TOWARDS THE PRACTICAL EVALUATION OF SERVICE LIFE — ILLUSTRATIVE APPLICATION OF THE PROBABILISTIC APPROACH

Practical probabilistic approach to service life

K. MOSER
Concrete / Building Chemicals, EMPA, Swiss Federal Laboratories for Materials Testing and Research, Duebendorf, Switzerland

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Abstract

Planning maintenance and repair of buildings requires detailed knowledge of the service lives of numerous building components. On the one hand, suppliers are often not in a position to give exact values for service life, let alone guarantee them, even under defined environmental and user conditions. Additionally, conditions over lifetime may differ from design assumptions and may change drastically over time. On the other hand, intricate methods and theories are often presented using rather elaborate methods for forecasting decay functions, distributions of service life and consequential costs.
This paper first discusses the conditions that govern the end of service life, considering the various but different properties of a simple building component. Thereafter, using probability density functions either from supplier's data, testing or estimates employing variations of the factorial method set out in ISO/CD 15686, simple examples are provided for a typical building component. Service life distributions for groups of similar building components are also established. These functions serve as a basis for forecasting financial requirements of maintenance activities. The proposed procedure does not rely on critical single value inputs, the results are easy to understand and contain much more information than just estimated mean values. Straightforward tools for processing these variables in the form of density functions are readily at hand.

Keywords: building component, density distribution, ISO/CD 15686, maintenance, service life, variables processing.

1 Introduction

Planning maintenance and repair of buildings requires detailed knowledge of the service lives of the numerous building components. Suppliers are often not in a position to give exact values for service life, let alone guarantee them, even under defined environmental and user conditions. On top of this, conditions over lifetime may differ from design assumptions and may change drastically over time. New or modified products inherently can not offer results for medium or long-time use.

The results of service life calculations using average values only are easy to understand, but they do not give information on the effective distribution of service life. This clearly does not coincide with reality, as all elements of group will never fail at the same (average) point of time.

Intricate methods and theories often are presented using rather elaborate methods for forecasting decay functions, distributions of service life and consequential costs, e.g. Lounis (1998). These methods require large inputs of detailed data and special data processing programs. Their use today is only of significance for owners of a large numbers of structures, such as a state owning thousands of bridges or a real estate company managing hundreds of large buildings.

However, the use of probabilistic tools must not necessarily be restricted to such large populations of structures, but can be handled fairly easily with limited effort. In order to demonstrate this, simple examples are shown for a typical building component using probability density functions either from supplier's data, from testing or estimated employing variations of the factorial method set out in ISO/CD 15686-1 (1997).

These functions serve as the basis of the forecast of the financial demand for maintenance and renewal. The proposed procedure does not rely on critical single value inputs, the results are easy to understand and contain much more information than just estimated mean values. Straightforward tools for processing these variables in the form of density functions are readily at hand, e.g. VaP 1.6 (1996)

Another important point is the definition of the criteria, which govern the end of service life. These have first to be discussed before developing the probabilistic approach.

2 End of service life

2.1 Relevant properties

Service life in general is defined in ISO/CD 15686-2 (1998) as: "period of time after installation during which all conditions of a building or building part meet or exceed the performance requirements". It is worthwhile to take a closer look at the different groups of properties of a building part involved:

- Safety properties,
- Functional properties,
- Aesthetic (appearance) properties.

The first group of properties are the safety relevant or crucial properties, that are commonly defined using an appropriate safety factor. By law or by established professional principles this factor must not be impaired. The safety factor is defined by two values, i.e. resistance and load, that are combined into a relation. No visible signs normally exhibit possibly reduced resistance or increased load leading to an inferior safety factor. In some cases even new codes stipulating higher loads or reducing the resistance to be taken into account can lead to unsatisfactory limit states. Thus safety aspects must be complied with for building parts, but detrimental changes may not be obvious to the owner or user.

