Application of the factor method to the service life prediction of ETICS

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Extended abstract

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February, 2016

1. Introduction

This Dissertation's objective is the development of a methodology for service life prediction of ETICS (External Thermal Insulation Composite System) using the factor method and follows a line of research related to the study of the durability of construction elements, taking into account the works of Gaspar and Brito (2008), Gaspar and Brito (2011), Silva *et al.* (2011), Sousa *et al.* (2011), Chai *et al.* (2014), Emídio *et al.* (2014), Galbusera *et al.* (2015) and Ximenes *et al.* (2015).

The methodology adopted is based on field data collected through visual inspections of buildings under current conditions of occupation and exposition, contemplating the degradation mechanisms and the characteristics of ETICS systems. In addition to the primary objective of determining the service life of ETICS claddings, this study is still relevant since it offers relevant information for optimization of maintenance and life cycle management strategies of ETICS, allowing quantifying the overall costs involved in these interventions. This research can also provide a suitable tool to aid the planning, implementation and rational use of the building management systems, aiming at the higher quality of construction solutions and enabling the improvement of the materials performance, while improving the prediction of the energy consumption and environmental impacts of constructions.

2. Service life definition

According to Gaspar (2002), service life is not simple to define, since it depends on the level of performance that is expected for the system, depending on the criteria of whom evaluates what, and is also variable according to the contexts and characteristics of the building and its surroundings. Masters and Brandt (1986) refer that the durability of materials and construction elements can be improved based on the knowledge of their service life and through proper and effective selection, use and maintenance, enabling the recognition of the most viable and profitable proposal. ISO 15686-1 (2000) defines service life as the period of time, after construction, in which the building and its parts equal or exceed the acceptable minimum requirements of performance established. These requirements are subjective parameters, which are quite variable according to the situation, because, in addition to the functional aspects, must also be taken into account aesthetic criteria, dependent on the assessment of each individual [GASPAR, 2009]. *The Guideline on Durability in Buildings* (CSA 1995), referenced by Sousa (2008) and Anselmo (2011), describes service life as the period of time in which the building or any part of it meet their objectives without unanticipated costs, without repairs, interruptions or alterations attributable to maintenance.

The main methods that allow the evaluation of service life are: probabilistic or stochastic methods (e.g. Markov chain), engineering methods (e.g. FMEA method) and deterministic models. The most recognized example of the latter is the factor method (proposed in the International Standard for Durability, ISO 15686: 2000), applied in this study, which is widely accepted in the scientific community and is characterized by its easy applicability and operability.

3. ETICS systems description

ETICS (External Thermal Insulation Composite System) are a system composed of fully harmonized and compatible components. The cladding system comprises the following layers: the thermal insulation material (boards of expanded polystyrene - EPS, extruded polystyrene - XPS, mineral wool, among others) and the necessary components and specified reinforcements (glue and/or mechanical fastening devices) to aid adherence to the substrate; the thin plaster laid in several coats reinforced with a glass fibber mesh (additionally, a primary coat can be applied after this reinforced layer) and, finally, the finishing decorative layer.

This system is applied to the external walls of new or refurbished buildings to improve the thermal insulation inside constructions and to achieve a number of other objectives such as: i) the correction of thermal bridges; ii) providing an active contribution to the conservation of natural resources by increasing the insulation of buildings against energy losses and substantially reducing heating or air conditioning costs.

According to Amaro (2011), there are four types of systems:

- Traditional system - system composed by panels of insulation with EPS, a mesh of glass fibre and an exposed and rough finishing;
- Strengthened system - when the system incorporates a double mesh;
- Resistant system - when materials such as carbon fibre mesh are applied to increase the durability of the system;
- Ceramic system - when ceramic elements are applied as a finishing solution.

4. Research methodology and field work

Initially, the research method adopted in this Dissertation was based on a bibliographical research and field work. These processes have enabled the compilation of data for the study of the claddings' service life, culminating in the integration of the information collected during the field work in the mathematical modelling process. The bibliographical research focused mainly on the service life prediction of ETICS and on their characteristics, application conditions and behaviour of the systems in use conditions.

