95.102A

Prepared by:
Proctor Engineering Group, Ltd.
San Rafael, CA 94901
(415) 451-2480

Persistence of Savings: An Assessment of Technical Degradation

Prepared for:
1997 Energy Evaluation Conference

Final Report
November 5, 1997

Author:
Michael Blasnik

PERSISTENCE OF SAVINGS: AN ASSESSMENT OF TECHNICAL DEGRADATION

Michael Blasnik, Proctor Engineering Group, Boston, MA

Introduction

The persistence of savings is a key aspect in assessing the net life cycle benefits of energy efficiency measures. There have been few studies undertaken which directly measure savings persistence due to the formidable experimental design obstacles inherent in analyzing long-term longitudinal energy consumption data. Instead of attempting to measure overall savings persistence, evaluators and policy makers have focused research efforts on measuring specific identifiable aspects of persistence. A number of measure retention studies have been, and are being, performed to assess true useful measure life under field conditions. In addition to measure retention, technical degradation and market effects (*net* persistence) are two other key aspects of savings persistence which have been identified. This paper presents the methodology and results of a study of relative technical degradation performed for the California DSM Measurement Advisory Committee (CADMAC).

The study focused on 13 key measures identified by major California electric and gas utilities as providing the bulk of expected DSM program benefits. The measures ranged from residential air conditioners to commercial lighting, drives, motors, and cooking appliances. The overall approach involved a combination of an exhaustive search for existing information on the technical degradation of efficient and standard measures and an engineering analysis of specific design differences between the two measures. Conclusions were drawn for measures where sufficient evidence was found that relative degradation was either zero or negative (increasing savings over time). For measures where considerable uncertainty remained, research plans were developed to collect the needed data for assessing relative degradation.

The study found that, although little hard data on technical degradation is available, strong and defensible conclusions concerning technical degradation could be developed for nearly all measures. For most measures, the engineering analysis was able to determine that efficient measures suffer from comparable or less technical degradation than the standard measures which they replace. For two of the thirteen measures, significant relative degradation was deemed possible and conclusions could not be drawn.

The results of the study are being used by CADMAC to refine estimates of measure persistence and overall net DSM program benefits. The study also provided recommendations for retention study design concerning technical degradation issues which were deemed premature failure/removal. The study could also be useful to others in assessing some of the technical issues related to promoting efficiency measures.

Research Objectives

The project is part of a multi-faceted approach to estimating the persistence of energy savings from DSM programs in California. The general research question which this study was 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 standard measures they replace?*

More specifically, the project sought to quantify the annual changes in energy savings which can be expected over the effective lives of specific measures due to any differences in the technical degradation rates of the efficient measures compared to the baseline measures.

The focus of the project was on longitudinal changes in the energy usage associated with the measures. The analysis timeframe was from the period covered by the first year impact evaluation (defining the base level of performance) through the end of the measure's useful lifetime as determined in the California evaluation protocols or by another CADMAC study. Changes in energy usage due to operating conditions, product design or human interaction were included within the scope of the project. Types of degradation which do not affect energy usage, but only level of service were examined where applicable but were not the focus of this project and have not been subject to the same level of research and analysis.

The research question was interpreted to exclude premature measure failure or removal in order to avoid overlap with retention studies.

Study Measures

Measures were selected for inclusion in this project by the sponsoring utilities on the CADMAC subcommittee based on the measures' contribution to overall DSM program resource value. The final list of efficient and baseline technologies selected for the study are shown in Table 1.

Table 1. Study Measures

Efficiency Measure	Baseline Technology
Residential Central A/C - high efficiency.	Std. SEER A/C
Commercial A/C - Package DX	Std. eff. unit
Oversized evaporative cooled condenser	Air cooled condenser
Refrigerator - high eff.	Std. eff. refrigerator
Electronic ballast	Eff. magnetic ballast
T8 with elec. ballast	T12 w/eff. mag. ballast
Reflector & delamp	Standard Fixture
Metal halide lighting 250-400W	Mercury Vapor 400-1000W
Occupancy sensor	On/off switch
Motor - high efficiency	Std. eff. motor
Adjustable speed drive for HVAC Fan	Variable inlet vanes or damper
Infra-red gas fryer	Std. atmospheric fryer
Residential ceiling insulation	Std. insulation levels

Several of the measures encompass a wide variety of specific products with differing characteristics. For example, higher efficiency air conditioner designs may involve changes to evaporators, condensers, compressors, refrigerant metering devices, and fans. In order to focus the research on the most applicable design characteristics, considerable effort was expended to identify the particular products that were most representative of the California market. In some instances, program databases had to be analyzed to calculate market shares for specific products and then dealers and distributors were interviewed to identify comparable baseline products.

