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Negative Technical Degradation Factors
Supplement to Persistence Studies

Prepared for Cadmac

Final Report
October 18, 1998

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EXECUTIVE SUMMARY & INTRODUCTION

The Statewide Measure Performance Studies (*Persistence 1* – PEG 1996 & *Persistence 2* — PEG 1998) were sponsored by the California DSM Measurement Advisory Committee (CADMAC), Persistence Subcommittee to examine the relative technical degradation of demand side management (DSM) measures compared to standard efficiency equipment. In the original studies, existing information was synthesized into an engineering analysis of technical degradation factors (TDFs). The TDFs are yearly multipliers. By applying these multipliers to first year savings, the savings in subsequent years are estimated. 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) By CADMAC directive, negative degradation rates (TDF>1.0) were set equal to one (1.00) in the original studies.

In this supplemental report, the four negative TDFs from the first two studies are estimated. The four technologies covered and references to the original report are given in Table ES-1.

Table ES-1 Measures with Negative TDF Estimates

Efficiency Measure	Original Report	Section #
Air Conditioners D/X - Residential	*Persistence 1*	2.1
Residential Refrigerators	*Persistence 1*	2.3
Process adjustable speed drives — waste water pumps	*Persistence 2*	2.3
Agricultural Pumps	*Persistence 2*	2.7

<u>Air Conditioners D/X - Residential</u> Residential direct expansion air conditioners have larger coil face areas. These were determined to foul at the same rate as conventional equipment. The same level of air-side fouling results in less efficiency degradation for the efficient unit. A TDF was calculated based on the analysis presented in *Persistence 1*.

<u>Residential Refrigerators</u> PEG determined that compressor and fan motor efficiency improvements were the main approaches to higher refrigerator efficiency. These strategies were deemed to result in no absolute technical degradation. Negative relative degradation was found because of cabinet insulation degradation. A TDF was calculated based on the analysis presented in *Persistence 1*.

<u>Process adjustable speed drives — waste water pumps</u> A TDF of one is estimated for this measure based on adjustable speed drives with pumps of diversified time in service ages.

<u>Agricultural Pumps</u> The baseline and efficient measures are the same pump. The abrasive qualities of well water significantly degrade the efficiency of agricultural pumps over time. In the *Persistence 2* report, PEG analyzed a pump test dataset to derive a time in service versus efficiency curve. A TDF was calculated based on this analysis.

TDF Summary Table

Technical degradation factors (TDFs) were estimated for each measure. These estimates are displayed in Table ES-2.

Table ES-2 Summary of TDFs

YEAR	Resid DX AC	Resid Refrig	ASD Process Pumping	Ag Pumps
1*	1.00	1.00	1.00	1.00
2	1.00	1.04	1.00	1.00
3	1.01	1.06	1.00	1.00
4	1.01	1.07	1.00	1.00
5	1.02	1.08	1.00	1.00
6	1.02	1.08	1.00	1.01
7	1.03	1.09	1.00	1.01
8	1.03	1.09	1.00	1.01
9	1.04	1.09	1.00	1.01
10	1.04	1.09	1.00	1.01
11	1.05	1.10	1.00	1.01
12	1.05	1.10	1.00	1.01
13	1.06	1.10	1.00	1.01
14	1.07	1.10	1.00	1.02
15	1.07	1.10	1.00	1.02
16	1.08	1.10	1.00	1.02
17	1.09	1.10	1.00	1.02
18	1.09	1.10	1.00	1.02
19	1.10	1.10	1.00	1.02
20	1.10	1.10	1.00	1.02

* First year savings are one (1.00) by definition. The TDF modifies the first year savings for subsequent years.

1. ANALYSIS OF TECHNICAL DEGRADATION

1.1. Residential D/X Air Conditioners (Persistence 1 Section 2.1)

PEG concludes that energy savings from high efficiency residential air conditioners are unlikely to degrade over time and may actually increase due to a lower degradation rate than standard efficiency designs. (*Persistence 1*, page 12)

1.1.1. Design Differences

From the *Persistence 1* report, PEG determined that the only design difference subject to differential degradation is the condenser face area. Other design differences, such as a scroll compressor, are not expected to experience relative degradation.