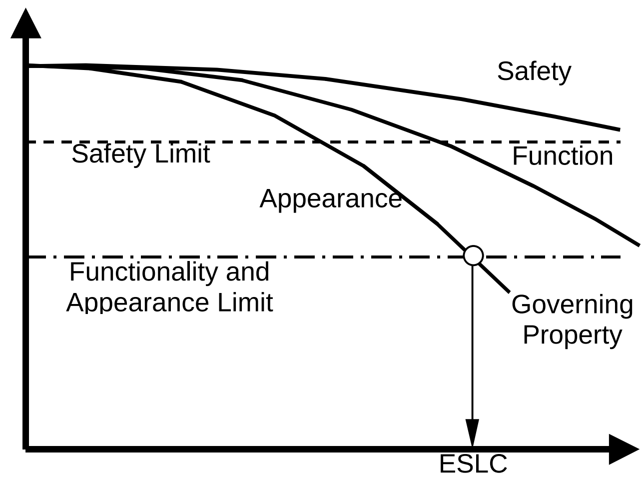


Fig 1: Schematic degradation of different groups of properties

A second group of properties are the functional properties required to fulfil the stipulated functions of the part, i.e. keep out wind, driving rain, coldness or to provide functioning wings for ventilation, glass panes to remain at least translucent, etc.

A third group of properties can be identified as aesthetic properties. Most of them deal with the superficial appearance of the part, be it a painted or of natural surface, a windowpane staying fully transparent or turning cloudy, etc. This group of properties typically sets off at very high levels for new parts, but naturally decreases towards much lower accepted levels during service life.

Taking the definition of ISO/CD 15686-2 (1998) literally, would mean that the end of service life is defined by any of these very different properties falling below the level specified, see Figure 1. This may be very sensible for safety conditions but, in the author's opinion, not necessarily for functional and aesthetic properties.

2.2 Combination of functional and aesthetical properties

Functional and aesthetical properties may be defined by a number of parameters. Instead of handling each parameter as critical on its own, which would make it dominant for service life, a combined value should rather be considered. It is proposed, that a simple average may be used (say 50% of “new”) possibly combined with individual minimum values, which should be set relatively low (say 30% of “new”). Such an approach results in a judgement similar to the one performed by the user: One characteristic property may degrade to a relatively low level, without rejection of the part as a whole. If several properties degrade simultaneously, rejection occurs at a much higher level.

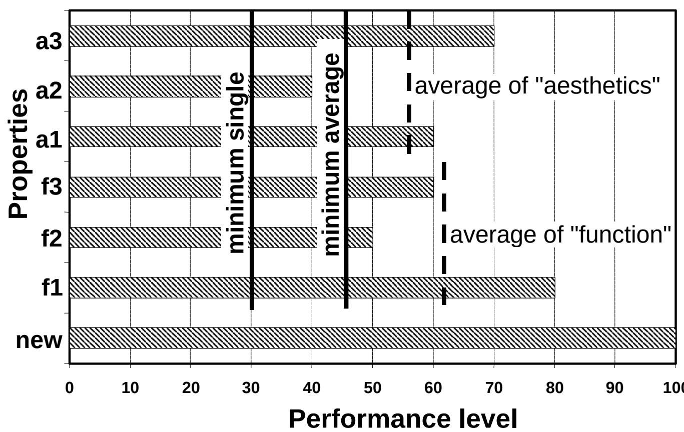


Fig. 2: Discussion of limits for different properties

3 Simple deterministic approaches

One simple approach to service life consists of giving just one plane figure for the estimated service life for the respective component.

Somewhat more advanced is the approach according to ISO/CD 15686-1 (1997): Average values for the reference service lives *RSLC* of the different building parts are set up and combined with factors according to the following equation:

$$\mathrm{ESLC} = \mathrm{RSLC} \times \mathrm{A} \times \mathrm{B} \times \mathrm{C} \times \mathrm{D1} \times \mathrm{D2} \times \mathrm{E} \times \mathrm{F} \qquad \textbf{(1)}$$

From this equation one single value for the estimated service life of the component *ESLC* is derived. (The short definitions of the other variables can be found in Table 1.) It is quite evident, that the real behaviour of a group of similar building parts can not be characterised significantly by one single value. The service lives of the parts are not at all identical but exhibit a more or less large scatter around an average value.

These two and similar simple approaches can be helpful for a first orientation and may be satisfying for rough estimates. For more sophisticated planning, as for the proper scheduling of larger maintenance funds, they are clearly unsatisfactory.

4 Probabilistic approach

Hence a more detailed analysis is generally required. In most cases, this is a probabilistic approach. Figure 3 shows a schematic density curve based upon experience or manufacturer’s data. However, if sufficient data from experience, from testing or from the manufacturer is not available, a density curve of the estimated service life can be defined by professional estimate or by the (recursive) Delphi method. This is best done by setting values to the average (50%) and to the minimum and maximum values (typically chosen as fractiles of 5% and 95% of all elements). The fractiles are partial integrals of the density function, whose total integral is 1.0 or 100% equal to all elements included.

