustainable over time?"

High efficiency commercial package air conditioners can attain efficiency gains through a variety of means: changing to a scroll compressor, changing the metering device, changing motors, and /or increasing coil surface area by adding face area or adding rows of coils. *Persistence 1* found no relative degradation was likely from the above means with the possible exception of adding rows to the coils. Due to size limitations of the cabinets, most manufactures increase the surface area by adding rows to the evaporator and condenser coils. Air cooled heat exchangers are widely known to be subject to degradation due to fouling of the coils. It is unknown how adding rows to the coils affects the fouling rate.

The effects of fouling on the indoor evaporator coil are to reduce coil heat transfer by reducing the air flow and heat transfer coefficient. The reduced heat transfer will reduce both the compressor power draw and the capacity. The overall efficiency is reduced because capacity is reduced at a greater rate than the power draw. With both the compressor and the evaporator fan using less energy the connected load of an individual AC unit will decrease from evaporator fouling. However, more energy overall will be used due to increased run time needed to meet the load. Therefore, the diversified load on utility systems will increase due to increased coincidence of air conditioner loads.

Some technical data exist on the rate of coil fouling in conventional package systems. Information on the long term performance of high efficiency package systems is not available. This task will provide a technical evaluation of the relative coil fouling rates and measure the relative efficiency changes due to those changes.

1.3. Analytical Approach

The estimates of coil fouling were conducted in two stages: 1) evaluating and establishing reasonable bounds for coil contamination, and 2) defining the best fit of the test data to those estimates.

Proctor Engineering Group established a time series estimate for condenser and evaporator coil fouling rates in standard efficiency units. This was derived from available research. Laboratory testing established the differential rates of fouling between standard and high efficiency coil configurations. In order to determine the relative technical degradation, Proctor Engineering Group tested the efficiency of coils undergoing coil contamination. The laboratory testing was completed at the National Research Council, Thermal Technology Centre Laboratories.

Laboratory testing was deemed the most cost effective and reliable approach to estimating degradation. PEG completed a series of efficiency tests, evaluating the efficiency of various coil configurations and fouling rates. All testing was performed in two psychometric rooms simulating American Refrigeration Institute (ARI) standard indoor and outdoor conditions (95°F outdoors, 80°F dry bulb and 67°F wet bulb indoors).

The coil contamination was done with an aerosol duct sealing tool developed by Lawrence Berkeley Laboratory. This tool injects a fine aerosol mist into the air stream. This aerosol tends to build up in areas of significant pressure drop, very similar to dirt deposition. The tool was fitted with special equipment to provide more accurate control of the aerosol injection process. Reasonable analysis was done to provide the most reasonable fouling technique. The two most important variables were determined to be the particle size and the thermal resistance of the material. Aeroseal has an R-value that is lower than ASHRAE dust and the particle sizes were controlled by the use of impactor plates to lower the particle size.

The experimental variable is the number of rows in the coil. This variable is isolated in the testing by using a high efficiency unit, where both standard and high efficiency coils were alternately installed. Aerosol contaminants were introduced into the return side of the evaporator and intake of the condenser coils. The aerosol injection rate was maintained to provide as constant an injection rate of contaminant as possible. The tests continued until the contamination process resulted in a 35% drop in the air flow rate on the high efficiency coil set. The air flow across the standard efficiency coil was reduced by the same amount. The fouling profiles for both coils showed the same pattern: there was a small reduction in air flow until the surface of the coil became matted. Once that occurred, the air flow reduction accelerated rapidly.

The units were tested to determine the efficiency impact of the fouling. Efficiency measurements were made at various steps during the testing. Tests were run to establish the baseline efficiency, efficiency with the evaporator fouled, and with both the evaporator coil and the condenser coil fouled. The coils were then removed and the standard efficiency coils installed. The proper measured charge was reinstalled and the testing repeated.

The data collected provided a profile for each set of coils: the efficiency at a baseline and the efficiency with the various amounts of coil blockage. The results from these tests were compared to other research conducted on the effects of air flow reduction on air conditioning systems.

2 METHODOLOGY - Commercial DX AC

In *Persistence 1*, the TDF developed for Commercial Direct Expansion Air Conditioners (Commercial DX AC) was determined to have a high degree of uncertainty. This research study is designed to provide a more reliable TDF.

2.1. Research Objectives

The main research objective was to determine whether the efficiencies gained by increasing the number of rows in an air conditioning coil are sustainable over time. The second objective was to quantify the relative technical degradation between the standard and high efficiency air conditioning coil. Projecting, on a yearly basis, the differences in the degradation between the standard and high efficiency coil systems created the TDF table.