Before starting the field work, it was necessary to characterize the sample previously studied by Ximenes (2012), identifying its peculiarities and gaps, in order to determine the minimum number of new claddings to analyse (80 new cases - Table 1). A methodology for data gathering through simple visual inspections of façades exposed to various degradation agents was subsequently adopted and the collected data were registered and systematized in an inspection and diagnosis sheet. At this stage, the difficulties in finding claddings older than 20 years were emphasized, due to the fact that the use of ETICS systems in Portugal is still relatively recent.

The pathological manifestations detected in the claddings were aggregated in a classification system and the most frequent defects in ETICS were grouped in four distinct categories:

- Staining/colour or texture changes - this group integrates biological growth, drainage signs, dirt deposits, humidity stains, efflorescence and oxidation stains, among others;
- Loss of integrity anomalies - this group includes cracking and deterioration of reinforcement corner profile caps and material gaps;
- Loss of adherence defects - this group includes peeling and blistering manifestations in façades;
- Joints defects - this group comprises cracking in joints and discernible joints between panels associated to dirt or humidity.

The information compiled in this field work stage, relative to 133 new case studies, was statistically treated, and the registered evolutional defects were differentiated according to their severity, extent and effects, while defining probable causes for their occurrence. The discrete phenomena were excluded in this analysis since this methodology only considers degradation phenomena evolving over time, suitable to be modelled. At this stage, ten of the case studies were excluded for presenting very different degradation patterns when compared to the average results obtained from claddings with similar ages and features. As the initial sample of Ximenes (2012) comprised 170 cases of study, the entire methodology described is based on the appraisal of the degradation state of 293 claddings with ages up to 31 years.

Table 1. Minimum number of claddings to be analysed in the new field work

Age	Minimum number of claddings needed									Total
	Orientation	Distance from the sea	Exposure to damp	Exposure to rain/wind action	Exposure to pollutant sources	Type of system	Type of finishing	Colour	Protection level	
5 to 9 years	0	5	0	5	0	**10**	5	**10**	5	10
10 to 14 years	**15**	10	0	10	0	10	10	5	5	15
15 to 19 years	0	5	0	10	5	5	10	**15**	0	15
20 to 24 years	10	10	5	10	5	10	15	**20**	10	20
> 25 years	**20**	10	5	10	5	10	15	**20**	10	20
										80

5. Degradation models

After data collection, a specific software is used to analyse the photographic information gathered in the field work, allowing initiating the development of the service life prediction models. For each group of defects, five levels of degradation were defined through a visual and physical classification, numbered from 0 (no visible degradation) to 4 (generalized degradation), determined by the existing conditions analysed *in situ*. This degradation scale was set according to the defect type, severity, extension, intensity and effects of the registered defects. Thus, the field data were converted and used to calculate some numerical indicators, enabling the degradation quantification and the graphical determination of deterioration patterns. The adopted methodology uses the degradation severity index (S_w), which reflects the overall state of degradation of the claddings, based on the data obtained during field work. This quantitative index was calculated through the ratio between the weighted degraded extension of the cladding and the maximum level of possible degradation (Equation 1), allowing a statistical comparison between the various claddings. From this information, a global degradation curve was drawn (Figure 1) based on a simple regression analysis, in which a third degree polynomial line was adjusted to the scatter of points belonging to the sample, using a methodology similar to the one proposed by Gaspar (2009).

$$S_w = \frac{E_w}{k} = \frac{\sum(A_n \times k_n)}{A \times k} \times 100 \quad \textbf{(1)}$$

Where [XIMENES, 2012 and XIMENES *et al*., 2015]: S_w represents the degradation severity, expressed in percentage; E_w the weighted degradation extension, expressed in percentage; k the multiplying factor corresponding to the highest degradation condition level of the cladded area A (in this case, k = 4); A_n the cladding area affected by an defect n, in m^2; k_n the multiplication factor for n anomalies, in terms of their degradation level, taking the belonging values to K= {0, 1, 2, 3, 4}; A the total facade area with ETICS, in m^2.

