Factor method for aluminium windows and curtain walls

RE CECCONI Fulvio[1,a*], RIGONE Paolo[1,b] and VATAVALIS Pavlos[2,c]

[1]Politecnico di Milano, Department of Architecture, Built Environment and Construction Engineering, Via G. Ponzio, 31 – 20133 Milano (MI), Italy

[2] European Aluminium, Building market group, 12 Av. de Broqueville, BE -1150, Brussels, Belgium

[a]fulvio.rececconi@polimi.it, [b]paolo.rigone@polimi.it, [c]vatavalis@european-aluminium.eu

Keywords: Factor method, Service life, Aluminium windows, Aluminium Curtain walls.

Abstract. Buildings and building components service life are vital information in a design process because most the choices to be made during this process are influenced by life cycle costs or by environmental impacts over the life cycle, i.e. elements that are strictly related to the service life of building systems and components. The ISO 15686 standard series suggests a way to predict the service life of a building components: the factor method. Estimating the service life a construction products would have in a set of specific in-use conditions (determined from reference service life data after taking into account any differences from the reference in-use conditions) is an error prone process. The error could influence significantly the estimation if the factor method is applied at the multiplication level, therefore significant research on reliability of the factor method to be used for specific construction products is required.

Aluminium construction products like windows, CE marked in accordance to EN 14351-1, or curtain walls, CE marked in accordance to EN 13830, are some among the others in a building, of the most influencing life cycle costs and environmental impacts and therefore a highly reliable estimated service life for these products is needed. Applying the factor method, stakeholders and manufacturers have been interviewed to define which are the elements most influencing the service life of aluminium windows and curtain walls. The outcomes of this study have been used to create a specific factor method for each family of components under analysis, which can be classified according to ISO 15686-8 as a combined level factor method where the estimated service life may be computed by combining the multiplication and function level for groups of different factor categories.

The Factor Method for service life prediction

The service life of a building or a building component is strictly related to its durability, i.e. *ability of an item to perform a required function under given conditions of use and maintenance, until a limiting state is reached* [2]. Studies on durability of buildings and building components are quite recent, maybe the first research product that achieved fame was the first state of the art report of CIB W80 – RILEM 71 PSL joint working group, “Prediction of service life of building materials and components” [3] published in 1987, while the first available standards on the topic was the British BS 7543 issued on 1992 [4]. Besides these, one of the most famous documents in the field is the English translation of “Principal guide for service life planning of buildings” published in 1993 by the Architectural Institute of Japan [5], a short version of the Japanese guide that contains a general method for service life prediction based on the evaluation of physical deterioration.

In the Principal guide [5], for example, the service life of structural steel frame building is computed as:

$$Y = (Y_{ss} \times B_s \times C_s \times M_s) + (Y_{sp} \times D_p \times B_p \times C_p \times M_p) \tag{1}$$

Where:
Y_{ss}: Standard service life (years) of steel;
B_s: Part of building where the steel element is installed;

C_s: Execution level of steel element;
M_s: Level of maintenance;
Y_{sp}: Standard service life (years) of coating film on steel component;
D_p: Area and environment for deterioration of coating film;
B_p: Part of building where the coated element is installed;
C_p: Execution level of coating film;
M_p: Level of maintenance.

The method described in the Principal guide [5], besides some changes when applied to different construction materials or components, contains a listing of conditions which influence the service life and which are reflected into factors used in an equation to change a reference service life i.e. the Factor Method. The guide largely influenced the first edition of the ISO 15686-1 on service life planning [7] where terms like Reference Service Life (RSL) and Estimated Service Life (ESL) had been standardized as far as the idea of transforming the first in the latter multiplying seven factors.

While RSL remains "the service life of a product, component, assembly or system which is known to be expected under a particular set, i.e. a reference set, of in-use conditions and which can form the basis for estimating the service life under other in-use conditions" ([7] second edition), and ESL is still "service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, determined from reference service life data after taking into account any differences from the reference in-use conditions" ([7] second edition), Part 8 of the standard [8], published in 2008, changed the approach to FM. Before its publication FM had been often seen as a mere multiplication of eight factors and a (reference) service life probably because of the formula in clause 9.1 "Outline of the factor method" of ISO 15686-1 [7] and because of the examples found in its Annex F "Worked examples of factorial estimates".

