USE OF COMMERCIAL ENERGY EFFICIENCY MEASURE SERVICE LIFE ESTIMATES IN PROGRAM AND RESOURCE PLANNING

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ABSTRACT

The cost-effectiveness and reliability of energy efficiency measures is highly dependent on the service life of those measures. To gain a clearer idea of how service life influences the value of efficiency measures to consumers and utilities, the Bonneville Power Administration contracted for a study of service life for energy efficiency measures in commercial buildings. This paper summarizes the methods and results of that study, and describes how the results of such a study can be used for equipment selection, program management and resource planning. The study was based on a series of questionnaires to and interviews with laboratory experts, equipment manufacturers and installers, equipment service and maintenance personnel, equipment users, and research and development specialists.

The fundamental principle presented in this paper is that the duration of energy or demand savings in commercial buildings is dependent on far more than the life of the individual equipment. To understand how long savings will last, one must know what happens when efficiency measures wear out, are removed, or are replaced. Both the engineering characteristics of specific pieces of equipment and the nature of the buildings they are placed in are significant influences on the service life of the equipment. Additionally, the life of energy efficiency measures is highly dependent on the maintenance environment that the measures are placed in. The Xenergy study developed estimates of service life based on current maintenance practices, which, outside of the largest and most sophisticated firms, involve only minimal maintenance. Utility energy efficiency programs which include an active component to support more effective operation and maintenance of equipment will result in longer service lives for many measures. These considerations are used in this paper to develop separate estimates of the life of the hardware vs. the life of the savings for an extensive list of commercial energy efficiency measures.

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INTRODUCTION

The cost-effectiveness and reliability of energy efficiency measures (EEMs) is highly dependent on the service life of those measures. This paper summarizes the methods and results of a study of the service life of EEMs in commercial buildings, and then presents a framework for interpreting that data which is built around the needs of the sponsoring utility. The first section of this paper reviews the methods and results of a study of commercial energy efficiency service life which was performed for the Bonneville Power Administration (McRae, et.al.,1987). The second section presents some problems in interpreting the results in a way which is useful for users. The third section presents an adaptation of that data, with some additional information, for utility resource planning and program management purposes.

DATA COLLECTION CONCERNING SERVICE LIFE OF COMMERCIAL ENERGY EFFICIENCY MEASURES

Approach

Estimates of service life for individual EEMs have been developed using both laboratory tests and surveys of field experience (ASHRAE Handbook, 1984, EPRI, 1976, IES, 1984). However, the work has always covered a limited number of EEMs. Service life estimates were needed by the sponsor of this project for a comprehensive set of EEMs in order to establish the cost-effectiveness of individual EEMs in energy audits, and to analyze the resource value of EEMs in resource models.

Laboratory tests provide the most rigorously collected data on product life, but they tend to imperfectly simulate field conditions. However, laboratory tests generally do not assess many factors which influence how long an EEM actually saves energy. These factors include the care with which an EEM is installed, the maintenance which it receives, the type of building in which it is located, the ambient conditions, the intensity of use, and the characteristics of other equipment which is used in conjunction with the EEM. The life of savings from some EEMs is also affected by changes in building use, such as remodeling, renovation, and demolition of buildings.

To assess the influence of different factors on service life, three definitions of service life for equipment were developed. Test life reflects how long equipment can be operated until it breaks down irreparably if installed, operated, and maintained according to manufacturer's specifications for best performance. Operational life is how long equipment is expected to save energy under typical field conditions, if the equipment is not removed. Effective life considers field conditions, and also considers the impact of obsolescence, building remodeling, renovation, and demolition. For the purposes of this study, renovation was defined as an overhaul of spatial organization and support systems in which most of the lighting systems and all but the most permanent heating, cooling, and ventilation (HVAC) elements are replaced. Remodeling was defined as a redesign of a building's interior which may be substantial enough to result in major changes to the lighting system.

While quality data on test life of some measures is available from laboratory engineers and scientists, authoritative sources for data on operational and effective life are more difficult to find. Sales representatives, design professionals, maintenance staff, and utility field engineers all have experience working with equipment in the field. Unfortunately, each individual has experience with a limited range of equipment, and in a professional context which might skew experience towards undue optimism (in the case of sales representatives) or pessimism (in the case of maintenance contractors).