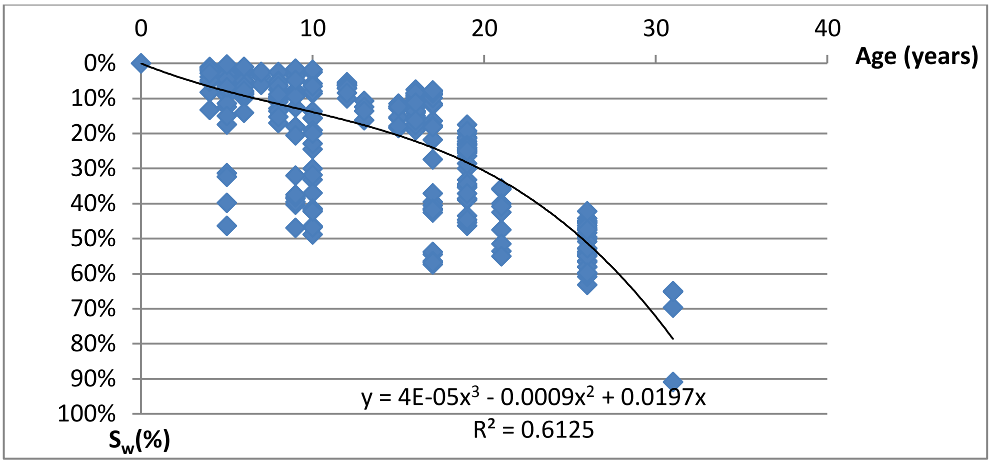

Figure 1. Degradation curve obtained from the 293 analysed cases inspected in the field work

The global degradation curve intended to translate the evolution of the behaviour of ETICS over time, through the graphical representation of the loss of performance of the totality of the sample, distributed according to the age of each case study. Simultaneously, the method allowed determining the sample reference service life based on the setting of a maximum acceptable degradation level (S_w = 30%). In this context, the same criterion as Gaspar (2009) and Ximenes (2012) was applied, which defined the degradation level 3 (moderate degradation - S_w = 30%) as the service life limit for ETICS systems. Thereby, claddings with a degradation level of 3 or higher are assumed to have reached the end of their service life and are not appropriate to perform their expected functions, requiring some intervention (repair and/or substitution of elements) in order to re-establish their original characteristics.

The reference service life value was obtained by solving the equation of the regression curve in order to obtain *x* for *y* equal to 0.30, yielding a value of 19.73 years (approximately 20 years). This value was similar to the ones defined by various publications such as CSTB (1981), which refers a service life equal or higher than 30 years; ETAG 004 (2000), which reports a service life higher than 25 years for ETICS claddings subjected to regular maintenance actions and Falorca (2004) and Silva and Falorca (2009), who suggested a predicted service life value between 24 and 28 years for ETICS systems, without maintenance.

The determination coefficient (square of the instant correlation coefficient of the Pearson product), associated with the degradation pattern, showed a relatively high value (R^2 = 0.61), which acceptably characterized the loss of performance of ETICS claddings (61% of the variability of the degradation is explained by age and the other 39% is due to other factors, not considered in this model). However, this graph also translates a significant scatter in the values, particularly evident when one considers that some of the cases with the same age are located in the same building. Thereby, the claddings ages that presented the highest variability were 5, 10, 17 and 31 years. The observed dispersion can be justified, partially, by the high sensitivity of ETICS systems to the existing conditions of execution and use. These factors were not considered in this analysis due to the difficulty in precisely evaluating this type of information through simple visual inspections.

The curve configuration (a "S" shaped pattern) also indicates that claddings tend to show early changes that have a visual impact shortly after the end of the construction, whose actions progress over time, increasing the degradation potential of the ETICS systems near the end of their service life.