Analysis Approach

The overall analytical approach for the project was based on the assumption that there would be little data available concerning measure degradation and that any available data was likely to represent only certain measures or technologies, operating conditions, and time frames. To help overcome the lack of available data, a systematic engineering analysis of technical degradation for each measure would be developed to act as an analytical framework for the project.

The goal of the engineering analysis was to identify, understand, and quantify the underlying mechanisms of technical degradation for each measure. Once the physical causes for changes in performance of a measure are understood, then existing information can be fully and appropriately utilized in assessing any technical degradation. The analysis plan involved employing a combination of engineering and statistical techniques to estimate degradation rates and/or identify key uncertainties.

We also anticipated that engineering analysis alone may be able to determine or put bounds on degradation rates for some measures. While engineering methods have often been found to be biased in developing point estimates of program impacts due to inaccurate inputs/assumptions and oversimplified algorithms, their application in this project was quite different in that we were generally seeking only the sign (i.e., direction) of the effect, not an estimate of its magnitude.

If the result of the analysis indicated substantial uncertainty for a measure, then the engineering framework would be utilized to help develop optimal research and sampling plans for estimating relative performance changes. By identifying the key performance factors and sources of uncertainty, the analysis would allow these plans to focus on just one or two factors which are amenable to quick laboratory tests or simple spot measurements over time instead of expensive long-term monitoring.

Data Collection

The data collection plan included an exhaustive search of available studies, papers and reports along with extensive efforts to locate unpublished “gray” literature from researchers, utilities, and manufacturers concerning performance degradation characteristics of the measures. A general literature search was carried out utilizing journal and periodical indexes, internet search facilities, and fee-based on-line database search services. We interviewed numerous manufacturers, industry associations, utilities, government agencies, national laboratories, and researchers. As expected, existing empirical data on performance changes over time was limited for most measures. However, there was often sufficient information available for pursuing an engineering analysis of degradation.

Findings

We were able to utilize the information that was available to develop a systematic engineering analysis of technical degradation for each measure.

The engineering analysis found that relative degradation is very unlikely for ten of the thirteen measures. Indeed, some measures (residential air conditioners and refrigerators) are likely to degrade less than their standard efficiency counterparts, resulting in increasing savings over time, or “negative” degradation. In one case, HID lighting, a small and quantifiable degradation was found. In three cases (occupancy sensors, optical reflectors, and adjustable speed drives), the potential degradation mechanisms were considered related to measure retention and further investigation would be best performed via retention studies. In two cases (commercial package air conditioners and oversized evaporative cooled condensers), the engineering analysis found that potentially significant relative technical degradation could occur and therefore research plans were developed to collect additional information.

While few measures were found to suffer from relative degradation, many measures are likely to experience absolute degradation (i.e. decreases in efficiency over time). In particular: air conditioners, refrigerators, fryers, and insulation may all suffer from absolute technical degradation. However, this degradation tends to lead to stable or increasing savings over time relative to the standard measure.

Measure specific analysis results are briefly summarized below.

Residential Central Air Conditioners

The major design differences between the standard and high efficiency units involved the size of the condenser and, in some units, the type of the compressor. The condenser size increase typically involved doubling the face area and minor changes to the condenser fan. The engineering analysis of potential degradation mechanisms found that heat exchanger fouling could degrade the performance of both the standard and efficient units. However, the increase in face area for the efficient unit should lead to a lower rate of degradation primarily due to the lower sensitivity of systems with oversized heat exchangers to changes in heat exchanger capacity.