The research team set out to develop a set of estimates of test, operational, and effective life, using these experts. In order to allow for some interaction between respondents, and to probe the reasoning behind opinions concerning service life, the research team used a version of the Delphi technique (Dickey and Watts, 1978), modified to work with the geographically scattered group of experts and a finite budget. The Delphi method relies on structured feedback between respondents to create a convergence of opinions. As such, its usefulness depends not on the power of statistical sampling techniques, but on the ability of experts to arrive at reasonable judgments concerning complex issues through a series of processes involving feedback between the group and individuals.

For each of several groups of EEMs, a set of highly knowledgeable experts was selected, including individuals in manufacturing, service and repair firms, architects and engineers designing EEMs, users of EEMs, and research and development experts. To meet the needs of the sponsor, people with particular experience in the Pacific Northwest were selected. In selecting the participants, it was recognized that the panel would have greater knowledge of factors limiting test life and operating life than they would of additional factors limiting effective life.

Participants were given a written questionnaire concerning the test life, operational life, and effective life of a list of EEMs. The results of this first round of questioning were averaged. Then, telephone discussions were held with each participant concerning their scores, the average scores, and possible reasons for any differences. In this second round of questioning, respondents were asked if they wanted to revise their original estimates. They were also asked to describe the factors that they believe limit service life. In these discussions, service life was also clarified to mean the age at which 50% of the equipment of this type is retired, and 50% is still in operation. It was also stated at this point that the research team sought the age at which total replacement of the unit occurs, not the age when the first major servicing or repair might be required. For the third round of the Delphi, the draft findings from the study were submitted to the participants. The resulting comments were incorporated into the final results.

In the Delphi, the lives of lamps and ballasts were expressed in hours of operation. This reflects prior research on lamp life (IES, 1984) which indicates that, although the service life of lamps is influenced by the number of times a lamp is started, the hours of operation are a greater influence. Lives for all other EEMs were expressed in years because this is the most accessible way to relate experience with those EEMs.

Assessing the Results

Respondent Estimates of Service Life. Table I presents a summary of the highest, the median, and the lowest estimates of test and operating life, and the number of respondents for each of the EEMs included in the study. The number of respondents differ based on the size of the group of experts polled on various EEMs, and based on the number of respondents who offered an opinion for each EEM and service life definition. Interpretation of the study's results for some EEMs is complicated by the lack of convergence of opinion at the conclusion of the three rounds of the modified delphi. Table I shows a virtual consensus for some measures and a wide range of opinion for others.

Estimates of life for many EEMs showed an inconsistent pattern from one definition to another for some respondents, with many respondents listing longer effective lives than operating lives for certain EEMs. Comments from some of the participants indicated that the effective life category was not clearly understood. Given these problems and the limited expectations from this aspect of the Delphi, most of the data on effective life was judged to be of little use. Data on insulation was also abandoned when comments made it clear that insulation was considered to last as long as the building did.

For some EEMs, the median estimates of test life exceeded that for operating life. Parabolic reflectors provide one example of this. For that EEM, the difference appears to reflect the opinion that field life will exceed the period used in laboratory tests. In other cases, such as motion sensors, a longer average estimate of effective life is shown because a different number of respondents offered estimates of the test life vs. operating life. Since the number of respondents for some EEMs was small, the opinions of individuals could significantly impact the median.

TABLE I. Median Service Lives as Estimated through Delphi (part 1)