2.2. Research Methodologies

High efficiency commercial package air conditioners can attain efficiency gains through a variety of means: changing to a scroll compressor, changing the metering device, changing motors, adding face area, and adding rows of coils. *Persistence 1* found the following:

“PEG concludes that the use of scroll compressors in some efficient units should produce no degradation in energy savings over time.”

“PEG concludes that the use of thermostatic expansion valves (TXV’s) in some efficient units may lead to some changes in energy savings over time, but the direction of this change is uncertain and the magnitude is likely to be small.”

“PEG concludes that energy savings from high efficiency motors will not decline over time due to technical degradation.”

“PEG concludes that the differences in condenser coil face areas should produce no degradation in energy savings over time and may actually lead to increases in long-term savings.”

The single largest undetermined factor in the degradation is the effect of adding rows of coils to evaporator and condenser coils. Due to size limitations of the cabinets, most manufactures increase the surface area by adding rows to the coils. Air cooled heat exchangers are widely known to be subject to degradation due to fouling of the coils. It is unknown how adding rows to the coils affects the fouling rate.

Evaporator coils are subject to dust, particulates, and vapors from the indoor environment, most of which will pass through or around a typical filter (20-30% particulate arrestance). The coils tend to trap particulates because of the tight fin spacing and the “sticky” nature of both the coil (due to condensation) and the indoor air (cooking and/or tobacco smoke). The rate of dust build-up will depend on a large number of factors. These are: the amount of air passing through the coil, the indoor air quality, the amount and environment of return duct leakage, the filter design and location, maintenance, and the design (coil fin spacing, geometry, and number of rows). The dust may load throughout the coil providing an insulating layer over the fins, or it may primarily build up on the face, reducing the effective coil size.

The impacts of this fouling are: reduced air flow through the coil, and a reduced heat transfer coefficient. The reduced air flow will result in less work being done by the blower. This reduces the amperage required by the blower. Reducing the heat transfer coefficient reduces the number of BTUs that can be extracted from the air stream. Cooler return temperatures result in less work for the compressor. Thus, changes will reduce system capacity while reducing indoor fan power draw and compressor power draw. The overall efficiency is reduced because capacity is reduced at a greater rate than the power draw. More power will be needed, due to increased run time needed to meet the load. The connected load will decrease from evaporator fouling.

Condenser coils are exposed to the outdoor environment and are subject to fouling from dust and dirt much like evaporator coils. In general, the coil fin spacing is tighter than on the evaporator but the surfaces are less sticky (e.g., they are dry and generally subject to fewer aerosols such as smoke and grease). Condensers are also subject to corrosion from salt and pollution that can be a substantial problem in coastal areas (manufacturers tend to use special anti-corrosion coatings or materials to minimize corrosion).

Condensers are generally more accessible and therefore easier to maintain than evaporator coils. Field experience indicates that such maintenance is rarely performed. This is particularly true in commercial rooftop units. A dirty condenser coil will slightly reduce outdoor fan power draw and increase compressor power draw. The dirty coil results in a lower air flow. The condenser fan power draw is consistent with the air flow, although the relationship is not linear. The decrease in heat exchange efficiency will raise the temperature and head pressure. This will result in increasing the power needs of the compressor. The overall effect is to reduce system capacity and efficiency while increasing power draw. In both cases, the run time of the appliance will be extended.

One would expect a greater rate of fouling in a heat exchanger with more rows because it would act as a better filter. However, if the fouling process is dominated by loading at the coil face, then the additional rows may not increase particulate arrestance. It is not known whether the potential increase in fouling would create a greater proportional decrease in heat exchanger effectiveness for units with more rows. If the decreases are not more than proportional, then no relative degradation should occur.

Laboratory testing was used to determine the relative technical degradation of efficient versus baseline equipment. The pros and cons of performing laboratory testing versus field measurements were examined. Laboratory testing was deemed the most cost effective and reliable approach to estimating degradation. The features that led to that decision are:

The laboratory offers a controlled setting. Standard and high efficiency equipment can be tested in the same environmental conditions.

The laboratory allows extensive, real time monitoring of all pertinent parameters. This is virtually impossible in a field setting.

The accuracy of the sensors available in the lab far surpasses the accuracy of the sensors readily available for field use.

The control and oversight allows the researchers to determine if the testing is progressing as anticipated and make changes in the testing as needed.

Field measurements offer the ability to see a larger sample of units. Comparing the measured results from these tests presents technical concerns. The field measurements are prone to having numerous factors, other than age, thrown into the equation. Items such as indoor and outdoor air quality; maintenance schedules; refrigerant charge uncertainties; indoor and outdoor conditions at the time of the test; blower and fan motor uncertainties and air flow variations will all have an impact on the test results. These uncontrolled variables make analyzing the data, and making conclusions based on the sample, extremely difficult.