Figure 1 shows the relationship between condenser face area and normalized efficiency based on air conditioner simulations performed using the Oak Ridge National Laboratory PUREZ model. The condenser area and efficiency are both normalized (i.e., expressed as percentages relative to a baseline system). The figure shows that a 60% increase in the effective heat exchange area of the baseline unit improves efficiency by about 11%. A 120% increase in area only improves efficiency by about 5% more. The nature of this relationship has important implications for assessing fouling impacts because fouling may be viewed as a decrease in effective heat exchange area (although the actual effects may be reduced air flow, lower surface heat transfer rates, and reduced area).

One could estimate the impacts of a given amount of fouling on the efficiency of systems with differing condenser sizes by expressing the fouling rate in terms of a percentage change in effective area. For example, if fouling reduced effective area by a third each on systems with standard and doubled condenser areas, then the effective normalized areas after fouling would be .67 and 1.33, respectively. The efficiencies of these systems would change from 1.00 to 0.87 for the standard system and 1.14 to 1.07 for the efficient system. Therefore, percent savings would increase from 12.3% to 18.7% and kWh savings would increase to 21.5% of the baseline system's initial usage. Energy savings increase from equal fouling percentages because the system with the oversized condenser is less sensitive to changes in effective area than the system with

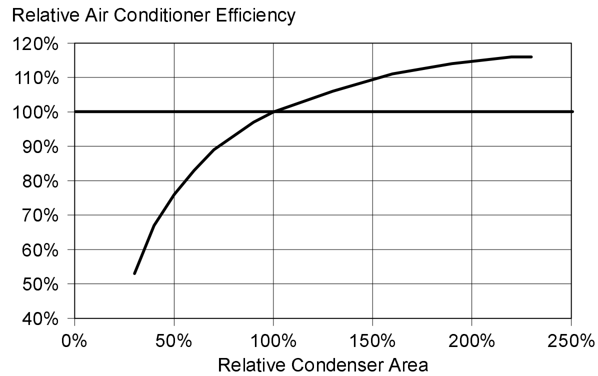

Figure 1. Condenser Area and System Efficiency

the standard sized condenser -- the efficiency curve is flatter with a larger condenser.

Therefore, relative degradation will only occur if the relative rate of fouling for the efficient unit's heat exchanger is significantly greater than the standard unit's rate.

The use of scroll compressors in some of the more efficient units was also examined and again the efficient unit was found to be less likely to experience degradation than the baseline unit.

We did conclude that the small percentage of efficient units which utilize tighter fin spacing on the evaporator may experience some relative degradation from increased fouling. In addition, some efficient units have TXV instead of orifice refrigerant metering. TXVs may experience positive or negative degradation depending on the circumstances. Overall, we concluded that the potential magnitude of relative degradation due to fin spacing and TXVs on a modest percentage of units is likely to have a much smaller impact on overall savings than the long-term superior performance expected from the other design changes. We also examined other performance factors such as refrigerant charge problems, duct leakage, and evaporator air flow and no relative degradation for the efficient unit was indicated.

Based on detailed component and system level analyses of design differences, we concluded that the high efficiency residential central air conditioners rebated in 1994 are unlikely to experience relative performance degradation compared to baseline units. In fact, they are more likely to exhibit superior long-term performance.

Commercial Package Air Conditioners

Commercial package air conditioners are similar in many ways to their residential counterparts. However, instead of increasing face area, cost and space constraints led the manufacturers to increase heat exchanger surface through additional tube rows. Heat exchangers with more rows may foul more rapidly, causing relative degradation. Insufficient information was found to identify the net impact of this design change on degradation and therefore we concluded that additional research is needed. A research plan was needed to assess degradation.

Oversized Evaporative Cooled Condenser

This measure involves replacing air cooled condensers with evaporative cooled condensers in supermarket refrigeration applications. Oversized evaporative cooled condensers may suffer from scaling. The rate of scaling depends on proper water treatment, bleed rates, and spray patterns. Monthly maintenance contracts with water treatment companies are common. Industry sources provided widely varying estimates of the frequency and severity of scaling problems and the effectiveness of standard maintenance practices. Some sources suggested that efficiency problems are common due to inadequate bleed rates set by water treatment companies attempting to reduce the amount of treatment chemical required. The potential impact of scaling is severe and can lead to failure to meet the required loads. Air cooled condensers can also degrade due to fouling and, in coastal areas, corrosion. We concluded that there is insufficient information to assess the relative degradation of evaporative cooled condensers. A research plan was needed to assess degradation.