EQUIPMENT TYPE:	TEST LIFE Hi.	Med.	Low	#	OPERATING LIFE Hi.	Med.	Low	#
	Median Life Estimates (# of respondents)							
Lamps and Ballasts:	**Life in 1000's of hours:**							
Energy Eff. Fluor. Lamp	20	20	16	(9)	20	18	12	(9)
same w/ built in ballast	10	10	9	(6)	10	9	8	(6)
Eff. Electromagnetic Ballast	58	45	35	(7)	58	45	30	(5)
Electronic Ballast	150	55	35	(4)	70	40	7	(4)
Metal Halide Lamp	20	20	10	(5)	20	10	5	(5)
Low Pressure Sodium Lamp	24	18	18	(4)	24	18	13	(4)
High Pressure Sodium Lamp	24	24	20	(6)	24	21	10	(5)
Lighting Fixtures and Controls:	**Life in years:**							
Parabolic Fixture	40	18	9	(6)	40	20	9	(6)
Dimming Systems	21	15	9	(5)	21	20	9	(5)
On-off Switching	30	11	3	(4)	15	7	3	(5)
Motion Sensor	10	5	4	(5)	10	10	5	(3)
HVAC:	**Life in years:**							
Economizer	25	15	8	(11)	17	12	3	(14)
Chiller Strainer Cycle System	20	18	8	(6)	20	15	8	(8)
Air-to-Air Packaged Heat Pump	20	12	7	(10)	15	10	5	(14)
Water-to-Air Packaged Heat Pump	20	15	6	(9)	20	15	4	(11)
Ice Thermal Energy Storage	25	20	10	(10)	20	19	10	(12)
Water Thermal Energy Storage	30	20	8	(7)	20	20	10	(9)
Plate Type/Heat Pipe Heat Recovery System	25	19	7	(8)	20	14	7	(10)
Rotary Type Ht. Recovery System	25	15	5	(6)	20	11	7	(8)
Heat Recovery from Refrigerator Condensers	20	12	7	(12)	25	11	6	(14)
Low Leakage Dampers	20	12	10	(9)	20	11	5	(11)
Variable Inlet Vane VAV System	20	11	7	(8)	18	11	5	(10)
Variable Pitch Fan for Cooling Tower	20	15	10	(5)	17	13	8	(7)
Make-up Air Unit for Exhaust Hood	20	15	7	(10)	20	10	5	(12)
Air Destratification Fan:								
Paddle Type	12	10	5	(6)	10	10	4	(6)
High Inlet/Low Discharge	25	20	15	(3)	25	15	15	(5)
Air Curtain	25	13	4	(8)	18	10	4	(10)
Deadband Thermostat	25	14	8	(8)	25	13	6	(10)
Spot Radiant Heat	20	10	5	(9)	15	10	4	(10)

TABLE I. **Median Service Lives as Estimated through Delphi (part 2)**

		Median Life Estimates (# of respondents)							
		TEST LIFE				OPERATING LIFE			
EQUIPMENT TYPE:	RESPONDENT:	Hi.	Med.	Low	#	Hi.	Med.	Low	#
Controls:	Life in years:								
Computer Logic Energy Management System		20	15	10	(8)	20	12	6	(9)
Electronic Controls		20	12	5	(7)	20	11	5	(9)
Time Clocks		15	13	9	(6)	15	10	2	(9)
Motors, Drives, & Transformers:		Life in years:							
Standard Electric Motor		25	15	10	(8)	20	15	7	(8)
High Efficiency Elec. Motor		25	17	6	(8)	20	17	10	(8)
Variable Speed DC Motor		25	18	12	(6)	25	18	12	(6)
Var. Speed Drive, Solid State		25	15	10	(7)	25	15	12	(7)
Var. Speed Drive, Belt Type		20	15	4	(7)	20	10	3	(7)
Efficient AC Elec. Transformer		25	17	11	(5)	20	15	8	(5)
Domestic Hot Water:									
Heat Pump Water Heater		17	13	7	(6)	15	10	5	(6)
Point-of Use Heater		25	12	10	(7)	18	12	10	(7)
Solar Water Heater (active)		25	20	15	(5)	20	15	12	(8)
Refrigeration:									
Unequal Parallel Compressors		20	15	15	(6)	20	14	10	(7)
Condenser Floating Head Pressure Control		20	16	10	(4)	20	10	8	(6)
Automatic Cleaning System for Condenser Tubes		25	20	15	(3)	25	15	8	(5)
Hot Gas Bypass Defrost		20	13	8	(6)	15	10	5	(8)
Polyethylene Strip Curtain		10	5	2	(4)	8	3	2	(6)
Refrigeration Case Cover		13	11	8	(4)	13	11	6	(4)
Building Envelope:									
Double Glazing		30	20	13	(7)	30	20	12	(6)
Heat Mirror		15	15	15	(2)	25	18	12	(4)
Low Emissivity Coating		25	20	15	(2)	30	14	12	(4)
Solar Shade Film (Retrofit)		20	10	3	(4)	15	7	2	(5)
Tinted & Reflected Coating		15	15	10	(3)	20	14	5	(6)