2.3. Laboratory Testing

2.3.1. Equipment Selection

Research in Phase 1 of this study analyzed databases of rebated air conditioner makes and models to identify market leading units. Distributors and manufacturers were contacted to confirm this analysis, and identify the most popular models. For the California market these are the Carrier models 48TJE006 and 48HJE006.

These units are comparable five ton, horizontal discharge, rooftop package heating and air conditioning units. Although the exterior dimensions and cabinet are identical, the high efficiency unit has a number of upgraded features. The most notable are the compressor, blower, and the number of heat exchanger rows. Changes in the high efficiency unit result in it being seventy pounds heavier. Other significant features of the units are the same, including the metering device, coil design and construction, coil materials, and nominal air flows. Specific features are listed in Table 2-1. Our original research plan specified a direct comparison between the two units. After more detailed analysis, we concluded that limiting the analysis to the effects of the coils would provide more comprehensive and applicable research results.

In order to isolate the effects of adding rows of coils, PEG purchased a high efficiency unit and tested it with both the standard and high efficiency coils installed. The results of this testing provided information necessary to make reliable conclusions on the performance of these and other systems.

Table 2-1 Standard & Efficient Unit Characteristics

	Standard Efficiency Unit	High Efficiency Unit
CONDENSER COIL		
Number of Rows	1	2
Fin Spacing (per inch)	17	17
Total Face Area (sq.ft.)	13.19	16.5

Coil Type	Copper Tube/ Alum. Fins	Copper Tube/ Alum. Fins
EVAPORATOR COIL		
Number of Rows	3	4
Fin Spacing (per inch)	15	15
Total Face Area (sq. ft.)	5.5	5.5
Coil Type	Copper Tube/ Alum. Fins	Copper Tube/ Alum. Fins
COMPRESSOR		
Type	Hermetic	Scroll
EFFICIENCY		
SEER	10	13
EER	8.5	11

2.3.2. Equipment Set-up

PEG purchased one high efficiency air conditioning unit, an additional set of standard efficiency evaporator and condenser coils, and replacement blowers. The test unit was installed in the outdoor side of the psychrometric chamber. Ducts were installed to connect the unit to the indoor chamber. Baseline efficiency tests were run on the high efficiency system and the coils fouled in-situ. The same set of tests was run with the standard efficiency coils installed. The experimental setup utilized the two psychrometric rooms to simulate ARI standard indoor and outdoor conditions (95°F outdoors, 80°F dry bulb and 67°F wet bulb indoors). The air flow rate through the coils was controlled by the standard operating fans. An elaborate fan evacuation system was installed on the supply duct and condenser, to filter, measure and provide adequate pressure compensation. This system is an integral part of the psycrometric chamber. It integrates pressure and flow measurements with measurements of the environmental conditions and adjusts the temperature and humidity before reintroducing the air to the chamber.

On the evaporator side of the system, the duct pressure was maintained at .4”WC (water column) to simulate a standard duct system. On the condenser side of the system, the control fan was adjusted to compensate for the modifications made to the unit. During the testing, the speed of the control fans was reduced as the fouling occurred. This was done to maintain the established test pressures.

2.3.3. Testing Procedures

PEG and National Research Council staff conducted a battery of tests. Table 2-2 details the minimum efficiency and fouling tests that were planned. The efficiency was tested at different indoor air flow rates. This helped to establish the effects of air flow compared to change in the thermal heat transfer characteristics at the surface of the coil. Essential data were also collected at various points during the coil fouling process. The High efficiency coils were exposed to a consistent concentration of contaminants until the desired flow reduction was reached. The performance of the standard coils was tested with the same air flow reductions. Due to the length of the test procedure, controlling for the amount of contaminant that reached the coil was not possible. The drop in air flow as a function of the exposure time was very close under these experimental conditions. Once we had established that the fouling characteristics were similar, the loss in air flow was used as the controlling variable. The intermediate test results were used to interpolate the losses across the appropriate range of expected reductions.