> "For residential units, SEER 12 units dominated. The most consistent design modification to achieve high efficiency was a dramatic increase in the condenser face area. This improvement was usually accompanied by slightly increased condenser air flow and reduced fan power. The most popular units coupled this with a scroll compressor. Other units incorporated increased evaporator face area and fins per inch, and used TXV instead of fixed orifice refrigerant metering." (*Persistence 1*, page 5)

> "For condensers in residential systems, the design difference is face area and air flow, not fin geometry or spacing or number of rows. The efficient systems have about twice the face area and 20%-50% greater air flow, leading to 25%-40% lower coil face velocities. There are two reasons why the larger coil units should experience less efficiency degradation than the smaller coil units." (*Persistence 1*, page 8)

1.1.2. Degradation Curve

In the *Persistence 1* report, PEG determined a condenser face area versus EER curve. Because the curve gets flatter at larger face areas, an equal loss in face area affects standard equipment more than high efficiency equipment, Figure 1, (Figure 1, page 9 *Persistence 1*).

> "Second, even if the two condensers experienced the same relative reduction in effective surface area and heat rejection capacity, the impact on system efficiency would be smaller for the larger coil. This smaller impact is due to the non-linear relationship between condenser heat transfer capacity and system efficiency. Figure 1 shows the relationship between condenser face area and normalized efficiency (based on air conditioner simulations performed by PEG using the Oak Ridge National Laboratory PUREZ model)." (*Persistence 1*, page 8)

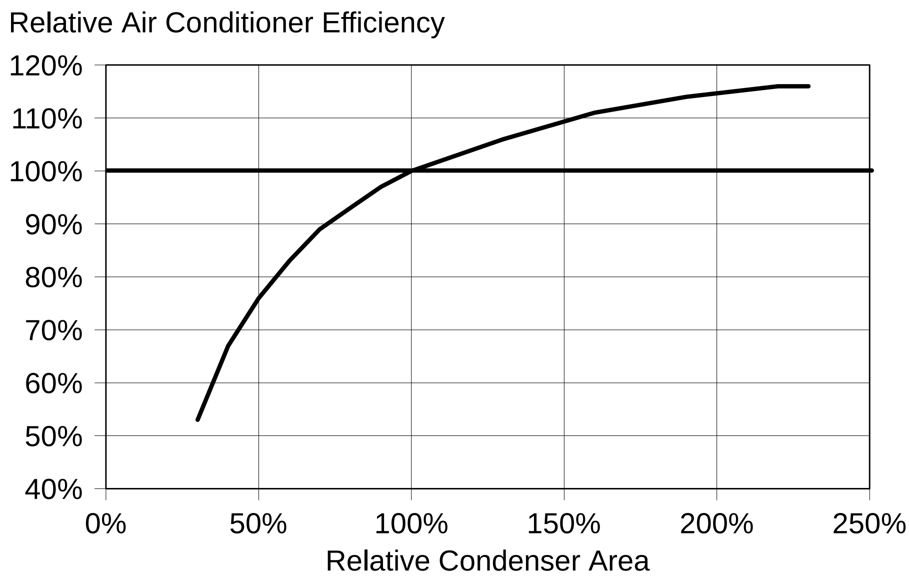

Figure 1-1. Impact of Condenser Area on System Efficiency

> "The condenser area and efficiency are both normalized in the figure (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." (*Persistence 1*, page 9)

1.1.3. Degradation Limit

PEG estimates that the maximum degradation is 45% condenser face surface loss, resulting in a +10°F condensing temperature increase, and 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 ~ 10°F. 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 have malfunctioned." (Jung, 1976, page 20).

1.1.4. Degradation Rate

PEG estimates that the maximum degradation rate is 6.8%/year condenser face surface loss based on Trane (1990) and Braum (1986). Under conditions of accelerated fouling for a multi-row coil, Trane found a 27% efficiency loss. This efficiency loss corresponds to a 54% relative condenser area loss, Figure 1. Since this accelerated fouling is equivalent to 8 years of typical operating conditions, yearly fouling would be 6.8% for commercial coils.

"Trane provided data from an experiment performed in the 1970's where two air conditioners were operated continuously with condensers 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."

This maximum estimate is for commercial multi-row condenser coils. 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).

PEG estimates a diversified degradation rate of 2.5%/year condenser face surface loss for single row residential units, 0.37 of the typical commercial multi-row coils. This estimate is conservative; a higher fouling rate would favor the high efficiency units more. The maximum predicted fouling is not achieved in the estimated 15 year life of the equipment.