Comparison to Other Estimates. The median operating life estimates were compared to service life estimates for eight EEMs based on a previous study (ASHRAE, October, 1978). They were also compared to average estimates of service life for twenty-one EEMs in energy audits from the Bonneville Power Administration's Commercial Audit Program (CAP audits). The estimates from these other sources were usually higher than those in Table I, and sometimes much higher. For example, the median estimate for air-to-air heat pump life of ten years in Table I compares to estimates of fifteen years from the ASHRAE study, and fifteen years from the CAP audits. For efficient AC Transformers, the median estimates are fifteen years in Table I and thirty years from ASHRAE. In one of the few exceptions, both Table I and the CAP audits have median estimates of fifteen years for water-to-water heat pumps, while ASHRAE has an estimate of thirteen years.

Reasons for the Differences in Estimates. None of the three sources are completely independent. The CAP auditors probably made some reference to ASHRAE data when estimating service life. Some of them were also participants in the McRae study. Nevertheless, the differences are significant. While it is likely that each of the three sources used slightly different definitions of service life, the differences described above are probably too large to be explained by definitions alone.

Since the ASHRAE study is ten years old, the McRae study may reflect greater field experience with EEMs. It is also likely that the differences are partially a result of the context in which the estimates were made. Respondents to the modified Delphi were asked to produce three estimates, one of which stressed ideal conditions, and two of which stressed typical conditions. Thus, the McRae study may have succeeded in focusing the respondents on the differences between test and operating life. Also, because service representatives were included in the McRae study, it may reflect more experience with repair and maintenance than the CAP auditors can offer. This theory is supported by the fact that auditors in the Delphi were more optimistic than other participants concerning the lives of many EEMs.

Causes for End of Service Life. The respondents pointed to a number of different factors which influenced the useful lifespan of EEM's.

Deterioration of the product was thought to limit test lives of double glazing, reflective and low emissivity window coatings, variable pitch fans, rotary type heat recovery systems, and economizers. The quality of the product or the manufacturer was noted as a major variable influencing the test lives of most lighting and HVAC EEMs.

For most HVAC EEMs, the respondents felt that the lack of proper operations and maintenance practices resulted in a significant reduction in operating life. Some went so far as to volunteer estimates of what the service life of properly maintained equipment might be. They believed that most equipment is not commonly calibrated, cleaned, and lubricated on a regular schedule. Other studies have indicated that, outside of large owner-occupied buildings, this is often true. (Kolb, 1988) They also felt that poor understanding or inadequate attention to controls often leads to their disconnection or misuse.

Scheduled relamping was thought to shorten the effective lives of many lamps and ballasts, and high operating temperature was cited as a determinant of the operating lives of individual lamps. Respondents explained that operating temperature tends to vary with the design and location of the lighting fixture. In particular, some open design fixtures with parabolic reflectors may operate at a cooler temperature, resulting in longer lamp life.

The operating lives of motion sensors, water thermal energy storage systems, air curtains, all control systems, solar water heaters, unequal parallel compressors for refrigeration, and all building envelope measures except tinted and reflective coatings were thought to be diminished primarily by problems with installation. Operating lives of air destratification fans, air curtains, and most motor, drive, and transformer EEMs were thought to be highly dependent on duty cycle and load factor.

ADOPTING THE SERVICE LIFE DATA FOR UTILITY APPLICATIONS

The sponsoring utility needed to modify the median estimates to reflect some of the information offered in the background comments from the respondents, and to adopt this service life data for a number of purposes. To understand these modifications, it is important to first describe the applications of service life data within the sponsoring utility.

Major Uses of Service Life Data

Energy Analyses for Individual Investment Decisions Regarding EEMs. As part of energy audits of individual buildings, service life data is used to estimate the duration of savings from EEMs in order to project the amount of likely kWh saved by EEMs. Customers use this information when deciding whether they wish to have EEMs installed. The utility uses the data in calculations to determine whether the individual EEMs are potential cost-effective to the utility as an energy resource. If the EEMs are cost-effective, the estimated savings are then used to help determine the level of financial incentives to be offered to consumers.