The recursive Delphi method uses first inputs by experts. After due consideration of the results from comparisons and processing of the values of the first input, the experts are invited to give a modified second and usually much more precise input. This procedure has proved to give extraordinary good results in fields with lack of sufficient statistical data (e.g. in risk engineering).

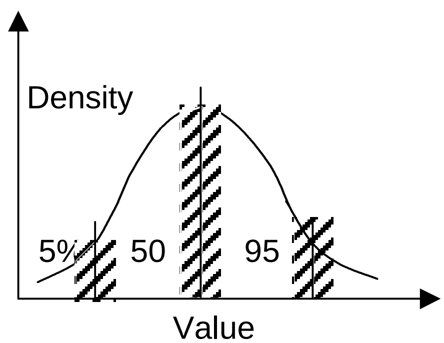


Fig. 3: Visualised typical fractiles defining density distributions

5 Numerical example

In order to demonstrate the procedure, a simple numerical estimate is calculated based on the example offered in ISO/CD 15686-1 (1997) for softwood windows.

5.1 Estimated service lives for the windows in all four faces

The basis of the numerical example is a squared building of a length of 50 m, a width of 25 m and a height of 30 m. The long sides are facing due south and north respectively. The windows of the four façades of the building are treated separately. Table 1 shows the arbitrarily assumed relevant conditions for all factors and faces. Therefrom the factors for the three fractiles 5%, 50% and 95% are defined in the sense of the Delphi method, in this case based on the factors and their description given in ISO/CD 15686-1 (1997).

Table 1: Fractile values of factors to calculate design life

Factor		Face	Relevant conditions	Factors for the fractiles 5% / 50% / 95%
A	Quality of component	all	general variations of components	1.2 / 1.5 / 1.8
B	Design level	all	good, identical value	1.2
C	Work execution level	all	general variation, but insufficient quality repaired	1.0 / 1.2 / 1.5
D1	Indoor environment	S	occasional risk of condensation	0.9 / 1.0 / 1.2
		W	medium risk of condensation	0.8 / 0.9 / 1.1
		N	high risk of condensation	0.7 / 0.8 / 0.95
		E	medium risk of condensation	0.8 / 0.9 / 1.1
D2	Outdoor environment	S	occasional cycling dry / damp	0.8 / 1.0 / 1.3
		W	regular cycling dry / damp	0.6 / 0.8 / 1.0
		N	sheltered from rain	1.0 / 1.2 / 1.5
		E	occasional cycling dry / damp	0.8 / 1.0 / 1.3
E	In use conditions	S	occasional access by children [1])	0.8 / 1.0 / 1.2
		W	regular access by children [1])	0.6 / 0.8 / 1.0
		N	occ. / reg. access by children [1])	0.7 / 0.9 / 1.1
		E	occasional access by children [1])	0.8 / 1.0 / 1.2
F	Maintenance level	all	painted on judgement of caretaker	0.9 / 1.0 / 1.1

Note 1) according to example in ISO/CD 15868-1 (1997)
(other descriptions for wear and tear may appear more realistic).

The factors for *C* reflect the fact that a quality of workmanship usually is such that all parts are not likely to be repaired to a degree sufficiently adequate to meet the requirement, whereas those exceeding the requirement are naturally left at their higher level. This procedure leads typically to asymmetric distributions (Figure 4).

The values for the fractiles given in Table 1 are approximated by the functions given in Table 2 for ease of processing. The functions chosen represent those generally used: determistic-, normal-, lognormal- and Gumbel- (extreme-value-) distributions. The program used for the data processing, VaP 1.6 (1996), supports 11 types of distributions plus the possibility of user defined functions. The variables *m* and *s* are the first and second moments of the respective distributions (see VaP 1.6 (1996) for additional details and system requirements).

