ASHRAE Journal

Peer-Reviewed

Determining Equipment Service Life

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Where does one find accurate equipment service life data? That question has long been the focus of ASHRAE's Technical Committee (TC) 1.8, Owning and Operating Costs. Thorough examination of available equipment "life" data, including most of the data in the *ASHRAE Handbook—HVAC Applications* chapter on Owning and Operating Costs, reveals that most data reported to be equipment "service life," is not scientifically derived, and is in reality not "service life" information at all. That is not to say, however, that the available information is not useful. Rather, it is important to understand the limitations of that information, and what it really represents.

Scientific Studies vs. Surveys

True equipment service life information can be obtained only by performing rigorous scientific studies, where actual equipment installation and removal dates are tracked over long periods of time, for substantial numbers of similar equipment. However, most reported equipment "life data" actually has been obtained by performing "opinion" surveys among people believed to be knowledgeable about the equipment.

There are several problems with opinion survey information.

First, if the respondent has not maintained actual installation and removal data for the equipment over a long period of time, and has not performed the rigorous mathematical analyses necessary to determine equipment survival rates, the respondent will be unable to state with certainty what percentage of units have been replaced at any given age. That person most likely will provide an opinion of how long equipment lasts based on the individual's experience with equipment removed from service—with little regard for equipment still in use. At best, opinion surveys only can produce age at replacement information. Age at replacement information and survival or service life information are *not* the same. See the discussions that follow for an explanation.

Second, many equipment types have service lives longer than the typical career span of a person in the industry. This means that a respondent often relies on "second-hand" information, unless the firm has long-term records of equipment installation and removal dates, and the individual has used proper procedures to analyze that data.

Third, opinions are easily swayed by rumor, exaggeration, and false advertising. Unfortunately, bad news usually travels much faster than good news. It takes only one manufacturer of a product type having a problem to give a bad reputation to that equipment type in general. In some instances, proponents of competing technologies have run negative advertising campaigns by overstating maintenance and service life problems of their competitors.

Scientific Data vs. Opinion Data

Scientific Life Data

Scientifically obtained service life data always is derived from study of actual equipment installation and removal dates. Because of this, it is possible to produce a curve of percent equipment survival vs. age. Such "survival curves" are used to identify the true "service life" for the equipment, which is usually defined to be the median service life—that is—the age at which 50% of equipment is still in use and 50% has been replaced. As seen in *Figure 1*, survival curves always start

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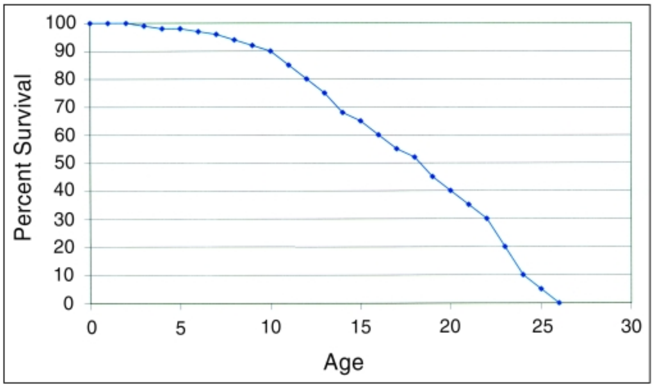

Figure 1: Classic equipment survival curve.

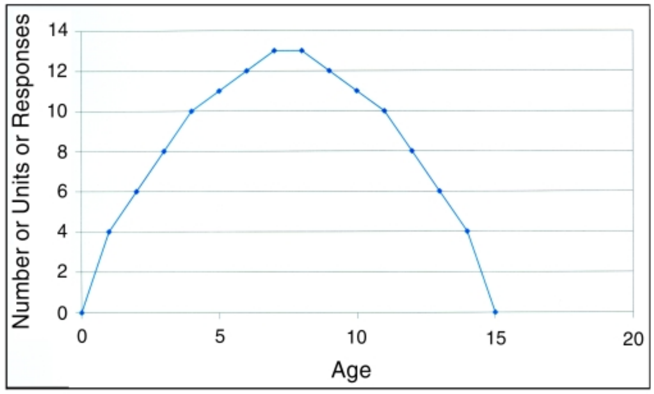

Figure 2: Classic age at replacement curve.

at 100% survival at age zero, and always remain steady or decrease with age. In mathematical terms, survival curves are "monotonically decreasing."

Scientific life studies can produce both the equipment survival curves discussed earlier, and the age at replacement distribution curves discussed later.

Opinion or Age at Replacement Data

Opinion surveys always produce "bell-shaped" curves, such as shown in *Figure 2.* Bell-shaped curves are typical of the distribution of ages at replacement of equipment that has been replaced. Average age at replacement (often mistakenly referred to as service life) is the age corresponding to the peak of the bell-shaped curve. At best, opinion surveys produce age at replacement information, and at worst, produce little or no useful information at all. Opinion surveys are not scientifically verifiable.