Residential Refrigerators

The major design differences between the efficient and standard units involved compressor efficiency and motors. Some units also increased heat exchange area and one unit used an improved defrost control. Research on compressor degradation found that compressor performance is fairly constant over time and that the design differences between the efficient and standard compressors are unlikely to lead to relative degradation. The higher efficiency motors are also unlikely to lead to any relative degradation. Other minor design differences were also examined and again no relative degradation mechanisms were found.

While no relative degradation mechanisms were identified directly from the design differences, We did locate some measured data which indicated that refrigerators may suffer from significant performance degradation with usage increasing by 5-10% early in the life of newer units and perhaps much more over the life of older units.

We examined degradation mechanisms common to new efficient and baseline units in order to assess whether some mechanism may affect the two types of units differently. We performed a detailed analysis of insulation R-value degradation and gasket leakage as two potentially significant common degradation mechanisms which could explain the usage increases. That analysis indicated that degradation of foam insulation R-value may increase energy usage by 5%-10% over the first one or two years and perhaps by 20% over the life of a refrigerator. However, because the high efficiency units have more efficient compressors and motors, this degradation would lead to increasing energy savings over time when compared to baseline efficiency units ("negative" relative degradation). The same conclusion would hold for any factor which increased cabinet loads (e.g., gasket deterioration) because identical increases in cabinet loads lead to essentially equal percentage increases in energy usage for both units, which leads to a larger absolute difference in usage.

Based on the analysis of design differences and common degradation mechanisms, we concluded that efficient refrigerators will not experience relative degradation compared to the baseline efficiency units. Instead, the savings from high efficiency units are likely to increase over time due to degradation mechanisms which affect both units by an equal percentage.

Electronic Ballasts

The superior performance of electronic ballasts arises from high frequency operation (which improves lamp efficacy) and reduced losses from solid-state circuitry. Neither of these performance enhancements will lead to relative degradation. High frequency operation provides a fundamental improvement which will not degrade. Transformer and other losses are generally stable in both types of ballasts (some magnetic ballasts may experience a small increase in usage from capacitor failure). All sources contacted noted that the power draw of a fluorescent lighting system is very stable over time. Although system power draw does vary with lamp bulbwall temperature, no long term usage trends occur. In terms of light output, poor electronic ballast designs may adversely affect lamp lumen maintenance and life. However, most newer ballasts have overcome these problems. We concluded that electronic ballasts will not suffer from relative degradation.

T8 Lamps with Electronic Ballasts

T8 lamps have improved efficacy compared to standard T12 lamps because of their smaller diameter and superior phosphor composition. Fluorescent lamp efficacy improves as the tube diameter decreases. In addition, smaller diameter tubes allow more of the lumens produced to exit the fixture, providing for better illumination of the space per lumen. These performance benefits from a smaller diameter tube will not lead to relative degradation. T8 lamps also use rare earth phosphors with fundamentally better efficacy than standard phosphors. These improved phosphors also provide for better lumen maintenance over time. Lamp manufacturers take advantage of this fact, along with the improved luminaire light output per lumen, to further reduce lamp wattage. The net result is that T8 lamps typically provide fewer initial lumens than comparable T12 lamps, and may even provide fewer mean lumens, but will tend to provide the same average level of illumination to the space. We concluded that T8 lamps with electronic ballasts will not suffer from relative performance degradation compared to standard T12 lamps with efficient magnetic ballasts.

Optical Reflectors and Delamping

Not surprisingly, the energy savings from delamping after reflector installation are unlikely to degrade. The retrofit may increase the power draw of the remaining lamps due to thermal effects, but this change occurs immediately, not over time. The CADMAC subcommittee was more concerned with relative degradation in light output from reflector retrofits.

We examined surface depreciation, dirt depreciation, and interactive effects as the key factors which may cause relative light output degradation. Both reflectors and standard luminaire surfaces may depreciate over time. The little data available (from one manufacturer performing a limited range of tests) suggests that their front-reflective silver film reflector surfaces do not significantly depreciate due to ultra-violet, moisture, temperature cycling, or dirt build-up. These tests did not examine potential depreciation caused by abrasion or chemical attack from improper cleaning. In summary, we concluded that, while existing data are encouraging, there is insufficient information available to determine whether reflector surfaces may experience a relative degradation in light output over time compared to standard luminaires. However, we did identify a potentially more important light output degradation mechanism. Much of the apparent ability of reflector retrofits to maintain pre-retrofit illumination levels is due to lens cleaning and installation of new lamps. The impacts of these actions will degrade over time as standard maintenance schedules are re-established.