Table 2: Functions for approximating the estimated fractile values

Factor	Type of Distribution	Face			
		South m / s	West m / s	North m / s	East m / s
RSLC	Deterministic	25 years	25 years	25 years	25 years
A	Normal	1.5 / 0.185	1.5 / 0.185	1.5 / 0.185	1.5 / 0.185
B	Deterministic	1.20	1.20	1.20	1.20
C	Gumbel	1.25 / 0.10	1.25 / 0.10	1.25 / 0.10	1.25 / 0.10
D1	Lognormal	1.05 / 0.10	0.95 / 0.10	0.80 / 0.10	0.95 / 0.10
D2	Lognormal	1.05 / 0.20	0.80 / 0.20	1.25 / 0.20	1.05 / 0.20
E	Normal	1.0 / 0.12	0.80 / 0.12	0.90 / 0.12	1.0 / 0.12
F	Normal	1.0 / 0.06	1.0 / 0.06	1.0 / 0.06	1.0 / 0.06
ESLC (years)	Lognormal [1])	62.0 / 20.4	34.2 / 11.8	50.6 / 14.8	56.1 / 18.6

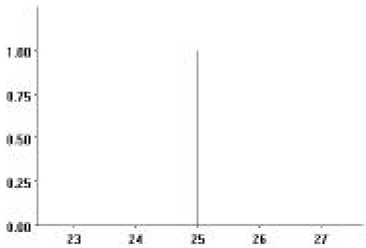
Note: [1]) close fit

The functions for the south windows are plotted in Figure 4 as representative illustration for all four faces. The average of *ESLC* (first moment *m*) can be found by simply multiplying the *RSLC* by all *m*-values. The second moment *s* can e.g. be determined using the appropriate equations from statistics or by carrying out Monte Carlo simulations. The results were calculated by both methods using VaP 1.6 (1996). The results of the direct method are shown on the last line of Table 2. The average results of two runs of a Monte Carlo simulation match these results by a maximum difference on the average value of 0.1 years. These simulations yielded detailed results as shown graphically in Figure 5. The absolute densities are derived by dividing the relative densities shown on the vertical axis by the number of runs, in this case by 100, 000.

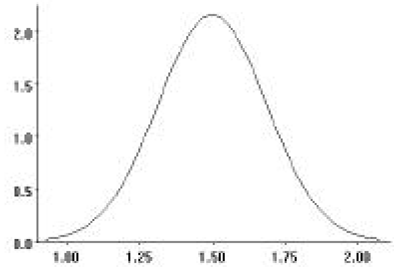
5.2 Comparison of four facades

The results for the estimated service lives of the four facades as provided in Figure 5 are different in several aspects. First, one notices the different widths of the distributions, all plotted against the same horizontal scale. The spread is largest for the south face and narrowest for the west face. Some of this effect is relative: Due to the high average value, the same relative spread is larger in absolute terms.

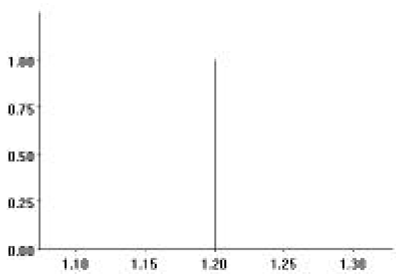
The west face shows as expected the shortest service life, mainly due to the unfavourable outdoor climate and the in-use conditions. The effect of the higher risk of condensation, assumed for the north face indoor climate, is offset by the more favourable outdoor climate. The main difference originates from the in-use conditions. Both effects combined yield some 15% less estimated service life.