After ISO 15686-8 publication this general view changed, as according to it "the FM can be applied at different levels of sophistication, from working as a simple checklist to complex calculations. The level should be selected taking into account factors such as the actual purpose of the estimation, type and quality of available data and models, skill level and type of expertise of the user(s) making the estimation and resources and time available for the calculation". Namely ISO 15686-8 [8] points out four levels:

1) *check list level*: experience and consideration of the overall set of differences between the object-specific and reference in-use conditions and their influence on the RSL guide the assessor to an estimation of the ESL;

2) *multiplication level*: the estimation of the ESL is carried out by multiplying the value of RSL by numerical factors A to G designated ϕ_A, ϕ_B,.... ϕ_G, each of which reflect the relative dependence on the service life of the difference between the object-specific and the reference in-use condition within a respective factor category as given in Equation (2);

3) *functional level*: the estimation of the ESL is carried out by multiplying the value of RSL by an appropriate mathematical function, Φ ,of variables a, b,.... g, each of which reflects a dependence on the service life of the difference between the object-specific and the reference in-use condition within a respective factor category, as given by Equation (3);

4) *combined level*: ESL is estimated by multiplying RSL by one or more functions and one or more factors.

$$ESL = RSL \times \phi_A \times \phi_B \times \phi_C \times \phi_D \times \phi_E \times \phi_F \times \phi_G \quad (2)$$

$$t_{ESL} = t_{RSL} \times \Phi(a, b, c, d, e, f, g) \quad (3)$$

Since the introduction of the FM in ISO 15686-8 there had been disputes over its accuracy, i.e. over the error in ESL due to uncertainty in the way degradation mechanisms are taken into account by the modification factors. In fact, under its apparent usability, FM, when applied at the multiplication level, hides a great sensitivity to errors in input factors that can lead unaware users to large inaccuracy in ESL. An example of how big this sensitivity is can be found in Table 1, where a 10% variation of every factor leads to a prediction that differs from -52% up to almost 95%.

Table 1: An example of the sensitivity of FM to errors in input. An amount of ±10% variation in input lead to a -52% + 94% variation in the ESL

ESL		RSL	A	B	C	D	E	F	G
11.95	-52.17%	25	0.9	0.9	0.9	0.9	0.9	0.9	0.9
25	0.00%	25	1	1	1	1	1	1	1
48.71	94.87%	25	1.1	1.1	1.1	1.1	1.1	1.1	1.1

Many authors have proposed methods dealing with the problem of accuracy in different ways, for example using probability distribution function instead of numeric value for the seven factors [9][10], or using guidelines in form of tables [11] or grids [12] that, driving the user through a specific path for assessing each factor, minimize the probability of error. Table 2, for example, is a general guideline for selecting factor values prepared by Hovde [11].

Table 2: Guideline for selecting factor values [11]

Factor Values	General condition for selection of factor values						
	A	B	C	D	E	F	G
5	Treated material				Relevant climate component lacking		Best available maintenance procedures
3	Excellent quality		Very good execution level				
2	Very good quality				Mild climate		Very good maintenance
1.5	Good quality		Good execution level				
1.2							
1	To be applied if conditions are similar to the RSL conditions, or factor does not apply						
0.85							
0.67	Reduced quality		Bad execution level				
0.5	Poor quality				Severe climate		Poor maintenance
0.33	Very poor quality		Wrong mounting and fixing				
0.2	Material not applicable				Extreme climate		Lack of maintenance

Another example of guideline for selecting factor values can be found in Germany, where the Association of Window and Facade Manufacturers (Verband der Fenster und Fassadenhersteller e.V.) published a guideline for the prediction of wooden windows durability based on the use of surface treatments. Even if the guideline is not related to ISO 15686, it is an interesting example of a similar treatment of durability and service life of some specific building components by quantifying and combining important factors that are of main influence [13].

When more than one element affects a factor, two are the alternatives: one can either define sub-factors and assess each single sub-factor value or list all the possible combination of sub-factors and assess the combination value for the factor. In the first case, when the relative importance of more than two elements should be evaluated the Analytic Hierarchy Process (AHP) may be used. AHP, introduced by Thomas Saaty [17], is an effective tool for dealing with complex decision making, helping the decision maker to set priorities and to make the best decision.

By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process. Eventually the AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. An application of AHP can be found on the factor method for aluminium windows.