Overall, we conclude that energy savings from reflector retrofits will not degrade over time. However, light output may experience relative degradation due to reflector surface depreciation and, perhaps more importantly, the short-lived benefits of lens cleaning and relamping performed during the retrofit. Light output issues need to be explored in retention studies.

HID Interior Metal Halide Lamps

Metal halide and mercury vapor lamps are two types of high intensity discharge (HID) lighting. The primary difference is that the metal halide lamp contains certain combinations of metals in addition to the mercury vapor in the discharge gas. These metals improve lamp efficacy and shift the radiation spectrum to provide better color rendering. HID lamps are operated using ballasts with a variety of designs, making generalizations difficult. The most common lamp/ballast combinations for mercury vapor lamps produce a constant power draw over the life of the lamp. However, metal halide lamps experience rising arc voltage over time. This increase in arc voltage will lead to increased power draw of about 3-5% over the life of the lamp. Lower wattage systems (<175 W) will not experience these energy usage increases due to differences in ballast design.

The net effect of the increasing energy usage over time will be a modest reduction in average savings of about 4%. The values of specific degradation factors for use in adjusting annual savings estimates depend upon not only the actual rate of usage increase, but also the nature and timing of the first year impact evaluation, the annual lamp operating hours, the lamp life, and relamping strategies. A table showing degradation factors under a variety of assumptions was developed to aid in applying the results.

In terms of light output, metal halide systems have comparable initial and mean lumen ratings as the mercury vapor systems which they replace. Differences in rated lamp life, variations in lamp/ballast/fixture combinations and interactions, and differing shapes to the lumen depreciation curves provide a complex set of factors for comparing light output over time. However, manufacturers and lighting experts all consider the lumen maintenance characteristics of metal halide lamps superior to those of mercury vapor.

Occupancy Sensors

The performance of an occupancy sensor may be considered unsatisfactory if it fails to turn and keep the lights on when the space is occupied or fails to turn and keep the lights off when it is unoccupied. The former situation has been known to create annoyances to occupants and may lead to the system being defeated, but does not otherwise reduce energy savings. The latter situation may occur due to false detection of occupancy and would reduce energy savings. Both major types of sensors (passive infra-red and ultrasonic) are subject to both types of problems. However, this study is only concerned with factors which may change sensor performance over time.

The only direct technical degradation mechanism identified was dust or dirt accumulation on the detection ports, leading to decreased sensitivity. While no data on this effect were found, reduced sensitivity would not reduce energy savings because the lights would turn off more often. But if this reduced sensitivity caused occupants to over-ride or tamper with the system, energy savings would be compromised. These potential occupant interaction problems need to be explored through retention studies.

Motors

High efficiency motors have lower losses than standard efficiency units due to many changes in materials, design, and manufacture. Core losses are reduced by the use of high grade silicon steels, thinner gauge material, improved interlaminer insulation, and changed core dimensions. Stator and Rotor I^2R Losses are reduced by improved slot designs, increased copper content, and increased cross-sectional areas of the rotor bars and end rings. Friction and windage losses are reduced by modifications to the ventilation system. Stray load losses are reduced through maintaining a concentric air gap, the use of coil spans in the winding, and improved casting of the squirrel cage. These design differences between standard and high efficiency units are primarily due to fundamental changes in materials and dimensions which are unlikely to degrade over time.

Researchers and manufacturers agree that motors do not degrade in efficiency over time unless they are improperly rewound. Operational problems which reduce the efficiency of the motor (e.g., bearing and insulation failure) rapidly lead to motor failure, not continued operation at reduced efficiency. A key study which supports these conclusions measured actual in-field efficiency of older motors and found that there was no performance degradation in units that had never been rewound.