1.1.5. Calculation of Persistence

Based on engineering estimates of the impact of condenser area on system efficiency, maximum fouling, and fouling rate; the TDF was calculated, Table 1-1.

Table 1-1 TDF — Residential DX AC

YEAR	TDF
1*	1.00
2	1.00
3	1.01
4	1.01
5	1.02
6	1.02
7	1.03
8	1.03
9	1.04
10	1.04

YEAR	TDF
11	1.05
12	1.05
13	1.06
14	1.07
15	1.07
16	1.08
17	1.09
18	1.09
19	1.10
20	1.10

* First year savings are one (1.00) by definition. The TDF modifies the first year savings for subsequent years.

1.2 Residential Refrigerators (Persistence 1 Section 2.3)

PEG concludes that the energy savings from high efficiency refrigerators will not degrade over time and may actually increase. (*Persistence 1*, page 22)

1.2.1. Design Differences and Degradation

In the *Persistence 1* report, PEG determined that compressor efficiency improvements were the main approach manufacturers used to boost refrigerator efficiency. Based on an analysis of potential compressor degradation mechanisms and research findings, PEG concluded that there is no evidence to suggest that higher efficiency refrigerator compressors should experience any greater performance degradation than standard compressors..

PEG determined that the second most common efficiency increase mechanism is the use of higher efficiency evaporator and condenser fan motors (if used), and that higher efficiency motors are unlikely to suffer from relative degradation.

Other potential design differences were also considered. Overall, the analysis of design differences between the standard and high efficiency units indicated that there should be no relative performance degradation in any of the higher efficiency components.

1.2.2. Absolute Performance Degradation - Foam Insulation

PEG analyzed the potential impact of insulation R-value degradation on refrigerator energy usage. It is well known that urethane foam R-value degrades over time due to outgassing of the blowing agent and, more importantly, air components diffusing into the foam. This degradation may reduce the R-value per inch from an initial value of about 7 or 8 (hr·ft^2·°F/Btu) down to a fully aged value of 5 or 6. To assess the impact of this R-value degradation on the energy savings from the high efficiency unit, PEG performed additional simulations which confirmed that the relative usage impacts of R-value changes are essentially independent of the compressor and motor efficiency.

The increased cabinet loads over time should lead to increased savings (“negative” relative degradation) from the high efficiency units due to their more efficient compressors and motors. The insulation and case of the standard and efficient refrigerator are the same. Both standard and efficient models will experience the same 10% load increase due to the case insulation R-value degradation. However, the standard model will have a larger absolute electrical usage increase due to its using more energy per unit of cooling load. Therefore, absolute energy savings from the high efficiency refrigerator will increase over time as its electrical usage levels increase more slowly than those of the standard unit.

1.2.3. Degradation Curve

The impact of these R-value changes on refrigerator usage was modeled using the EPA’s refrigerator simulation software (EPA 1993). In *Persistence 1*, typical 1993 18 cubic foot top freezer model data were used as a baseline and then a series of simulations were run adjusting the foam R-value incrementally. The results of these runs were fit with a regression model relating foam R-value to energy usage. Energy use impacts by year were calculated by using the R-value degradation function with these simulation results. The resulting performance degradation curve is shown in Figure 2 (Figure 4, page 20 *Persistence 1*).

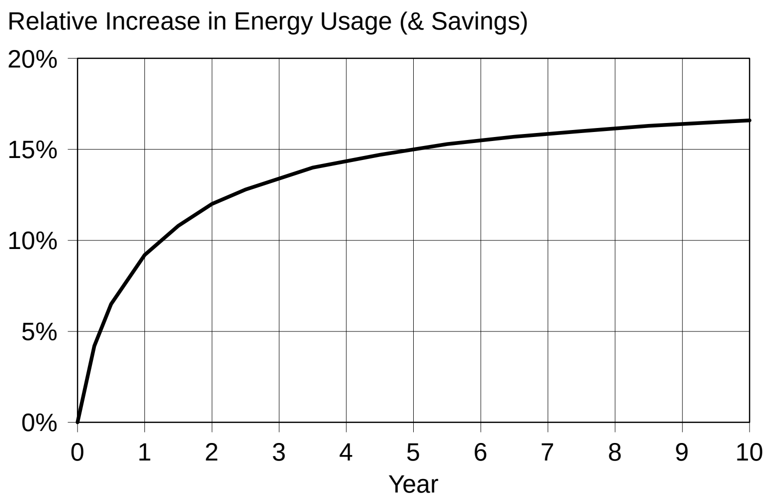

Figure 1-2. Refrigerator Usage Increase from Foam R Degradation

> "If initial savings were measured based on data from the entire first year (which includes a significant fraction of initial degradation), the analysis indicates that savings will be understated by about 4% for the second year, 6% for the third year, and eventually reach a 10% underestimate by year 14. All of these values are based on the assumed R-value degradation rates and the assumption that no other factors are changing over time." (*Persistence 1*, page 20-21)