Resource Planning. To quantify the amount of conservation resource available from all commercial buildings within its service territory, the sponsoring utility simulates a series of EEMs in building prototypes. The simulations provide estimates of typical costs and savings, which are then compared to other candidate energy resources (e.g., coal plants) to develop a least-cost strategy for meeting the agency's energy requirements over the next two decades. Decisions about the funding of near-term efficiency programs are dependent both on the cost of energy saved by the EEMs and on the timing of later opportunities to install them. Within this context, data on the service life of equipment is used to answer two questions:

- How long will the individual EEM save energy?
- Are there physical or first-cost barrier to replacing the EEM with less efficient equipment when it wears out?

If the answer to the second question is affirmative, then the EEM is likely to provide a reliable energy resource for a longer period than the life of the hardware itself. This is particulary important to utilities which are acquiring conservation resources years in advance of need. The installation of many EEMs requires modifications to a system or building which make it unlikely that the user will revert to inefficient equipment. For example, installation of T-8 fluorescent lamps and ballasts dictate that the lamp will be replaced with an equally efficient lamp until the ballast wears out or is removed. This is because the ballasts cannot operate with conventional, inefficient lamps. T-8 assemblies also require a different set of connectors than standard lamps and ballasts, making it a nuisance to replace them with conventional equipment. We can call this a "replacement-certain" measure because it is likely to be replaced with equally efficient equipment until there is a major remodeling or renovation. EEMs in new buildings and major renovations can be replacement-certain if they are installed in conjunction with a downsizing of electrical systems or associated equipment which makes it impractical to revert to inefficient equipment. For example, reduction of lighting power densities sometimes permit a downsizing of wiring for the lighting, and of cooling systems. (Seton, Johnson, and Odell, 1987)

For other EEMs, there is no major physical or first cost barrier to prevent replacement with less-efficient conventional equipment. For example, replacement of a conventional 40 watt fluorescent lamp with a 34 watt lamp is a reversible action. Thus, the 34 watt lamp is considered to be a "replacement-uncertain" EEM.

The sponsoring utility decided that, for their purposes, effective life was the most salient definition for addressing equipment life, since it attempts to account for most important influences on service life. This left the research team with the dilemma of how to develop useful estimates of effective life, given the weakness of the effective life estimates in the Delphi. To move in this direction, the research team made the following assumptions:

- The most important influences on effective life not included in the McRae definition of operating life were judged to be remodeling, renovation, and demolition.

- Obsolescence may result in the replacement of equipment, but, to justify replacement, the new equipment usually provides equal or greater energy savings. Thus, obsolescence does not greatly influence the life of savings from a preexisting measure.

Based on these considerations, the life of the savings was judged to be dependent on the effective life of the equipment for replacement-uncertain EEMs and on the period until the equipment is removed through remodeling, renovation, or demolition for replacement-certain EEMs.

Filling in the Gaps in the Delphi Service Life Estimates

A modified set of service life estimates was developed for specific utility applications. These estimates, shown in Table II, are based in part on the operating life data in Table I, but include some additional information, some judgments about the value of specific values reported in McRae, and a systematic concept of how building life cycles effect service life of EEMs. These estimates are also adjusted to reflect important comments provided by the Delphi participants but not reflected in their numerical responses. Table II provides estimates of the effective life of the hardware, as defined in McRae, and of the life of the savings. The life of savings is the period of time that loads are likely to be reduced by an EEM, and, for replacement-certain EEMs, by its likely replacement. The adjustments and modifications to the data are explained in the following paragraphs.

Effects of Remodeling, Renovation, and Demolition. The respondents to the Delphi indicated that the effective lives of certain EEMs can be shortened by remodeling, renovation, and demolition. These influences also limit the life of savings for some replacement-certain measures. Initial attempts to develop reliable data on the length of remodeling and renovation cycles indicated that the issue is too complex to empirically quantify without an extensive study of diverse buildings. (George, 1987). The number of years until a building is demolished, remodeled, or renovated is dependent on its construction and use. Even within a specific building type, these cycles may vary dramatically with the building's age, the type of organization owning it, the specific product being sold, business cycles, local economic growth, turnover in rental buildings, and the competitiveness of rental markets.

The link between renovation and remodeling and the removal of specific energy systems is also less than perfectly defined. For example, lighting equipment is not always changed out as part of a remodeling. Sometimes, a major renovation will result in replacement of an HVAC system, and sometimes it won't. Prior research (George, 1987) indicates that these factors are not consistent even within building types.