Developing a factor method for aluminium construction products

A Factor Method for aluminium windows and curtain walls should take into account the effect on service life prediction of some items specific to these components such as:

- *upgrade*: windows, curtain walls are often upgraded during the service life of a building by e.g. keeping the framing part in place and replacing the glazing;
- *maintenance*: maintenance quality and frequency have a great impact on service life; some components / materials need more maintenance operation then others (e.g. gaskets);
- *accessories*: service life is often reduced due to the poor quality of accessories;
- *usage*: many façade components have operative parts, the service life of these components is very much affected by their use in terms of: a) functionality (proper or improper); b) frequency of use (low or high); c) intended use (residential, office, public, commercial);
- *environment*: different materials / components have different sensitivity to environmental condition (temperature, humidity, UV radiation, pollutants, etc.).

Factor method for aluminium windows.

Many are the factors affecting aluminium windows performance/function and, thus, their service life. Unfortunately some of them are not easily related to the actual change in service life. For example, from the interviews with stakeholders it is highlighted that both thermal transmission (U_w) and acoustic insulation (R_w) are related to windows durability but none of the interviewed can justify this relationship. Is a more durable window, one with a lower U_w, or another with a higher U_w? Does changing the glazing of a window from one with a higher U_g to one with a lower U_g improve its service life? Do low-emissivity coatings improve or reduce the durability of a window? These questions remain unanswered.

Further to the results of interviews, the elements influencing the service life of an aluminium window and that have to be considered in a factor method are listed in Table 3.

Table 3: Elements to be considered in a Factor Method for aluminium windows

Factor	Window part	Elements to be considered
A	Frames	Surface treatment type and thickness
	Gaskets	Material and type
	Whole window	Airtightness and watertightness
B	Whole window	Details taken care in the design stage
	Whole window	Material (chemical) compability
C	Whole window	Labor quality
D	Whole window	Presence of chemical agents
E	Whole window	Pollutants (i.e. industrial environment) and chemical agents (i.e. marine environment) UV radiation (particularly for gaskets)
F	Whole window	Type of user (as a measure of possible misuse)
G	Whole window	Frequency of maintenance and use of qualified labour

Quality of the components, Factor A. Aspects to be considered are:

- frame's surface treatment type and thickness;
- Anodized frames will last longer than the ones where polyester powders or vinilic paints are used regardless from coatings' thickness, provided that this is more than the minimum

stated in EN 12206-1 [14]. The thickness of coating is also an important factor for windows durability.

- materials used for gaskets and their type. The most common materials used for gaskets are PVC, EPDM and silicone, the last been the most durable and the first the one with the shortest service life. There are three types of gasket that also affect service life: linear sealed, corner sealed and vulcanized. PVC is usually used in linear or corner sealed gaskets and these are, usually, the ones with the shortest service life. On the other side, silicone gaskets are usually corner sealed or vulcanized and have the longest service life.
- airtightness and watertightness. A window with better performance usually lasts longer.

Design level, factor B, design level. Aspects to be considered are:

- details of construction, more specifically, whether the window is installed into recesses or on the external part of the façade, which is the most exposed to environmental agents;
- materials compatibility, that is to say whether during design stage efforts were taken to avoid incompatible materials in contact with the window (for example: steel critically affect aluminium service life; painted aluminium is sensitive to alkaline elements).

Work execution level, Factor C, is measured according to two different types of "standard site": the first one, the reference site, is a site where windows are installed by skilled labor or where there are no chances for windows to be in touch with incompatible materials (for example: painted windows stained with plaster); the second one is a site where no skilled labor is available and/or windows may be in touch with incompatible materials.

Indoor environment, Factor D, for which two different types of "standard environments" are considered: the reference environment is one where no chemical agents are in contact with the windows; the second environment is an aggressive environment, like a swimming pool, a SPA or an industrial environment rich of chemical agents.

Outdoor environment, *Factor E*. Again, a standard environment (no industries or far from the sea) with high solar radiation and high humidity is considered as the reference environment and more aggressive environment are taken into account as detrimental. Aspects to be considered are:

- the aggressiveness of the environment. For example, industrial or marine environment may cause an accelerated decay of aluminium windows based on the commonly used alloys;
- the solar radiation;
- the relative humidity.

Usage condition, Factor F, is related to the type of users and the intended use of the spaces where windows are installed. Improper use of windows and their accessories may happen e.g. in public access spaces and/or if children have access. Cyclic tests that are essential for doors but less substantial for windows aren't considered here.