Difference Between Average Age at Replacement and Median Service Life

The problem with age at replacement information is that it represents only that portion of the equipment population that has been replaced. It ignores the portion of the population still in use. Some scientifically performed equipment life studies have shown that the percentage of installed equipment that is still in use is much larger than the percentage that has been replaced.[1,2,3] It can be shown mathematically that average age at replacement is always less than median service life, and asymptotically approaches median service life only after an equipment type has been in general use for a period of time several times greater than that equipment's true median service life.

Opinion Survey or Age at Replacement Data

Most of the currently available "service life" information has been obtained from opinion surveys, and at best really represents "average age at replacement" rather than "median service life." This includes most of the data in the equipment life table in the handbook chapter on owning and operating costs.

Age at replacement information is useful in estimating a lower bound for equipment service life. However, true median service life has in some instances been shown to be two, three, or more times longer than average age at replacement.[4] In general, the longer an equipment type has been in use with minimal technological changes, the more closely average age at replacement reflects true median service life. It takes a time period two to three times longer than the equipment's true median service life before average age at replacement approaches median service life.

Great care should be used when making important decisions based on age at replacement information, due to the large uncertainties about how well age at replacement information relates to true service life information. This is especially true about equipment that is relatively new on the market. In the case of HVAC equipment, this means equipment that has been on the market in significant numbers for less than 40 to 60 years!

Scientific Equipment Life Information

Only a few scientifically performed equipment life studies have been published in the open literature.[1,2,3,5] Some manufacturers perform such studies on components of their equipment based on in-warranty claims, but rarely are results of such studies made public.

It is possible, however, to perform your own scientific equipment life studies. What is needed is knowledge of when and where equipment was installed (often available through knowledge of when new buildings were built), and when that equipment was removed from service. Data on when equipment was removed from service is sometimes obtainable from independent equipment service contract databases and/or independent service contractor records. Alternatively, as long as locations of equipment are known, current owners of the equipment (or of the location where the equipment was originally installed) can be surveyed by phone or mail (or both) to determine if the equipment is still in use there. If not still in use, often those surveyed have reasonably good information on when the equipment was removed from service. Obtaining the serial numbers of installed equipment during mail or telephone surveys can help narrow the uncertainty in installation dates (and hence removal dates for previously installed equipment). Serial numbers can be used to determine approximate date of manufacture of the equipment as a check on reported installation dates.

While it is not the intent here to outline all the considerations that must go into constructing a valid service life study, a few cautions should be mentioned. Care must be taken in determining what sites to survey, to avoid biasing survey results. Additionally, a large enough sample population, with enough age diversity, must be surveyed to produce statistically meaningful results. This usually means trying to obtain data for at least several hundred pieces of the same type of equipment, and preferably several thousand. Even larger sample sizes are needed to further disaggregate results into subcategories such as brand, year of manufacture, geographic location, and more. Once data on equipment installation and removal dates has been obtained, actuarial procedures must be used to analyze the data to produce equipment survival curves.

Among other things, actuarial procedures must account for partial-year installations and removals. Such analyses are best when analyzing age in terms of days, rather than years, if data is available with such fine date resolution. Using larger time intervals such as years adds many complications in terms of using mid-year conventions or other techniques to account for less than full-year time frames, but this is sometimes necessary when installation and removal dates only are known in terms of years rather than more precisely. Readers are encouraged to use knowledgeable statisticians and reference books if they wish to perform equipment life studies.[6]

Example: Simplified Life Study

Assume an equipment installation and replacement study has been performed, producing the data indicated in *Table 1*.

Unit #	Installation Date	Removal Date	Age at Removal	Maximum Possible Age When Survey Performed	Censoring Age
1001	1980	Still in use	n/a	15	15
1002	1994	Still in use	n/a	1	1
1003	1976	1983	7	19	n/a
1004	1981	Still in use	n/a	14	14
1005	1985	Still in use	n/a	10	10
1006	1987	Still in use	n/a	8	8
1007	1992	Still in use	n/a	3	3
1008	1977	1988	11	18	n/a
1009	1984	1989	5	11	n/a
1010	1990	Still in use	n/a	5	5
1011	1978	1992	14	17	n/a
1012	1980	1993	13	15	n/a
1013	1983	Still in use	n/a	12	12
1014	1979	Still in use	n/a	16	16
1015	1981	1989	8	14	n/a
1016	1988	Still in use	n/a	7	7
1017	1980	1988	8	15	n/a
1018	1987	Still in use	n/a	8	8
1019	1979	1990	11	16	n/a
1020	1983	Still in use	n/a	12	12

Table 1: Simplified example—installation and replacement study raw data.