Manufacturers and researchers stated that high efficiency motors are more reliable and less prone to problems than standard efficiency units because of their design, materials, and lower operating temperatures. In one manufacturer's accelerated life and extreme operating tests, high efficiency units had double the expected life of standard efficiency units. These tests also found that high efficiency motors are better able to withstand overloads, frequent starting, voltage and frequency variations, high ambient temperatures, and high elevations.

Our analyses of relative and absolute performance degradation mechanisms and other operating factors which may influence energy savings from efficient motors all indicated that there will be no relative degradation in energy savings over time when compared to standard efficiency motors.

Adjustable Speed Drives for HVAC Fans

Pulse width modulating adjustable speed drives are solid state devices with no moving parts. The primary components, rectifier and inverter, are not subject to performance degradation but may fail due to manufacturing defect or overheating (which is a well known problem, particularly when unit ventilation rates are low and/or air quality is poor). No efficiency degradation mechanisms were identified and any significant increase in losses would be quite unlikely without causing overheating and drive failure. Interactions between ASDs and motors were also explored and have been noted as a source of potential reliability problems. However, no evidence of motor efficiency degradation over time due to operation with an ASD was found.

While system efficiency is unlikely to degrade over time, overall energy savings may decline due to changes in control settings (e.g., from sensor degradation or changes in set points). One study identified changes in pressure control settings as a key factor in reduced energy savings at some sites with ASD control of VAV systems. No other information on sensor problems or improper control settings was located, but significant savings degradation could occur if these events are common. We concluded that ASD savings may degrade over time due to control problems and that these issues would be best addressed in the context of measure retention studies.

Infra-red Gas Fryers

Infra-red gas fryers are more efficient than standard atmospheric designs due to three design differences: burner/combustion design, vat/heat exchanger design, and ignition system. The burner efficiency improvements account for approximately one third of the savings and may degrade if the combustion air inlet to the blower becomes blocked or fouled. However, the standard atmospheric burner design may also experience fouling such as dust and grease accumulation in the burner ports. Neither of these problems are believed to be common and the average net impacts on efficiency should be small. Vat and heat exchanger design differences account for nearly half of the savings and are unlikely to degrade over time. It is more likely that the standard immersion tube design will suffer from degradation due to fouling and difficult maintenance. Some infra-red units use a split vat design to achieve even greater energy savings. These additional savings should not degrade over time. Infra-red fryers also use an electronic ignition instead of a standing pilot light. While electronic ignition can suffer from reliability problems, the energy savings will not degrade.

In summary, the energy savings from infra-red fryers could degrade slightly due to some units experiencing problems with combustion air supply. However, other design advantages are at least as likely to create an offsetting amount of "negative" degradation. We concluded that infra-red fryers are unlikely to experience an overall average degradation in energy savings relative to standard atmospheric fryers.

Residential Ceiling Insulation

Energy savings from increased levels of attic insulation depend on proper coverage and performance of the material at rated R-value and may be reduced by parallel heat transfer mechanisms into the attic (air or duct leakage and other "thermal bypasses"). Performance degradation may occur over time if the insulation is removed, compressed, disturbed, or damaged. We investigated five mechanisms which may lead to these circumstances: human intervention, settling, wind shifting, moisture damage, and animal disturbance.

A literature review and discussion with insulation contractors and weatherization practitioners identified human intervention as the primary potential cause for degraded performance of blown and batt fiberglass (the most common material used in the California programs). In particular, the use of attic space for storage and disturbances/removal of insulation from contractor activities (e.g., cable TV, alarm, electrical, and HVAC contractors) were identified as two common causes for performance degradation. Heat transfer calculations were used to assess a "worst case" insulation disturbance scenario involving these events. The calculations indicated that the absolute rate of heat loss will increase by about the same amount in attics with the higher and lower insulation levels. Therefore, while disturbances to attic insulation caused by human intervention may have a large impact on heat loss, no significant relative degradation should occur from higher insulation levels.

The lack of savings degradation from attic insulation is also supported somewhat from the encouraging results of billing analysis-based persistence studies of residential weatherization (which typically have attic insulation as a key component). In particular, a carefully performed persistence study covering a seven year period found that net savings were stable or increasing over time. While the stability of these savings over time may be due to many factors, including comparison group usage increases, they tend to refute the idea that insulation savings are significantly degrading over time. In summary, no mechanisms for significant relative degradation were identified and available studies support this conclusion. Therefore we concluded that the energy savings from increased levels of attic insulation will not degrade over time compared to the standard levels.