Level of maintenance, Factor G, may be measured by the frequency of maintenance and the skill of the labor used.

Members from UNICMI [15] were anonymously interviewed using the Delphi Method [16] to facilitate the discussion and an agreement was found on the factors suggested values shown in Table 4 where the reference condition (factor value equal to 1) is the most common in the market.

Table 4: Suggested factor values for windows

Factor	**Sub-Factor**	**Possible choices**	**Value**
A -Inherent quality	Coating material & Coating thickness [mm]	20 μm Polyester powder	0.85
		40 μm Polyester powder	1
		50 μm Polyester powder	1.15
		20 μm Vinilic	0.9
		40 μm Vinilic	0.95
		50 μm Vinilic	0.95
		15 μm Anodized	1.1

Factor	Sub-Factor	Possible choices	Value
		20 µm Anodized	1.2
	Air permeability EN 1026	1 (150 Pa)	0.7
		2 (300 Pa)	0.85
		3 (600 Pa)	1
		4 (600 Pa)	1.2
	Watertightness EN 1027	1A (0 Pa)	0.7
		2A (50 Pa)	0.8
		3A (100 Pa)	0.9
		4A (150 Pa)	0.95
		5A (200 Pa)	1
		6A (250 Pa)	1
		7A (300 Pa)	1.05
		8A (450 Pa)	1.1
		9A (600 Pa)	1.2
		Exxx (>600 Pa)	1.3
	Gaskets	PVC - Linear sealed	0.7
		PVC - Corner sealed	0.8
		EPDM - Linear sealed	0.9
		EPDM - Corner sealed	1
		EPDM - Vulcanized	1.15
		Silicon - Corner sealed	1.1
		Silicon - Vulcanized	1.2
B - Design level	Details of construction	External exposure	0.9
		Installed into recesses	1
	Material compatibility	Unevaluated in design stage	0.9
		Taken care in design stage	1
C - Work execution level	Labour quality	Unskilled & incompatible materials	0.8
		Unskilled & compatible materials	0.9
		Skilled & incompatible materials	0.9
		Skilled & compatible materials	1
D - Indoor environment	Presence of chemical agents	Highly aggressive environment	0.8
		Standard environment	1
E - Outdoor environment	Type of environment & Solar radiation & Humidity	Industrial - High sol - High hum	0.8
		Industrial - High sol - Low hum	0.85
		Industrial - Low sol - High hum	0.85
		Industrial - Low sol - Low hum	0.9
		Sea dist <30 km - High sol - High hum	0.75
		Sea dist <30 km - High sol - Low hum	0.8
		Sea dist <30 km - Low sol - High hum	0.8
		Sea dist <30 km - Low sol - Low hum	0.85
		Standard - High sol - High hum	1
		Standard - High sol - Low hum	1.1
		Standard - Low sol - High hum	1.05
		Standard - Low sol - Low hum	1.2
F - Usage condition	Type of users	Public and/or children access	0.85
		Occasional public and/or chilren access	0.95

Factor	Sub-Factor	Possible choices	Value
		Private spaces and No children access	1
G - Maintenance level	Frequency of maintenance & labour	High frequency & skilled labour	1.2
		Medium frequency & skilled labour	1.1
		Medium frequency & unskilled labour	1
		Low frequency & unskilled labour	0.9

Members from UNICMI [15] made the pairwise comparison to assess the relative importance of each sub-factor related to factor A, the resulting comparison matrix is shown in Table 5. Although when pairwise comparisons are performed some inconsistencies may typically arise, the pairwise comparison matrix shown is fairly consistent, being the consistency index CI near 0.1.

The sub-factor weights computed according to Saaty [17] from matrix in Table 5 are: a) Coating type and thickness w_{a_1} =0.0336; b) Gasket material and type w_{a_2} =0.7014, Airtightness w_{a_3} =0.1300; Watertightness w_{a_4} =0.1350. Where sub-factors are lower than three, as in factor B, AHP is useless. Therefore members of UNICMI [15] specified w_{b_1} =0.6 and w_{b_2} =0.4.

Table 5: pairwise comparison of elements affecting factor A.