To perform the calculations to determine the equipment survival rate vs. age, we must account both for equipment removed from service and equipment still in use. However, the equipment cannot have been older than a certain age at the time the survey was performed. The procedure commonly used in actuarial analysis is to determine the "conditional survival" rates for each age, and from them, the total survival rate at that age.

Conditional survival means the percentage of units that made it to the beginning of any age level that survived through that age interval. For example, the percentage of units having made it to Year 10 that survive to Year 11. Total survival rate then is determined as the product of all the conditional survival rates up to a specified age. In practice, this means starting at 100% survival at age zero, and multiplying the total survival rate from the previous time period by the conditional survival rate of the current time period, to determine the total survival rate of the current time period. The analysis begins at age zero and moves forward in time (age).

The most difficult part of the actuarial analysis is accounting for the units that have not failed, but were not more than a certain age when the study was performed. These are called "censored" units. These units must be removed at the correct time period in the analysis to correctly determine the number of units in the denominator that is used in the calculation for conditional survival rate at any age.

In this example, which uses fairly large age steps of one year, we will use a simple "half-year" convention. We account for "censored" units by using as the denominator in the conditional survival rate calculation the average number of units from beginning to end of the year.

Table 2, shows the various calculations performed on the data of *Table 1*, leading to the determination of both the conditional and total survival rates vs. age. The column labeled "Total Number Surviving

Age	Number Removed During Age Bracket	Cum. No. Removed By That Age	Number of Censored Units	Total Number Surviving Entering Indicated Age	Incremental or Conditional Survival Rate	Total Survival Rate
y	Nr(y)	Nrt(y)	Nc(y)	Ni(y)	Sc(y)	St(y)
0	0		0	20		
1	0	0	1	20	1	1
2	0	0	0	19	1	1
3	0	0	1	19	1	1
4	0	0	0	18	1	1
5	1	1	1	18	0.94	0.94
6	0	1	0	16	1	0.94
7	1	2	1	16	0.94	0.88
8	2	4	2	14	0.85	0.75
9	0	4	0	10	1	0.75
10	0	4	1	10	1	0.75
11	2	6	0	9	0.78	0.58
12	0	6	2	7	1	0.58
13	1	7	0	5	0.8	0.46
14	1	8	1	4	0.71	0.33
15	0	8	1	2	1	0.33
16	0	8	1	1	1	0.33
17	0	8	0	0		
18	0	8	0	0		
19	0	8	0	0		
20	0	8	0	0		
21	0	8	0	0		

Table 2: Simplified example. Survival data derived from *Table 1.*

Entering Indicated Age" is calculated as (number entering previous age bracket, minus removals in previous age bracket, minus censored units in previous age bracket). The conditional survival rate in each age bracket is calculated as (1 – number removed during age bracket/[number entering age bracket – number of censored units/2]). Total survival rate at each age bracket is calculated beginning from 100% at age zero and multiplying the total survival rate at the previous age bracket by the conditional survival rate from the current age bracket.

In equation form, the calculation procedures used in *Table 2* are as follows:

$$Nin(y) = Nin(y-1) - Nr(y-1) - Nc(y-1)$$
$$Sc(y) = 1 - [Nr(y)/(Nin(y) - Nc(y)/2)]$$
$$St(y) = [St(y-1)][Sc(y)]$$
$$Nrt(y) = Nrt(y-1) + Nr(y)$$

Where,

y = year or age

y – 1	=	previous year or age
Nin(y)	=	Number of units entering a given age or year y
Nin(y – 1)	=	Number of units entering the previous age or year (y – 1)
Nc(y)	=	Number of censored units in age or year y
Nc(y – 1)	=	Number of censored units in previous age or year (y – 1)
Nr(y)	=	Number of units removed in age or year y
Nr(y – 1)	=	Number of units removed in previous age or year (y – 1)
Nrt(y)	=	Cumulative total number of units removed by end of age or year y
Nrt(y – 1)	=	Cum.total number of units removed by end of previous age or year (y – 1)
Sc(y)	=	Incremental or conditional survival rate in age or year y
St(y)	=	Total survival rate in age or year y
St(y – 1)	=	Total survival rate in previous age or year (y – 1)
St(0)	=	1.0

Censored units = Units that were in use at the beginning of the indicated age or year and had not been removed from service at all, but were installed at a time such that they could not have been in service any longer than the indicated age or year when the life survey was performed. For example, a unit that was installed two years prior to the survey date and had not been removed from service at the time of the survey would be censored in age or Year 2.

The resultant survival curve from the data in *Table 2* is shown in *Figure 3*. We see that the 50% survival point occurs at approximately 13 years. (Note, however, that this example does not use a large sample size and in reality would not be statistically meaningful.) In comparison, the data from *Table 2* also can be used to produce the age at replacement curve shown in *Figure 4*. We see that the average age at replacement for this example is around 9.6 years.