Table 2-2 Summary of Tests

Test	Evaporator Coil	Condenser Coil
1-Baseline Test	High Efficiency - New	High Efficiency - New
2-Coil Fouling Test	**Foul Coil & Replace Blower**	
3-Evaporator Coil Test	High Efficiency - Fouled	High Efficiency - New
4-Coil Fouling Test		**Foul Coil & Replace Blower**
5-Combined Coil Test	High Efficiency - Fouled	High Efficiency - Fouled
	Install Standard Coil	**Install Standard Coil**
6-Baseline Performance	Standard Efficiency -New	Standard Efficiency - New
7-Coil Fouling Test	**Foul Coil & Replace Blower**	
8-Evaporator Coil Test	Standard Efficiency Fouled	Standard Efficiency -New
9-Coil Fouling Test		**Foul Coil & Replace Blower**
10-Combined Coil Test	Standard Efficiency Fouled	Standard Efficiency Fouled

The efficiency of the equipment was established by monitoring the air side of the system, coupled with temperature, pressure and mass flow of the refrigerant. This is verified by measuring temperatures, and energy use of the psychrometric chamber. The monitoring equipment was installed during the first phase of the testing and was cleaned throughout the coil fouling portions of the test. The sensors on the refrigerant system remained in place for the duration of the experiments. When the coils were installed, the refrigerant was removed, the system was evacuated, and the manufacturer’s suggested superheat procedure was used to reestablish the proper charge.

The baseline testing of the unit was compared to the manufactures' specifications. The measured EER was 10.52 at a fan speed of 1914 CFM. The standard rating for this unit shows an EER of 10.9 at an air flow of 2000 CFM. Using the manufacturer’s charging chart, the tested efficiency is slightly above the nameplate rating.

The energy balance of the calorimeter was established during the same baseline test. The energy balance is calculated by comparing the energy that is required to keep the rooms at the desired temperature and humidity to the energy used by the air conditioning unit. The results remained fairly stable throughout the testing. The overall energy balance was off by 6%. This can be due to a variety of assumptions that are programmed into the calculation and is not seen to be an important factor (e.g. the amount of heat gained through the indoor duct system). Variation around the established baseline is the important test variable. The variation was less than 3% for the high efficiency unit. The energy balance for the standard efficiency unit was similar to those run on the high efficiency unit.

Aerosol contaminants were introduced into the return side of the evaporator and subsequently into the intake of the condenser coils. Air flow and contaminant injection rates were continuously monitored. The amount of aerosol was maintained at a constant injection rate. The blower in the package unit was used to provide the pressure drop necessary to pull in the contaminated air. The experiment was set up to emulate the duct pressures that are normal in standard installations. A minimum static pressure of .25"WC is required for standardized testing. A more realistic pressure of .4"WC was used in this test.

All of the exhaust air was run through a filter bank. A single-pass system was used for contamination. The measurement of air flow and the effects of the contamination were very precise. The actual contamination process was less controlled. The test contamination was conducted in California, and went fairly quickly. A 5 Ton AC coil was contaminated over the period of three hours and the air flow was reduced by 37%. Changes were made in the contamination process to reduce the size of the particulates. This, combined with the requirements of the monitoring process in conjunction with fouling, resulted in the fouling in the laboratory taking considerably more time than planned. Coil fouling typically took three to four days of lab time. Cleaning of the equipment and intermediate tests were run during this time as well.

The initial plan called for the contamination to be completed once the indoor coil fouling had resulted in a 30% drop in the air flow rate on the high efficiency coil. The drop in air flow was very sudden close to the end of the fouling process. Over 40% of the reduction in air flow occurred during the last hour of the fouling process

Tests were run to confirm that the drop in air flow was a result of coil fouling, and not simply fouling of the blower wheel. Those tests showed that the reduction in air flow was almost entirely due to the face blockage of the coil and not the contamination of the blower.

The same basic procedure was used for the condenser coil tests. The target flow reduction for the condenser coils was 25%. Intermediate testing was done throughout the fouling for both the high efficiency coils and standard coils.

2.4. Evaluation Methodologies

Environmental conditions are a significant factor in the rate of coil fouling. Changing those conditions will have an enormous impact on the rate of fouling found on the coils. This evaluation is focused on performance degradation differences between standard and high efficiency appliances. The TDFs that are presented reflect the variance between the units measured in the laboratory. In any specific environment, the effective operational time could be accelerated or reduced. For the purposes of this study, we established a standard deterioration time line based on the best available field data.

Individual sites may have a higher or lower fouling rate. Additional research is needed in defining field contamination factors.

We collected all readily available information on coil fouling. We used these data to create engineering estimates of the evaporator and condenser fouling rates over time. Due to the scarcity of the data, we did not attempt to establish bounds for these estimates. These data are representative of standard efficiency coils. The coil fouling process in the laboratory provided us with an accelerated fouling data set. The data collected on the high efficiency coils provided us with a clear time series comparison of fouling rates for standard and high efficiency coils. These new technical data were used to revise the time series estimates.