1.2.4. Calculation of Persistence

The calculated foam R-value degradation curve was used to estimate the TDFs, Table 1-2.

Table 1-2 TDF — Residential Refrigerators

YEAR	TDF	YEAR	TDF
1*	1.00	11	1.10
2	1.04	12	1.10
3	1.06	13	1.10
4	1.07	14	1.10
5	1.08	15	1.10
6	1.08	16	1.10
7	1.09	17	1.10
8	1.09	18	1.10
9	1.09	19	1.10
10	1.09	20	1.10

* First year savings are one (1.00) by definition. The TDF modifies the first year savings for subsequent years.

1.3. Process Adjustable Speed Drives -- Pumps (Persistence 2 Section 2.3)

PEG concludes that savings from Adjustable Speed Drives (ASDs) are unlikely to degrade over time due to changes in measure performance. PEG concludes that savings from ASDs are likely to improve over time due to changes in pump efficiency. (*Persistence 2*, page 2-10)

1.3.1. Absolute Performance Degradation

The energy usage of pumping application depends the characteristics of both the prime mover (electric motor and potentially ASD) and the pump.

In *Persistence 1&2*, PEG concluded that the electric motor and ASD were unlikely to experience technical performance degradation.

An ASD runs a pump slower under conditions of lower load. At slower speeds many of the wear characteristics are reduced. Pump wear increases clearances and reduces pump efficiency. By slowing pump wear, the ASD will maintain the pump efficiency longer than a conventional constant speed drive.

1.3.2. Relative Performance Degradation

Wastewater pumps loose efficiency over their service life due to wear of their internal surface, similar to agricultural pumps. If the pump life is less than the ASD measure life, a negative degradation will result. However, unlike the agricultural pumps which were at known points in the process of wearout and replacement, the wastewater pump could be anywhere in its time-in-service life. If the constant speed and ASD controlled pumps are replaced at exactly the same efficiency, no diversified relative degradation would result due to changes in pump wear. The pump operated by the ASD loses efficiency slower, but is also replaced less often and over time the average efficiencies are equal.

1.3.3. Calculation of Persistence

PEG recommends a TDF of one (1.00) for all years for the ASD process pumping applications, Table 1-3.

Table 1-3 TDF — Process Adjustable Speed Drives -- Pumps

YEAR	TDF	YEAR	TDF
1*	1.00	11	1.00
2	1.00	12	1.00
3	1.00	13	1.00
4	1.00	14	1.00
5	1.00	15	1.00
6	1.00	16	1.00
7	1.00	17	1.00
8	1.00	18	1.00
9	1.00	19	1.00
10	1.00	20	1.00

* First year savings are one (1.00) by definition. The TDF modifies the first year savings for subsequent years.

1.4. Agricultural Pumps (Persistence 2 Section 2.7)

PEG concludes that abrasive qualities of well water significantly degrade the efficiency of agricultural pumps over time. (*Persistence 2*, page 2-34)

PG&E and SCE have provided agricultural customers with pump testing service for many years. To determine an efficiency versus time in service curve, a number of pumps must have known efficiencies at a minimum of two points in their time in service. Pumps tested more than once in PG&E's Ag. Pump MDSS database were analyzed to develop an estimate of the efficiency versus time in service. This analysis within *Persistence 2* lead to the following conclusion:

PEG concludes that energy savings from replacement of the bowl and impeller on agricultural deep well turbine pumps is unlikely to degrade over time and may increase. (*Persistence 2*, page 2-36)

1.4.1. Design Differences

In the *Persistence 2* report, PEG determined that the baseline and efficient measures are the same pump at different points of the time in service versus efficiency curve. The baseline measure is a standard vertical turbine agricultural pump that has worn and is operating at lowered efficiency. The efficient measure is an agricultural pump retrofitted with a new impeller and bowl assembly.