	Coating type and thickness	*Gasket material and type*	*Airtightness*	*Watertightness*
Coating type and thickness	1	1/7	1/7	1/9
Gasket material and type	7	1	1	1/9
Airtightnes	7	1	1	1/7
Watertightnes	9	9	7	1

$$ESL = RSL \times (a_1 \times w_{a_1} + a_2 \times w_{a_2} + a_3 \times w_{a_3} + a_4 \times w_{a_4}) \times \times (b_1 \times w_{b_1} + b_2 \times w_{b_2}) \times C \times D \times E \times F \times G \quad (5)$$

For example, in a residential building (standard indoor environment, private spaces) situated in a standard environment (low sun exposure and low humidity) a window (20 µm polyester powder coating, Air permeability class 3 according to EN 1026, water tightness class 5A according to EN 1027 and EPDM corner sealed gaskets), installed into recesses, with compatibility with nearby materials taken into account, by skilled labor and maintained properly may, if the RSL is 30 years, last:

$$ESL = 30 \times (0.85 \times 0.0336 + 1 \times 0.7014 + 1 \times 0.1300 + 1 \times 0.1350) \times \times (1 \times 0.6 + 1 \times 0.4) \times 1 \times 1 \times 1.2 \times 1 \times 1.2 \approx 42\ years \quad (6)$$

The same window installed in the same building and conditions by unskilled labor and incompatible materials (C=0.8) with low maintenance frequency and unskilled labor (G=0.9), will last:

$$ESL = 30 \times (0.85 \times 0.0336 + 1 \times 0.7014 + 1 \times 0.1300 + 1 \times 0.1350) \times \times (1 \times 0.6 + 1 \times 0.4) \times 0.8 \times 1 \times 1.2 \times 1 \times 0.9 \approx 30\ years \quad (7)$$

Factor method for aluminium curtain walls. The same approach used for windows may be adopted for curtain walls, tuning, wherever required, the different factors.

Quality of the components, Factor A, Aspects to be considered are the same as of windows.

Design level, factor B, design level. Aspects to be considered are similar as of windows:

- details of construction, more specifically, whether curtain walling is meeting other building works, such as copings, sealed and open joints, flashings, waterproof membranes and sills;
- materials compatibility, that is to say whether during design stage efforts were taken to avoid incompatible materials in contact with the curtain wall

Work execution level, Factor C, is measured as for windows.

Indoor environment, Factor D. Aspects to be considered as for windows.

Outdoor environment, Factor E, Aspects to be considered are the same as of windows.

Usage condition, Factor F, Aspects to be considered are the same as of windows.

Maintenance level, Factor F, Aspects to be considered are the same as of windows.

Even if the aspects in different Factors between aluminium windows and curtain walls are same or similar, there are areas in which it is not possible to use the same values of factors due to different technical specifications which those products have to comply.

The following Table 6 contain the list of factor values evaluated by UNICMI [15] experts for the case of curtain walls, they can be used with Eq. 5 to compute the ESL of a curtain wall.

Table 6: Suggested factor values for aluminium curtain walls

Factor	Sub-Factor	Possible choices	Value
A -Inherent quality	Coating material & Coating thickness [mm]	20 μm Polyester powder	0.85
		40 μm Polyester powder	1
		50 μm Polyester powder	1.15
		20 μm Vinilic	0.9
		40 μm Vinilic	0.95
		50 μm Vinilic	0.95
		15 μm Anodized	1.1
		20 μm Anodized	1.2
	Air permeability EN 12152	A1 (150 Pa)	0.7
		A2 (300 Pa)	0.85
		A3 (450 Pa)	1
		A4 (600 Pa)	1.1
		AE (>600 Pa)	1.2
	Watertightness EN 12154	R4 (150 Pa)	0.7
		R5 (300 Pa)	0.8
		R6 (450 Pa)	1
		R7 (600 Pa)	1.1
		RE (>600 Pa)	1.2
	Gaskets	PVC[1] - Linear sealed	0.7
		PVC[1] - Corner sealed	0.8
		EPDM - Linear sealed	0.9
		EPDM - Corner sealed	1
		EPDM - Vulcanized	1.15
		Silicon - Corner sealed	1.1
		Silicon - Vulcanized	1.2
B - Design level	Details of construction	Details design is poor or incomplete	0.9
		Details design is completely developed	1
	Material compatibility	Unevaluated in design stage	0.9
		Taken care in design stage	1

[1] Due to the complexity of replacing gaskets on curtain walls, PVC gaskets which have short service lives are rarely used. Gaskets with longer service life are commonly used.