Once the fouling rates were established, we used both engineering calculations and measured data to evaluate the change in efficiency of the units due to these differential fouling rates. We examined the experimental plan and evaluated the potential measurement errors in the testing. The final TDF was established by applying the efficiency changes to the long term fouling rate of the coils. The standard system was compared with the high efficiency system and the final results are expressed as multipliers for each year of the measure life. We have presented the TDF as a function of the evaporator fouling and as a combination of both the evaporator and condenser fouling.

The nature of the TDF is that there can be a reasonable trend line established for the technology. This trend will provide a conservative estimate of the technical degradation of the technology. It is rare to find a TDF that can be accurately applied to any individual unit. This particular technology has a number of uncontrolled variables. The TDF provides a standard of measure to evaluate the DSM measure. This testing significantly reduced the uncertainty in evaluating the measure.

3 RESULTS - Commercial DX AC

3.1. Coil Fouling

Fouling of coils was evaluated in terms of the maximum effective reduction in air flow and the probable rate of contamination. Research has shown that the condenser and evaporator coils generally exhibit linear decreases in performance until 50% of the flow is reduced. At that point, performance drops off significantly. If either coil exceeds this fouling rate, the performance and life expectancy of the unit are severely compromised. The coil systems were evaluated separately and the impacts of the fouling were combined to determine the TDF. PEG used all available field data to provide a “field calibration” for the data that were collected in the laboratory. Other test data were also used to provide a reasonableness test for the laboratory results.

3.2. Condenser Fouling

Condenser coils are hot dry coils that are subjected to contamination from the exterior environment. Air flow is created by a single speed fan that is designed to move between 750 and 1000 cfm per ton. Research on the contamination of these coils is sparse. These flows and pressures are difficult to measure in the field. Unit replacement or prescriptive cleaning are the most common efficiency procedures.

3.2.1. Condenser Degradation Limit

PEG estimates that the maximum degradation is 45% condenser face surface loss, resulting in a +10F condensing temperature increase, and a 20% EER decrease in the standard unit. This estimate is based on Jung (1976)

"Likewise, a change in the heat-transfer coefficient because of a dirty condenser is expected to increase the condensing temperature ~10F. If there is airflow blockage, the temperature could rise higher. These estimated temperature limits do not represent the worst possible case but reasonable expected limits because of reduced airflow or heat transfer. Long before the maximum limits are reached and especially during hot weather, the occupants should be complaining about inadequate cooling, or the unit may malfunction." (Jung, 1976, Page 20)

Test measurements showed that the standard efficiency had a 15.8F increase in condensing temperature with a 27% reduction in EER. The high efficiency has a 14F increase in condensing temperature with a 24% reduction in EER.

3.2.2. Condenser Degradation Rate

PEG estimates that non-maintained single row condenser coil will lose 50% of the flow over the 20 years. The maximum predicted fouling is not achieved in the estimated 15-year life of the equipment. Jung (1976) states that single row condenser coils are less subject to clogging than multi-row coils:

"Single-layered condenser coils, although not filtered, are not prone to get dirty if properly installed. Multilayer condenser coils are more likely to clog because of debris becoming trapped between the coils." (Jung 1976)

Jung's hypothesis is different than ours. Laboratory testing and significant field evaluations indicate that face fouling is the predominant means of air flow reduction and would not be different for single or multi-layered coils.

The degradation rate for multi-row condenser coils is 6.8%/year face surface loss based on Trane (1990) and Braun (1986). Under conditions of accelerated fouling for multi-row coil, Trane found a 27% efficiency loss. This efficiency loss corresponds to a 54% relative condenser area loss. Since this accelerated fouling is equivalent to 8 years of typical operating conditions, yearly fouling would be 6.8% for commercial multi row coils:

"Trane provided data from an experiment performed in the 1970's where two air conditioners were operated continuously with condenser exposed to a very dirty factory environment for 18 months, equal to perhaps 4-8 years worth of typical operating hours. (Trane 1990). Performance measurements at the end of the test indicated that the air conditioner with the standard plate fin coil had lost 17% of its capacity and 27% of its efficiency." (Persistence 1, 1996)

"An ASHRAE paper noted considerable capacity problems in two 20 ton chillers caused by dirty condensers (Braun 1986). The static pressure across the coils was measured at 2.5 times greater than design after 8 years. Cleaning was not very effective at improving capacity or reducing pressure drop.

The author noted that it is extremely difficult to clean a coil more than two rows deep and that coils with tighter fin spacing will tend to foul more quickly." (Persistence 1, 1996)

This maximum estimate is for commercial multi-row coils. The exposures in these cases were to extreme industrial or marine environments. These estimates can be used to evaluate the range of degradation that is possible under varying environmental exposures. This particular test would result in the contamination process being accelerated by 2.7 times. Without maintenance, the coils would reach the condenser degradation limit in seven years. This would hold true for both the standard and high efficiency coils.