1.4.2. Degradation Curve

Replacement of an agricultural pump will result in immediate energy savings due to the improved efficiency of the new bowl and impeller over the old worn bowl and impeller. The lifetime of the measure is determined by when the worn pump would have been replaced without the intervention of the program.

Calculation Methodology The calculation methodology was documented in Persistence 2. The resulting curve is presented in Figure 1-3 (Figure 2-6 in *Persistence 2*).

> "Pacific Gas and Electric Company's pump test database was cleaned and sorted. One hundred and sixty pumps were identified that were tested at the beginning of their times in service and at other times over their service life. The average initial efficiency was 61.7%. The data are consistent with a linear decay curve for each pump. The overall results can be modeled by a daily linear efficiency decay of .0000328 times the maximum measured pump efficiency. The confidence interval on the decay estimate was ± .0000097 at 95%. Figures 2-6 and 2-7 show the efficiency decay as a function of the fraction of service life (where service life is estimated to end at 90% of the maximum tested efficiency) based on efficiency at most recent test." (*Persistence 2*, page 2-34)

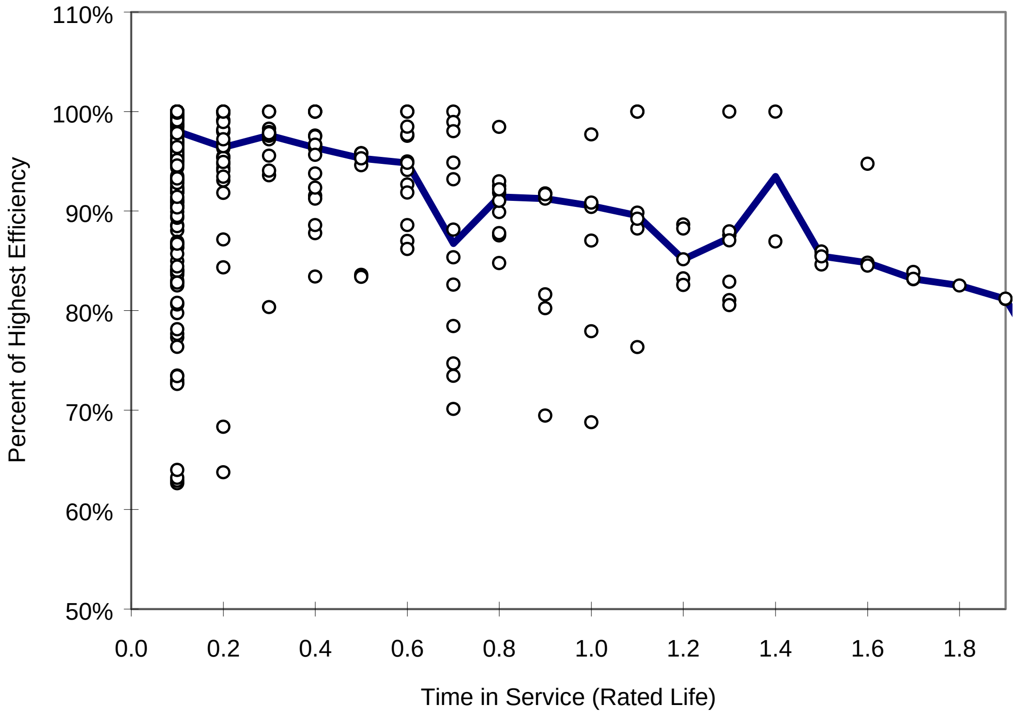

Figure 1-3 Efficiency Degradation vs. Time in Service

1.4.3. Calculation of Persistence

Average maximum efficiency was estimated as 63.8%. Based on the analysis of the pump test dataset, the baseline pump was modeled as 7 years old. This savings increases over time and results in a TDF greater than one. Calculated TDFs are presented in Table 1-4.

Table 1-4 TDF — Ag Pump

YEAR	TDF
1*	1.00
2	1.00
3	1.00
4	1.00
5	1.00
6	1.01
7	1.01
8	1.01
9	1.01
10	1.01

YEAR	TDF
11	1.01
12	1.01
13	1.01
14	1.02
15	1.02
16	1.02
17	1.02
18	1.02
19	1.02
20	1.02

* First year savings are one (1.00) by definition. The TDF modifies the first year savings for subsequent years.

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