Subsequently, the sample was evaluated according to different variables and their combined action, trying to figure out how the degradation factors influences the durability of ETICS systems and their properties over time (these factors are the basis of the factor method's calculation). In this regard, several regression curves were drawn and analysed, enabling the development of degradation models associated with each variable studied. In this analysis, some variables did not allow drawing unequivocal conclusions due to their statistically insignificant results (when the sample was divided into several sub-factors, some categories presented a very small number of cases). Some degradation curves also showed low correlation coefficients, revealing a low statistical relevance. As previously stated, such fact may be indicative that ETICS systems are affected by other factors, not considered in this study, which may be responsible for different degradation patterns. Regarding the degradation evolution of the claddings, the following considerations were drawn:

- ETICS facing North feature the lowest expected service life value (approximately 19 years), while façades facing South show the best behaviour (service life is approximately equal to 22 years);
- Although the outcomes regarding the distance from the sea are rather inconsistent, due mainly to the lack of cases located less than 1 km from the sea, the claddings located between 1 and 5 km from the coastal areas show a faster degradation than the cases more than 5 km away from the sea;
- The claddings with "high" exposure to damp have a slightly lower service life (around 19 years) than claddings with "low" exposure (about 20 years); these results must be cautiously analysed, given the low statistical significance of the models obtained;
- The data obtained for the combined action of rain and wind were not conclusive, because the curve associated with a "mild" influence of the atmospheric agents shows a faster deterioration than the curves associated with "severe" and "moderate" actions of rain and wind;
- Claddings with a lower exposure to pollution agents present an estimated service life 2 years higher than claddings situated near intensive traffic routes (with a higher exposure to these agents);
- Although the statistical significance of this analysis, due to the low representation of cases with "ceramic" and "strengthened" finishing, is small, systems with ceramic tiles show a slower degradation process (featuring a higher estimated service life), while the traditional systems are less durable;
- Claddings with lighter colours exhibit a faster degradation, while "dark" and "other" type of colours have slower decay trends; the "light" colours degradation pattern can be caused by the ease of inspection and the easier interpretation of pathological events in this type of claddings when compared to the darker colours [GASPAR, 2009];
- Claddings with "ceramic" finishing are the ones that show the best performance, although the results are not statistical significant due to the small number of case studies; claddings with "rough" finishing are more prone to deterioration than the other types considered in this study;
- Regarding the protection level, and as expected, the claddings less protected in accessible areas have a shorter service life (approximately 17 years); the façades with peripheral profiles show a better performance than the other types analysed (with a service life around 21 years);

- Although the ease of inspection is not influential on the durability and service life prediction of ETICS, the façades that facilitate the visual survey of the degradation state present a faster degradation than the claddings characterized by unfavourable inspection conditions; however, the two situations feature identical service life values (around 19 years);
- An inadequate execution level clearly reduces the expected service life of ETICS; the estimated service life for systems featuring poor execution is equal to 6 years, while claddings presenting a proper execution have a service life equal to 20 years.

6. Factor method

Prior to the application of the factor method to the sample, the average degradation curve was extrapolated to the different cases using the method of ordinates' conversion factor method [EMÍDIO *et al.*, 2014]. The trend line, concerning the expected service life distribution of the claddings over time, is shown in Figure 2. This line represents the average expected service life of the sample (approximately 22 years). The value obtained is close to the one calculated through the average degradation curve (approximately 20 years). Despite the scatter in the graph, acceptable results were obtained. The factors affecting the durability of ETICS were also further analysed and have led to results consistent with those determined through the degradation curves.