Air flow across the condenser coil is more than twice that of the evaporator coil. In response, the standard coil has more than double the face area. The high efficiency condenser coil that was tested had three times the face area of the evaporator coil.

PEG estimates that multiple row condenser coils will lose 50% of the air flow over 20 years. This is consistent with estimates for the standard efficiency flow and contamination ratios as well as the evaporator fouling rates. The maximum predicted fouling is not achieved in the 15 year life of the unit.

3.3. Evaporator Fouling

More information is available on the rate and effects of evaporator coil fouling. The data are still sparse and varied in quality and specificity. The best summary of the phenomenon was provided by O'Neil:

"Results shows that as evaporator air flow is reduced from a normal amount the electric demand, cooling capacity and EER decrease. Power consumption decreases in a near linear fashion, from 3.54% at 25% reduction in evaporator air flow to 17% at 90% reduction in evaporator air flow. This may imply that as utilities fix degraded air conditioners the demand may go up by 3-17% while usage goes down. Cooling capacity decreases linearly until about 50% evaporator air flow then dropped suddenly." (O'Neal 1992)

The phenomenon has two components: lower power use by the fan and lower compressor power use. The fan amperage increases as a function of air flow. Lower air flow reduces the instantaneous energy use. The lower air flow also lowers the ability of the heat exchanger to transfer heat out of the cooling fluid. Lower return fluid temperatures to the compressor reduce the head pressure and energy use by the compressor.

3.3.1. Evaporator Fouling Limit

The operational limit of fouling for units with thermostatic expansion valves (TXV's) is higher than those with capillary tubes. The limit for capillary tube metering devices is limited by the heat transfer of the coil to prohibit liquid refrigerant from returning to the condenser:

"As related by one air conditioner manufacturer, flood-back has been observed during tests conducted on their units with a capillary tube and an evaporator airflow reduction to 55% of the unit's rating at an outdoor temperature of 105F..."(Jung 1986)

This resulted in a 5F drop in the evaporator coil temp and a 9% drop in capacity. Although the flood-back condition should not occur in TXV systems, lack of capacity and cycling problems will be noticeable.

Jung conducted a theoretical analysis of reducing the evaporator coil temperature by 10F. This would simulate a reduction of air flow to 30% or a combination of air flow and heat exchange efficiency drop. This calculation was just before ice would be found on the evaporator. The capacity was reduced 19%.

O'Neil et. al. showed that the drop in performance was relatively linear until 50% reduction in air flow was reached. After 50%, the reduction was very dramatic (reduction in EER from -6.51% @ 50% to -34.63% @ 75%).

PEG has established that 50% is a reasonable outside limit for evaporator fouling.

3.3.2. Evaporator Fouling Rate

Research on air filter effectiveness indicates that the decrease in efficiency of coils is due primarily to the decrease in air flow.

"It shows that the COP can drop from 3.12 to 2.76 or 11.5% when only the air flow drops from 1000 to 500 ft3/min (1529 to 850 m3/min), or by 13.2% if the insulation effect of the dust layer is taken into account. This soiling was obtained for a 3-ton heat pump by retaining 600g of a 1000g dust load."(Krafthefer)

The same study estimated that the pressure drop across the coil doubles in 7.4 years. This would be reflective of a drop in air flow of 50% and a drop in capacity of 19%. This study was relatively aggressive in terms of both coil loading and evaluation of the arrestence of the coil.

Another research study showed a 50% reduction of air flow produced a 14.7% reduction in capacity (O'Neil).

Studies that have evaluated the increase in efficiency due to coil cleaning provide an indication of the available efficiencies that are gained in the field. This is an indicator of the efficiency gains that are achievable, and the flip side of the coil fouling evaluations. The total available gain is reflected in the savings and an estimate of the losses that were not recovered. Trane data showed that cleaned condenser coils only recovered 65% of the previous capacity. With this in mind, two additional research studies were reviewed. An evaluation completed by EPRI on the impact of maintenance on packaged unitary appliances showed a 5% average increase in air flow due to coil cleaning on 30 units. A study of 18 units in New England showed 6-11% savings from cleaning coils, adjusting charge, and other measures. Half of the evaporator coils were dirty and all of the condenser coils were clean. Neither of these studies provide a relative time line between cleanings.

All of the data suggests that the drop in evaporator air flow is at or below 50% in typical installations and represents up to 20% reduction in capacity. A conservative estimate of evaporator coil fouling is 40% over twenty years. The laboratory results show only minor differences in the coil fouling rate of the three and four row coil configurations. Although there are differences in efficiency, the coil fouling was within the measurement error and both coils were estimated to lose 40% of their air flow over a twenty year period.