The sponsor chose to leave estimation of these cycles up to the judgement of auditors for individual buildings, and to develop reasonable guesses for an average of all building types for resource planning. This acknowledges considerable uncertainty about these factors, but provides the ability to gauge the rough significance of the cycles on the lives of specific EEMs. The following factors were assumed for the aggregate of all commercial buildings for resource modeling:

- Typical new commercial buildings will last for at least fifty years.
- Remodeling occurs in most buildings about every thirty years, and results in replacement of most lighting and rooftop HVAC equipment.

Table II, part 1. Adjusted Estimates of Effective Life and Estimates of Life of Savings for Energy Efficiency Measures (Rationale for each estimate is provided in footnotes, which are indicated by numbers in parentheses)

EQUIPMENT TYPE:	Effective Life:	Life of Savings if: New/Remodel/ Renovation:	Retrofit:
Lighting:			
Energy Eff. Fluor. Lamp	20,000 hrs. (1)	20,000 hrs (1)	20,000 hrs (1)
same w/ built in ballast	10,000 hrs. (1)	10,000 hrs (1)	10,000 hrs (1)
lamp in T-8 system	20,000 hrs. (1)	30 years (3)	15 years (3)
Eff. Electromagnetic Ballast	45,000 hrs. (1)	45,000 hrs. (1)	45,000 hrs (1)
Electronic Ballast	70,000 hrs (7,9)	70,000 hrs. (7)	70,000 hrs (7)
Metal Halide Lamp	10,000 hrs. (1)	10,000 hrs. (1)	10,000 hrs (1)
Low Pressure Sodium Lamp	18,000 hrs. (1)	40 years (4)	20 years (4)
High Pressure Sodium Lamp	24,000 hrs. (1)	40 years (4)	20 years (4)
Parabolic Fixture	30 years (3)	30 years (3)	15 years (3)
Dimming Systems	30 years (3,17)	30 years (3,17)	15 years (3,17)
On-off Switching	30 years (3)	30 years (3)	15 years (3)
Motion Sensor	10 years (2)	10 years (2)	10 years (2)
Heating, Ventilating, and Cooling:			
Economizer	10-15 yrs. (8)	10-15 yrs. (8)	10-15 yrs. (8)
Chiller Strainer Cycle System	15-25 yrs. (8)	15-25 yrs. (8)	15-25 yrs. (8)
Air-to-Air Packaged Heat Pump	5-15 yrs. (8)	40 yrs. (4)	20 yrs. (4)
Water-Air Packaged Ht. Pump	11-15 yrs. (8)	40 yrs. (4)	20 yrs. (4)
Ice Thermal Energy Storage	19 yrs. (2)	50 yrs. (5)	25 yrs. (5)
Water Thermal Energy Storage	20 yrs. (2)	50 yrs. (5)	25 yrs. (5)
Heat Recovery System:			
Plate Type	14 yrs. (8,9)	14 yrs. (8,9)	14 yrs. (8,9)
Rotary Type	11 yrs. (2)	11 yrs. (2)	11 yrs. (2)
Heat Recovery from Refrigerator Condensers	10-15 yrs. (8)	10-15 yrs. (8)	10-15 yrs. (8)
Low Leakage Dampers	5-11 yrs. (11)	5-11 yrs. (11)	5-11 yrs. (11)
Variable Inlet Vane VAV System	11 yrs. (2)	40 yrs. (4)	20 yrs. (4)
Variable Pitch Fan for Cooling Tower	13 yrs. (2)	40 yrs. (4)	20 yrs. (4)
Make-up Air Unit for Exhaust Hood	10 yrs. (2)	40 yrs. (4)	20 yrs. (4)
Air Destratification Fan:			
Paddle Type	10 yrs. (2)	10 yrs. (2)	10 yrs. (2)
High Inlet/Low Discharge	15 yrs. (2)	15 yrs. (2)	15 yrs. (2)
Air Curtain	10 yrs. (2)	10 yrs. (2)	10 yrs. (2)
Deadband Thermostat	13 yrs. (2)	10-15 yrs (12)	10-15 yrs. (2)
Spot Radiant Heat	10 yrs. (2)	30 yrs. (3)	15 yrs. (3)

(footnotes are explained on the next page)