Factor	Sub-Factor	Possible choices	Value
C - Work execution level	Labour quality	Unskilled & incompatible materials	0.8
		Unskilled & compatible materials	0.9
		Skilled & incompatible materials	0.9
		Skilled & compatible materials	1
D - Indoor environment	Presence of chemical agents	Highly aggressive environment	0.8
		Standard environment	1
E - Outdoor environment	Type of environment & Solar radiation & Humidity	Industrial - High sol - High hum	0.8
		Industrial - High sol - Low hum	0.85
		Industrial - Low sol - High hum	0.85
		Industrial - Low sol - Low hum	0.9
		Sea dist <30 km - High sol - High hum	0.75
		Sea dist <30 km - High sol - Low hum	0.8
		Sea dist <30 km - Low sol - High hum	0.8
		Sea dist <30 km - Low sol - Low hum	0.85
		Standard - High sol - High hum	1
		Standard - High sol - Low hum	1.1
		Standard - Low sol - High hum	1.05
		Standard - Low sol - Low hum	1.2
F - Usage condition	Type of users	Public and/or children access	0.85
		Occasional public and/or chilren access	0.95
		Private spaces and No children access	1
G - Maintenance level	Frequency of maintenance & labour	High frequency & skilled labour	1.2
		Medium frequency & skilled labour	1.1
		Medium frequency & unskilled labour	1
		Low frequency & unskilled labour	0.9

For example, in a standard environment (low sun exposure and low humidity) a curtain wall (40 μm polyester powder, Air permeability class A4 according to EN 12152, water tightness class R6 according to EN 12154 and EPDM corner sealed gaskets), if the detail design is completely developed and takes into account material compatibility, installed into a building with occasional access of children by skilled labor and maintained properly may, if the RSL is 30 years, last:

$$ESL = 30 \times (1 \times 0.0336 + 1 \times 0.7014 + 1.1 \times 0.1300 + 1 \times 0.1350) \times \\ \times (1 \times 0.6 + 1 \times 0.4) \times 1 \times 1 \times 1.2 \times 0.95 \times 1.1 \approx 38\ years \quad (8)$$

The same curtain wall installed in the same building type, workmanship but different climate conditions (e.g. close to sea, with high solar irradiation and high humidity levels – Factor E=0.75), will last:

$$ESL = 30 \times (1 \times 0.0336 + 1 \times 0.7014 + 1.1 \times 0.1300 + 1 \times 0.1350) \times \\ \times (1 \times 0.6 + 1 \times 0.4) \times 1 \times 1 \times 0.75 \times 0.95 \times 1.1 \approx 24\ years \quad (7)$$

Conclusions

Factor method is a very known and used tool for service life prediction but may lead unaware users to huge errors because of its sensitivity to uncertainty on input factors. Thus, guidelines (Table 4 and Table 6) were developed to apply FM at combined level (Eq. 5) to estimate the service life of aluminium windows and curtain walls.

These guidelines allow for a more reliable estimation of service life but they don't limit ESL variability from the RSL. As can be seen in Fig. 1, the worst possible conditions foreseen in Table 4 for an aluminium window led to an ESL that is 72% smaller than the RSL and the best possible conditions to a ESL that is 74% bigger than the RSL, quite a large span of possible service life values.