3.4. Testing Results

Fouling of the evaporator coils did not produce a significant deterioration in the performance for either the standard or high efficiency coils. The performance of the fouled coils correlates well with test data on the performance of systems under reduced air flows (O'Neil, et at, 1996). Test results for standard efficiency coils, and the reference test data, are shown in Figure 3-1.

Figure 3-1. Depicts the change in performance (EER) as a function of the loss in air flow.

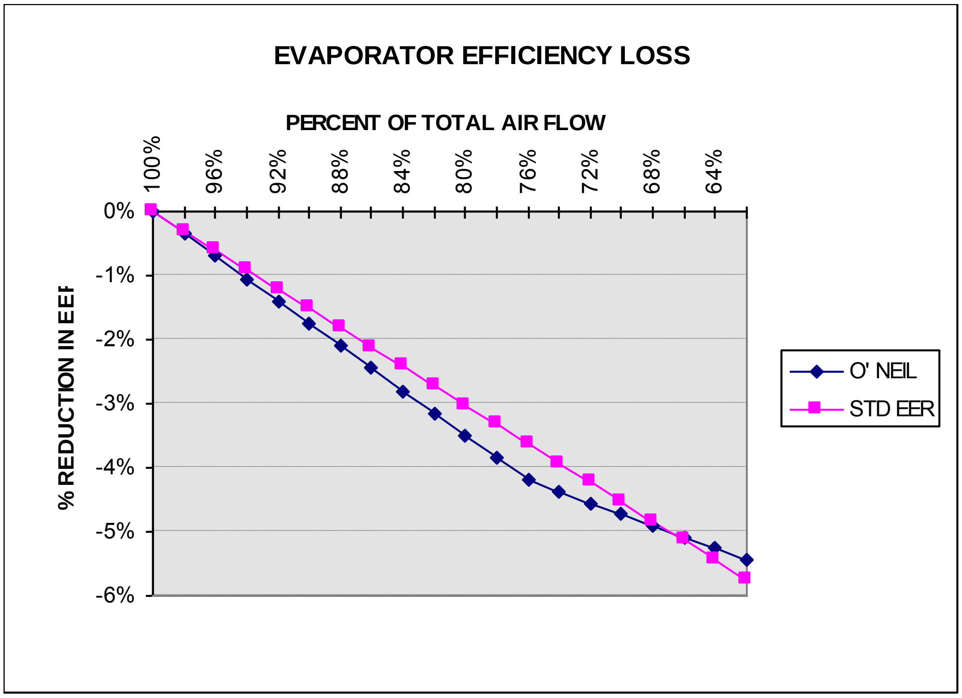

Figure 3-1 Change in efficiency with reduction in air flow

Additional tests were run on the system to determine if the reduction in air flow was due to fouling of the coils or fouling of the blower. The tests showed that the vast majority of the air flow reduction occurred at the coil and not the blower.

The comparison between the high efficiency coils and the standard coils are shown in Figure 3-2. This is equivalent to a 40% drop in air flow over this time period.

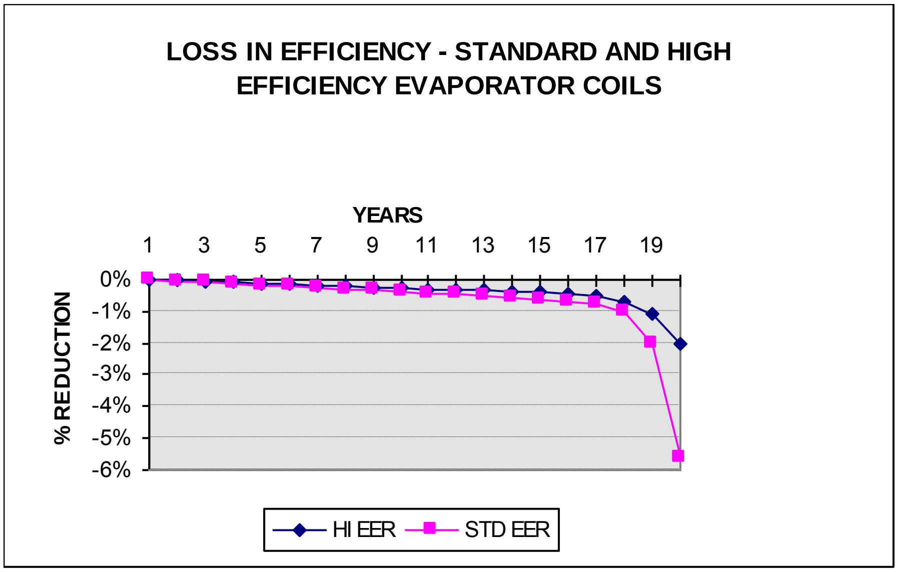

Figure 3-2 - Evaporator coil test results

Tests on the condenser coils demonstrated that the performance of the units was reasonably unaffected by loss of air flow. The combination of evaporator and condenser fouling resulted in the loss of performance due to flood-back of refrigerant to the compressor. As predicted, the efficiency and energy use dropped due to fouling of the evaporator and the efficiency dropped while the energy use increased by fouling the condenser.