Table II,part 2. Adjusted Estimates of Effective Life and Estimates of Life of Savings for Energy Efficiency Measures (Rationale for each estimate is provided in footnotes, which are indicated by numbers in parentheses)

EQUIPMENT TYPE:	Effective Life:		Life of Savings if: New/Remodel/ Renovation:		Retrofit:	
Controls:						
Computer Logic Energy Management System	12 yrs.	(2)	12 yrs.	(2)	12 yrs.	(2)
Electronic Controls	11 yrs.	(2)	11 yrs.	(2)	11 yrs.	(2)
Time Clocks	10 yrs.	(2)	10 yrs.	(2)	10 yrs.	(2)
Motors, Drives, & Transformers:						
Standard Electric Motor	15 yrs.	(6)	30-40 yrs.	(12)	15-20 yrs.	(12)
High Efficiency Elec. Motor	17 yrs.	(2,9)	30-40 yrs.	(12)	15-20 yrs.	(12)
Variable Speed DC Motor	18 yrs	(2,9)	30-40 yrs.	(12)	15-20 yrs.	(12)
Var. Speed Drive, Solid State	15 yrs.	(2)	15 yrs.	(2)	15 yrs.	(2)
Var. Speed Drive, Belt Type	6 yrs.	(13)	30-40 yrs.	(12)	15-20 yrs.	(12)
Efficient AC Elec. Transformer	15 yrs.	(2)	15 yrs.	(2)	15 yrs.	(2)
Domestic Hot Water:						
Heat Pump Water Heater	10 yrs.	(2)	10 yrs.	(2)	10 yrs.	(2)
Point-of Use Heater	12 yrs.	(2)	12 yrs.	(2)	12 yrs.	(2)
Solar Water Heater (active)	15 yrs.	(2)	15 yrs.	(2)	15 yrs.	(2)
Refrigeration:						
Unequal Parallel Compressors	14 yrs.	(2)	40 yrs.	(4)	20 yrs.	(4)
Condenser Floating Head Pressure Control	10 yrs.	(2)	10 yrs.	(2)	10 yrs.	(2)
Automatic Cleaning System for Condenser Tubes	15 yrs.	(2)	15 yrs.	(2)	15 yrs.	(2)
Hot Gas Bypass Defrost	10 yrs.	(2)	10 yrs.	(2)	10 yrs.	(2)
Polyethylene Strip Curtain	3 yrs.	(2)	3 yrs.	(2)	3 yrs.	(2)
Refrigeration Case Cover	11 yrs.	(2)	11 yrs.	(2)	11 yrs.	(2)
Building Envelope:						
Double Glazing	23 yrs.	(14)	23 yrs.	(14)	23 yrs.	(14)
Heat Mirror	18 yrs.	(15)	18 yrs.	(15)	18 yrs.	(15)
Low Emissivity Coating	14 yrs.	(15)	14 yrs.	(15)	14 yrs.	(15)
Solar Shade Film (Retrofit)	3-15 yrs.	(16)	3-15 yrs.	(16)	3-15 yrs.	(16)
Tinted & Reflected Coating	15 yrs.	(2)	15 yrs.	(2)	15 yrs.	(2)
Insulation	50 yrs.	(5)	50 yrs.	(5)	25 yrs.	(5)

Footnotes to Table 2:

(1) Based on Test Life (McRae, 1987)
(2) Based on Operating Life (McRae, 1987)
(3) Based on remodeling cycle. See text of this paper for explanation

Footnotes to Table 2, ctd.:
(4) Based on renovation cycle. See text of this paper for explanation
(5) Based on life of building. See text of this paper for explanation
(6) Includes rewinds.
(7) Assumes that quality control problems with some electronic ballasts will be reduced, or those brands will be discontinued.
(8) Depends on operations and maintenance, as per comments in (McRae, 1987)
(9) Renovations may shorten operating life where this EEM is retrofit.
(10) Depends on proper design, as per comments in (McRae, 1987).
(11) Low leakage dampers on customized large central HVAC systems may last longer than those on rooftop HVAC systems due to better design and less exposure to weather, as per comments in (McRae, 1987).
(12) The life of savings from this component depends on the life of the system it is being installed in.
(13) Based on a operating life estimates from a subset of the respondents in (McRae, 1987) who appeared to be referring to the correct EEM.
(14) Based on analysis of responses from engineers and designers. Manufacturers may have been reciting the warrantee period for this EEM.
(15) Conservative estimate for a new product. Longer life is likely.
(16) Respondents in (McRae, 1987) indicated great variability based on the manufacturer and the quality of installation.
(17) Respondents in McRae, 1987) believed that dimming systems and switches would last the life of the building, but would need repair. The remodeling cycle was chosen to represent this. A lesser life might be appropriate for add-on continuous dimming systems for conventional fixtures, since they can be overridden by rewiring during repair.