Further Research Plans

Research plans for assessing relative degradation for the two measures identified in the engineering analysis were designed to balance the need to develop reliable answers in a reasonable time frame while not expending more effort than the answers are likely to be worth. The plans focus on assessing particular technical degradation mechanisms which had been identified. The research designs are adaptive, in that the results of early phases of the research may affect the level of, or need for, future phases. This approach was taken because of the unique nature of these projects and the associated uncertainty in the variances of the data being collected.

The commercial package air conditioner plan involves two stages. In the first stage, laboratory testing will be used to simulate a variety of heat exchanger fouling scenarios and measure performance impacts. This testing may find that no relative degradation will occur, and the research will be complete. If the testing indicates that a small amount of relative degradation may occur, then the involved parties may be able to agree to default estimates of degradation factors, avoiding more costly research. If the testing indicates that large relative degradation may occur, then a model which relates measurable fouling parameters to system efficiency will be developed and field testing will be used to collect data needed to quantify the relative degradation rate.

The evaporative cooled condenser plan involves a relatively large number of brief site visits to characterize the population and typical field conditions (including a visual assessment of fouling/scaling) with more intensive site testing and modeling of a selected sub-sample of these sites. A combination of test data, population characteristics, and engineering simulations will be used to quantify relative degradation.

Installation, O&M, and Retention Issues

The performance and useful life of most efficient and baseline measures depends upon installation, operation, and maintenance practices. These factors were included within this study to the extent that they were found to influence relative changes in measure performance over time.

The scope of this study involved examining how performance may change over time *after* a measure is installed. Therefore, installation problems are only accounted for to the extent that they may lead to continuing performance changes over time. The immediate impacts of any initial installation defects are assumed to be accounted for in first year impact studies. For example, if an air conditioner is improperly installed, any reduction in its initial efficiency is not within the scope of this project but should instead be captured in a first year impact study. However, if installation defects lead to continuing declines in efficiency over time, then those effects are within the scope of this project.

The potential impacts and interactions of operation and maintenance practices with measure performance were also considered in the analysis. In most cases, the efficient and baseline measures are essentially two variations on the same equipment and therefore maintenance requirements are identical or very similar (e.g., lamps, ballasts, air conditioners, motors, refrigerators, fryers, insulation). The degradation analysis assumes that maintenance would be comparable for such comparable products. In a number of cases, the efficient version of the measure is believed to be more tolerant of poor practices or adverse conditions. However, for commercial package air conditioners, maintenance issues were identified as a key aspect of potential relative degradation.

For several measures, the efficient and baseline technologies are very different and require differing maintenance and operating procedures (e.g., evaporative vs. air cooled condensers, reflectors, occupancy sensors, adjustable speed drives). These differences were considered in the degradation analysis. In the case of evaporatively cooled condensers, maintenance is a key issue and a focus of the research plan. In the case of reflectors, maintenance issues may affect light output, but not energy savings. For occupancy detectors, dust build-up may lead to occupants changing control settings or over-riding the system. For adjustable speed drives, operators may over-ride the system or adjust settings which compromise savings. For each of these three measures, the CADMAC subcommittee determined that these issues should be addressed through retention studies.

The retention issues identified in this project need to be communicated to any parties performing retention studies on these measures. In particular, retention studies for reflectors need to measure light output, studies for occupancy detectors need to record control settings, and studies for adjustable speed drives need to examine control settings and sensor calibrations.

Conclusions and Next Steps

The project results were quite encouraging. The analytical approach developed and employed in the study has proven to be quite successful in providing strong conclusions concerning relative technical degradation rates, even though empirical data were limited. Because of this success, a follow-up study is currently being performed on another group of measures which should complete the analysis in terms of regulatory requirements (total resource value of covered measures equal to at least 50% of total resource value by sector and utility).

Acknowledgments

The research and analysis described in this paper was sponsored by the California DSM Measurement Advisory Committee. The work was carried out with assistance from Energy Investments Inc. and Texas A&M University. The opinions and conclusions expressed are those of the author and Proctor Engineering Group, as is the responsibility for any errors or omissions.