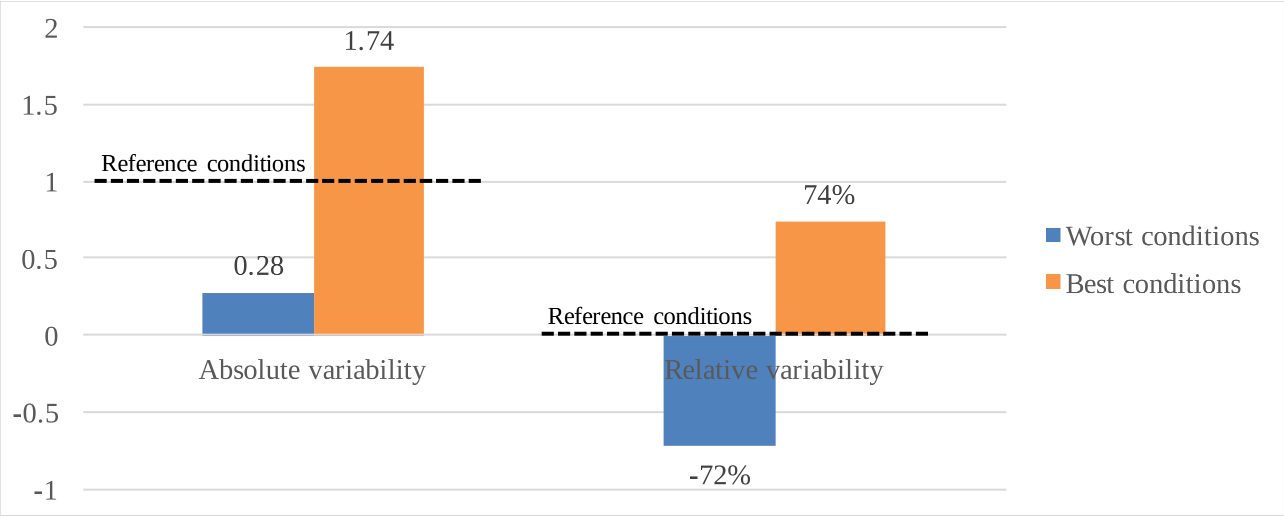

Fig. 1: Variability of the eight factors if computed using the suggested values for aluminium windows.

An extensive application of the outlined factor method will, hopefully, allow refinements on both proposed factors values and the Eq. 5 itself.

Acknowledgments

Results here presented are part of a research on service life prediction of aluminium construction products applied on building envelope funded by the European Aluminium [18].

References

[1] G.J. Frohnsdorff, C.H. Sjöström, G. Soronis, International standards for service life planning of buildings, in M.A. Lacasse, D.J. Vanier (Eds.), Proceedings of the 8th DBMC Durability of Building Materials and Components 8, Vancouver, NRC Research Press, Ottawa, 2, pp. 1537-42

[2] EN 13306, Maintenance terminology, European committee for standardization, (2010)

[3] L.W. Masters, E. Brandt, Materials and Structures (1987) Volume 20, doi:10.1007/BF02472728

[4] BS 7543, Durability of buildings and building elements, products and components, British Standards Institution, (1992)

[5] Principal Guide for Service Life Planning of Buildings (English edition), Architectural Institute of Japan, Tokyo, Japan (1993)

[6] L.W. Masters, E. Brandt, Materials and Structures (1987) Volume 20, doi:10.1007/BF02472728

[7] ISO 15686-1, Buildings and constructed assets - Service life planning - Part 1: General principles and framework, International Organization for Standardization, (first edition 2000, second ed. 2011)

[8] ISO 15686-8, Buildings and constructed assets - Service-life planning - Part 8: Reference service life and service-life estimation, International Organization for Standardization, (2008)

[9] Moser K., Towards: the practical evaluation of service life – Illustrative application of the probabilistic approach, in M.A. Lacasse, D.J. Vanier (Eds.), Proceedings of the 8th DBMC Durability of Building Materials and Components 8, Vancouver, NRC Research Press, Ottawa, 2, pp. 1319-1329

[10] Re Cecconi F., Engineering method for service life planning: the evolved factor method, Proceedings of Building for the Future: The 16th CIB World Building Congress, (2004), Toronto, Canada.

[11] Hovde P.J., The Factor Method – a simple tool to service life estimation. in Proceedings of 10th DBMC Durability of Building Materials and Components, (2005), Lyon, France

[12] Re Cecconi F., Iacono P., Enhancing the Factor Method – Suggestions to Avoid Subjectivity, in Proceedings of 10th DBMC Durability of Building Materials and Components, (2005), Lyon, France

[13] Hovde P.J., Moser K., Performance Based Methods for Service Life Prediction, CIB Report: Publication 294

[14] EN 12206-1 Paints and varnishes - Coating of aluminium and aluminium alloys for architectural purposes - Part 1: Coatings prepared from coating powder, European Committee for Standardization, (2004)

[15] For information: UNICMI - Unione Nazionale delle Industrie delle Costruzioni Metalliche dell'Involucro e dei serramenti, www.unicmi.it

[16] H. A. Linstone, M. Turoff, Delphi Method: Techniques and Applications, 1975, Addison-Wesley Publishing

[17] Saaty, T.L., “The Analytic Hierarchy Process.” McGraw-Hill, 1980, New York

[18] For information: European Aluminium, www.european-aluminium.eu