Why Equipment is Replaced

For the purposes of an equipment life study, replacement means the complete removal of the equipment for any reason. Note that repairs can keep equipment running indefinitely. However, one finds when performing real-life studies, that many factors impact replacement decisions, and often equipment is still fully operational when replaced. Here are some insights into equipment replacement decisions:

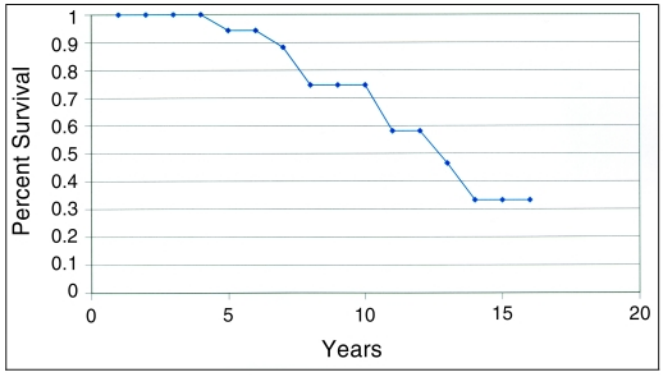

Figure 3: Example survival curve.

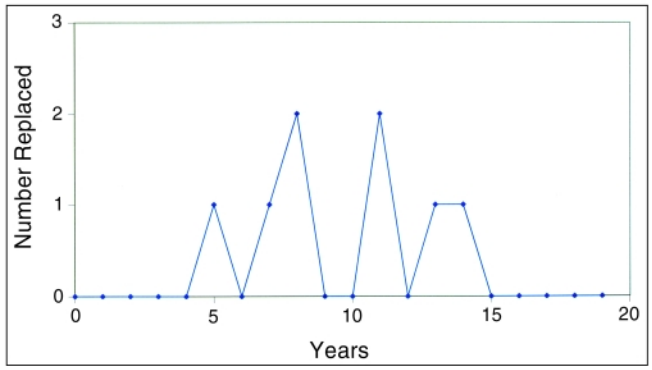

Figure 4: Example age at replacement curve.

An advertisement for the print edition formerly in this space

1. Equipment failure often is not the reason for replacing equipment. Rather, replacement decisions often are made on the basis of *anticipated* failures, which may or may not actually occur. Failure anticipation increases as equipment age increases.

2. Even major component failures early in equipment life are usually repaired, rather than replacing an entire unit. In comparison, even minor component malfunctions can initiate equipment replacement if they are viewed as occurring "late" in the life of the equipment from the decision-maker's perspective.

3. Physical appearance of equipment is often a strong factor influencing replacement decisions. This can be anything from simply looking old-fashioned, to looking worn-out. Items such as rusting screws and faded paint often contribute to perceptions of worn-out equipment.

4. Obsolescence is often a factor in replacement decisions, especially when capacity, speed, or capability of equipment are no longer acceptable compared to new needs or newly available equipment. Also, controls features of new equipment often are viewed as more desirable than old equipment.

5. Dissatisfaction with equipment performance is sometimes a factor in replacement decisions. Examples include issues of noise level, safety, comfort, convenience, location, and maintenance requirements.

6. Efficiency level or operating cost available with new equipment compared to older equipment are somewhat factors in some replacement decisions, but usually are not enough to drive a replacement decision.

7. Marketing influences and availability of a "good deal" are somewhat influential in replacement decisions, but usually are not enough by themselves to drive a replacement decision. Another factor, such as anticipated failures or general "old age" perceptions also must be present.

Whether or not any of these issues apply to equipment of interest to readers is uncertain. They are indicative, however, of the need to keep an open mind when trying to understand equipment life issues. The important message is that while equipment failure is sometimes a reason for equipment replacement, it is by no means the only reason.

Summary

Equipment service life information is useful for many purposes, for both consumers and manufacturers. However, most data currently available in the open literature that claims to represent equipment service life is, in reality, average age at replacement information rather than service life. True equipment median service life is always longer than average age at replacement, sometimes substantially longer. Opinion surveys cannot be used to gather true equipment service life information.

However, it is possible to perform scientifically valid equipment life studies if records are available showing where and when equipment has been installed, and a method (such as a mail or telephone survey) can be devised to determine when the equipment has been replaced. Often, data obtained from equipment life surveys can provide many insights about replacement decisions, which is useful for equipment design and marketing purposes, as well as being informative to end users. TC 1.8 is attempting to devise a method by which an ASHRAE database on equipment maintenance and replacement information can be established and maintained on an ongoing basis, with voluntary inputs in a standardized format from ASHRAE members.

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