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o Typical commercial buildings with large HVAC systems are assumed to be renovated, and most central HVAC systems replaced, every forty years or so. Renovated buildings are assumed to last another forty years.

EEMs installed in new buildings or during a renovation or remodeling are installed at the beginning of a cycle. To acknowledge this, it was assumed that EEMs which are sensitive to these cycles, and are installed at the beginning of a cycle would last for a full cycle. It was assumed that measures which were retrofit at other times would be in place for one half of a cycle. These periods were used as estimates of the life of savings. Also, if a service life estimated in this way is smaller than the estimated effective life of the EEM as otherwise estimated, the estimated effective life was reduced to the length of the cycle or half cycle.

Replacement of EEMs. The service life study provided engineering opinion concerning whether each EEM had properties which made it "replacement-certain". Based on this information, Table II provides separate estimates of the operational life of the hardware vs. the life of savings for EEMs. The life of the savings is stated in terms of the events which would lead to the removal of the entire energy using system (e.g, light fixture or HVAC system), such as remodeling, renovation, and demolition.

Operation and Maintenance. For several EEMs, respondents volunteered estimates of different potential service lives depending on the quality of operation and maintenance. These differences are shown in Table II. While these estimates are not based on the response of the entire panel for the given EEM, they are shown here because they reflect the opinion of the panel regarding the importance of maintenance for certain specific EEMs.

Lamp and Ballast Life. Median test life estimates from the Delphi were used in Table II for the effective lives of all lamps except metal halide. There were balancing arguments in the respondents' comments stating that laboratory tests were too conservative and that manufacturing defects lead to early burnout. The operating life estimates were close enough to the test life estimates to indicate that the differences were probably not significant, given the measurement method. The judgement that test lives are the best available indicator of field life for these EEMs implies that the different test life estimates which are available from manufacturers for specific lamp models may provide useful information. For metal halide lamps, several users believed that the lamps were not living up to the manufacturers' claims, so the McRae operating life estimate was used.

The life of savings for sodium lamps was assumed to be the period between renovations, because the fixtures do not work with other types of lamps. Thus, they can only be replaced with other equipment when buidings are renovated.

CONCLUSIONS AND IMPLICATIONS:

1. The prevalence of inadequate operation and maintenance practices among all but the most sophisticated commercial customers has resulted in a significant reduction in the life of many HVAC and control EEMs. Some of these EEMs may not be replaced with efficient equipment when they wear out. Thus, inadequate operations and maintenance are a major threat to the cost-effectiveness of EEMs and to the longevity of savings. Efficiency programs should not invest in HVAC or control hardware for smaller and less sophisticated commercial businesses in the absence of provisions to assure installation quality control, operator training, and maintenance.

2. However, some EEMs, including some HVAC systems, are likely to be replaced with similarly efficient equipment. Consequently, the savings from these measures are a long-term resource. It may be worthwhile for utilities to place emphasis on installation of these replacement-certain EEMs.

3. The duration of savings from replacement-certain EEMs is dependent on remodeling, renovation, and demolition cycles. These factors may also foreshorten the effective lives of other EEMs. It is probable that there are major differences in the length of the cycle between building types which result in shorter lives for some EEMs in certain types of

buildings. Further research in this area is needed, but would be complicated by the diversity of the commercial sector and the difficult-to-define relationship between renovation, remodeling, and replacement of EEMs.

4. Many EEMs installed during a general remodeling or renovation are likely to last much longer than EEMs installed at other times, and are, therefore, more cost-effective. Efficiency programs should concentrate on encouraging the installation of EEMs during general building remodeling and renovation.

5. Caution should be exercised when using the data presented in this study to compare the longevity of technologies with similar service lives. One to three year differences are within the margin of error of the data sources, particularly for EEMs with a life of more than 10 years.

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