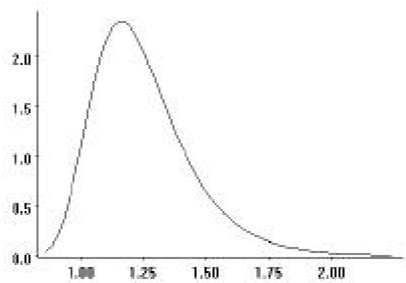
ESLC: Estimated Service Life



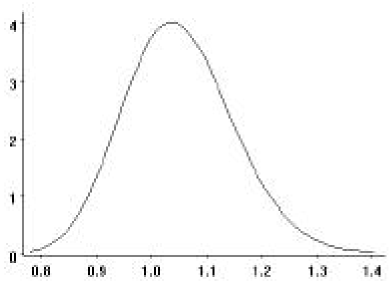
A: Quality of component



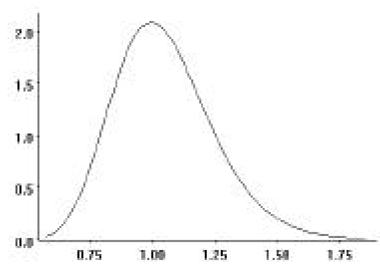
B: Design Level



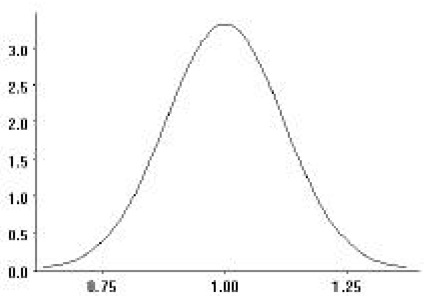
C: Work execution level



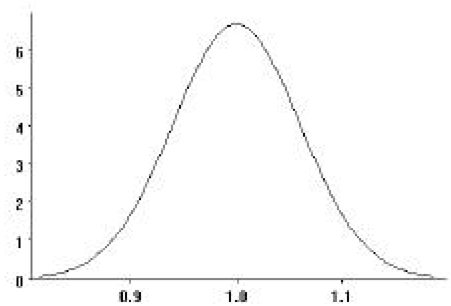
D1: Indoor environment



D2: Outdoor environment



E: In use conditions



F: Maintenance level

Fig. 4: South façade: variables defined as functions

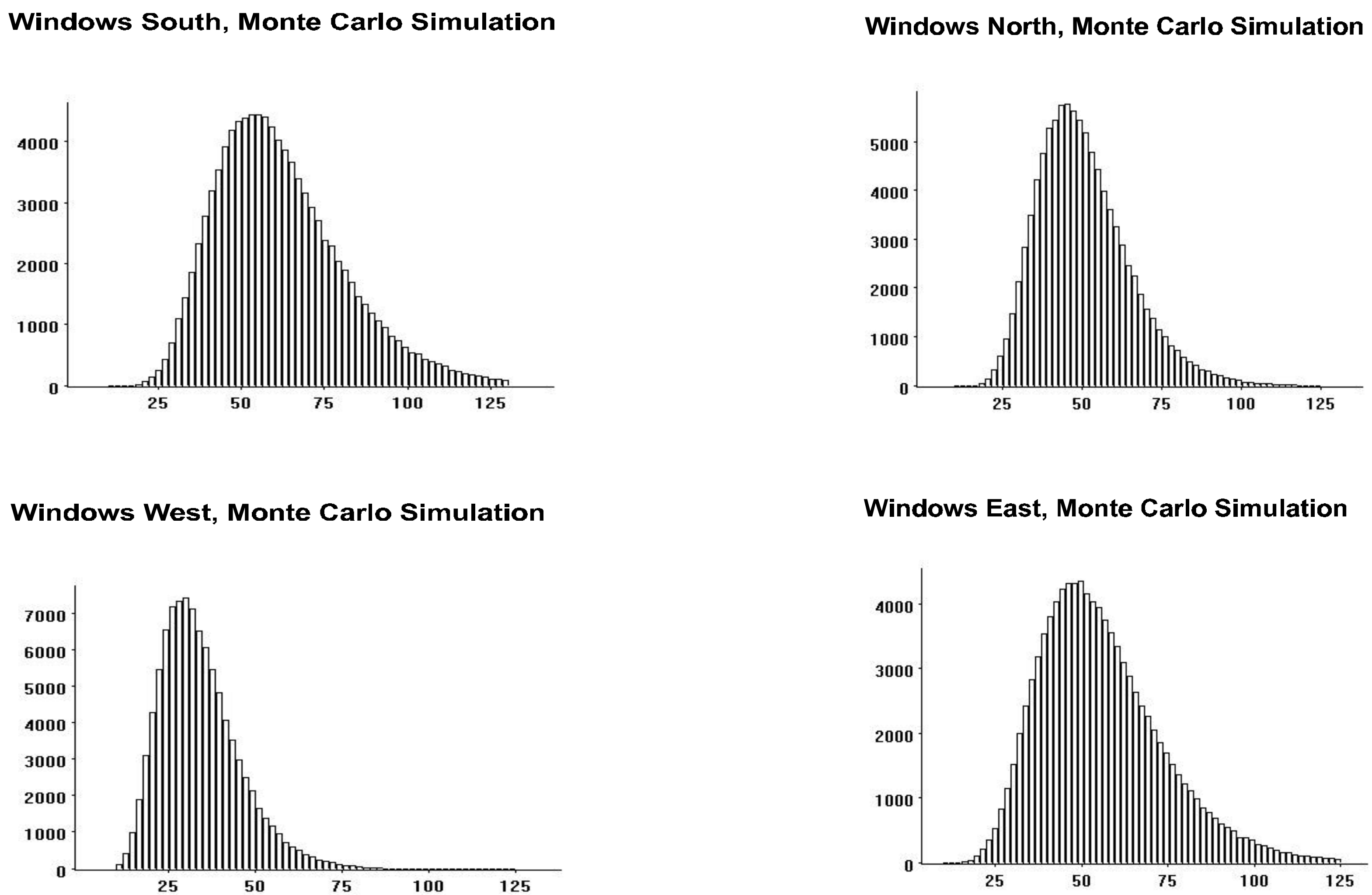


Fig. 5: Density distribution for the windows in the four faces

5.3 Financial demand

For the estimation of maintenance funds, the functions for the service lives of similar building components have to be superimposed. In general, this has to be done for all parts of a building considered. For the superposition, costs have to be allocated to the different groups of building components. In this example, typical results are shown in which only the superposition of all window areas to be replaced is considered in the calulations. It is assumed for this purpose, that the windows cover 40% of the area of the respective facades.

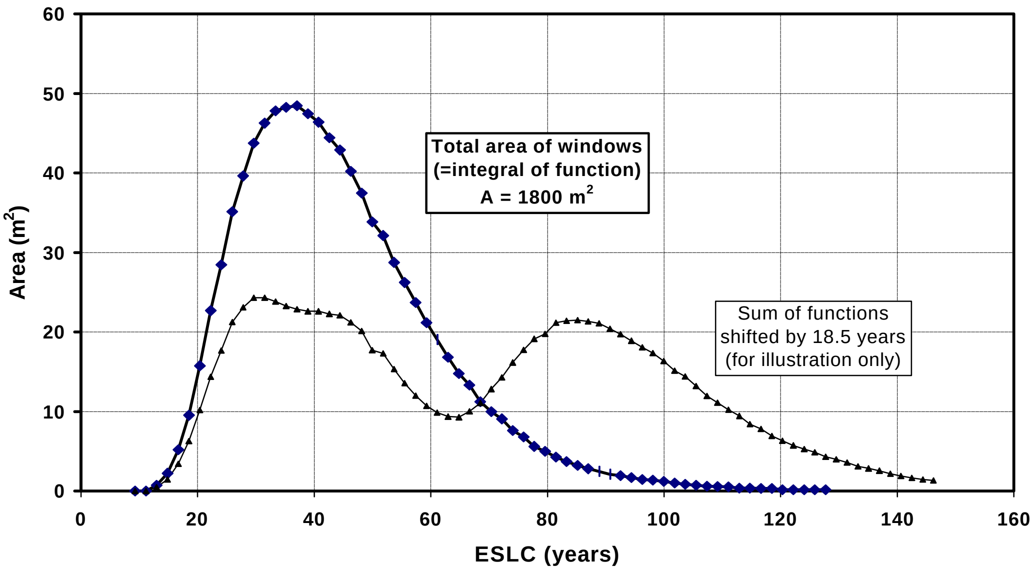


Fig. 6: Financial demand (shown as window area to be replaced)

The superposition yields an asymmetric function having a steep increase up to a peak demand of replacements after 37 years of 48 m^2/year. Then the demand decreases at a gentle slope down to 10 m^2/year after 70 years. In a next step, the same service life functions have to be applied to the replaced windows, and the results of the multiple replacements are summed up, leading to a fairly constant replacement function. This step is omitted here for clarity.

The lower curve depicts another sum function based on the same basic data, but the subfunctions of the individual façades being shifted apart by 18.5 years each for illustration purposes, thus resulting in a double hump shape. This curve is fairly representative for the superposition of elements with a remarkably different service life.

In general, the financial demand for similar components tends to merge into a one-peak function, whereas the superposition of the functions of all different parts of a building is more likely to result in several peaks or even a relatively steady demand over the lifetime of the building considered, starting at a certain age of the building.

6 Conclusion

The use of probabilistic tools for planning maintenance or replacement costs is no longer only restricted to projects having large funding requirements or numerous assets. Making full use of the information, e.g. given in ISO/CD 15686 and modified by professional opinion, permits the use of variables instead of deterministic factors in the equation for the estimated service life. The results give a much more detailed insight into the service life of building components involved and allow a far better planning of the investments required.

7 References

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