The standard efficiency and high efficiency condenser coils have similar fouling characteristics. The high efficiency unit was able to maintain a higher overall efficiency and thus have a longer life expectancy and operating efficiency. Figure 3-3 shows the results of the testing.

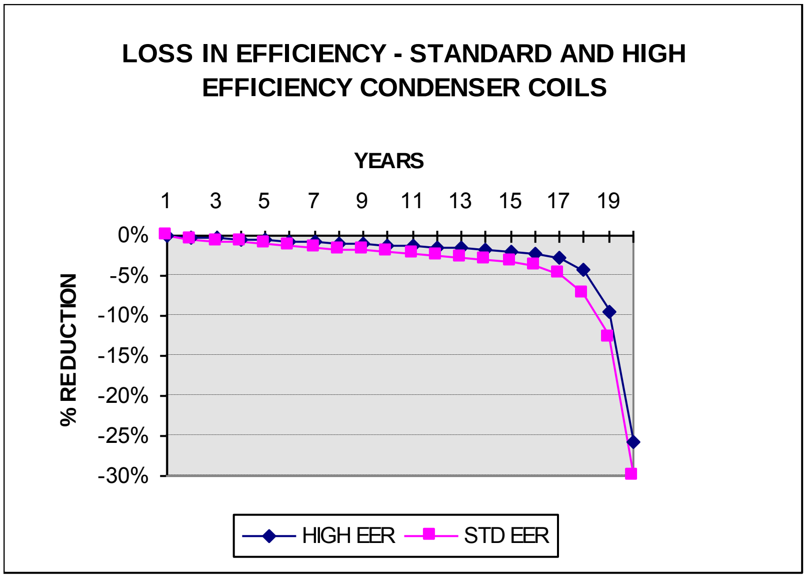

Figure 3-3 - Condenser coil test results

The TDF presented for Commercial DX AC was the evaporator coil fouling profile. The TDF was calculated for both evaporator coil fouling and the combination of the evaporator and the condenser coils fouling. The combined coil fouling projection trended slightly higher, but was within 1% until the last four years. The evaporator profile was chosen to represent the measure for two reasons: the expected life of a Commercial DX AC unit is 15 years and during that time there was little difference and, if any cleaning was done to the condenser coil during those 15 years, there would be no degradation.

It should be noted that the performance of the air conditioners and the TDF are not at all similar. Fouling of each coil produces a profoundly different change in capacity and energy use. This study focused on quantifying the difference between the performance of standard and high efficiency equipment. Considering this data, maintenance programs could be created to meet specific load and performance objectives.

4 RECOMMENDATIONS - Commercial DX AC

4.1. General Recommendations

This study provides a significant baseline for establishing the impacts of coil fouling on the operation of commercial package ac units. Competent commissioning of the units at the initial installation will provide the information needed to determine the present condition of the unit and the effect of coil fouling on the operation of the unit. More work needs to be done to evaluate the environmental characteristics that impact coil fouling.

4.2. Equipment Purchase

PEG recommends the purchase of high efficiency commercial air conditioner equipment. The results of the testing showed that the high efficiency coils start with and maintain a higher efficiency than standard efficiency coils. The slower degradation rate will increase the life of the equipment and use less energy over the operational lifetime.

4.3. Coil Cleaning

PEG recommends that the condenser coil be cleaned on a periodic basis or at least after an effective 10 year life. The evaporator coil should also be cleaned if possible. The TDF table for Commercial DX AC is based on the evaporator contamination profile. If the condenser coil is in an uncontaminated location or is cleaned once during its useful life, it will not have significant impact on the efficiency of the unit.

Contamination of coils in the field varies dramatically. Extremely harsh environments or high loading of the equipment will alter the “effective age” of the equipment. The historical data show that the effective age can vary by a factor of three. Both the standard and high efficiency units would be exposed to the same environment. In all cases, the high efficiency unit will continue to perform better than the standard efficiency unit. In all cases, the largest problems occur at high levels of coil contamination.

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