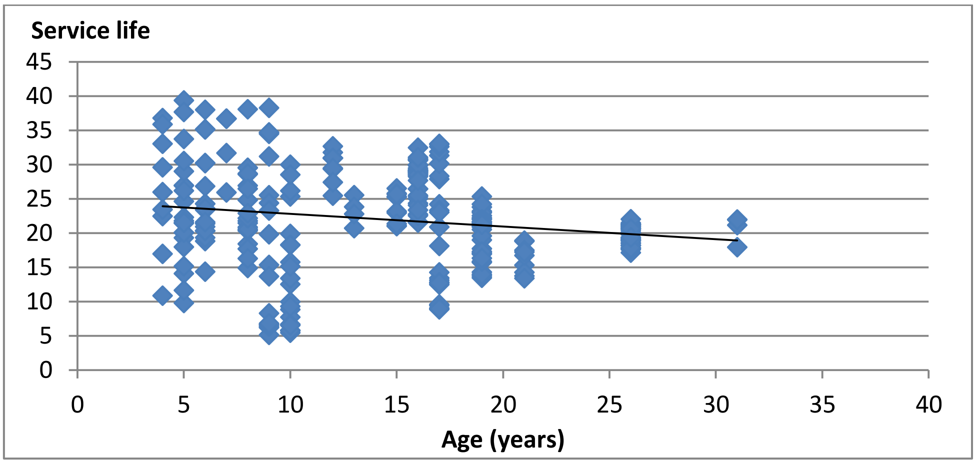

Figure 2. Service life distribution of the claddings over time

The reference service life was determined through three different methods, in order to minimize the uncertainty associated to this value:

- Average degradation curve - 19.73 years;
- Method of the average exposure conditions for the best case - this model adopts the weighting values proposed by the standard ISO 15686 (2000) - 1.2, 1.0 and 0.8 - and uses the predicted service life values calculated through the method of ordinates' conversion factor method; the objective was to find claddings exposed to an intermediate situation (all variables equal to 1.0). However, the sample does not have any cases with these characteristics and, therefore, the closest values to this situation (with a higher number of variables equal to 1.0) were identified; subsequently, the occurrences of 0.8 (x) and 1.2 (y) were counted and the predicted service life value was calculated through the consideration of

the average of all the cases with the mentioned characteristics. The formula used to calculate the reference service life of the claddings is expressed by Equation 2 [EMÍDIO *et al.*, 2014] - 22.1 years;

$$\text{Reference service life} = \frac{\text{Predicted service life}}{(0.8^{x} \times 1.2^{y})} \quad \textbf{(2)}$$

- Method of the average conditions for the whole sample - in this method, the ratio between the predicted service life and the reference service life calculated by the previous method was evaluated; only the ratios to which corresponded deviations from the total average below 3% were considered; taking only these cases into account, the average of the reference service life was calculated - 20.8 years.

The results achieved by the three models were coherent among them, revealing a good fit to the reality. The reference service life for ETICS was set at 21 years, corresponding to the average of the three values stated above.

The factor method, initially proposed by the Architectural Institute of Japan and developed by ISO 15686 (2000), establishes a calculation formula, applied to all the claddings of the sample, aiming to estimate the service life of a specific construction element exposed to particular conditions. This formula consists of the consideration of a reference service life multiplied by several coefficients associated to the variables that influence the claddings' deterioration process (Equation 3). To each variable a weighting value proposed by ISO 15686 (2000) was conferred: 0.80 for unfavourable situations, 1.2 for favourable situations and 1.0 for intermediate situations or for variables with a difficult evaluation.

$$\text{VUE} = \text{VUR} \times \text{A1} \times \text{A2} \times \text{B1} \times \text{B2} \times \text{C1} \times \text{E1} \times \text{E2} \times \text{E3} \times \text{E4} \times \text{E5} \times \text{G1} \quad \textbf{(3)}$$

Where: VUE represents the estimated service life; VUR the reference service life; A1 the type of system; A2 the colour;B1 the type of finishing; B2 the protection level; C1 the execution level; E1 the facade orientation; E2 the distance from the sea; E3 the exposure to damp; E4 the wind/rain action; E5 the exposure to pollution sources; G1 the ease of inspection.

Finally, six scenarios were analysed, through several iterations, in order to optimize the results and improve the reliability of the weighting coefficients. The criteria that led to the quantification of the sub-factors in each scenario are listed in Table 2. The evaluation and the interpretation of the obtained results were based on statistical indicators and the methodology applied was similar to the one adopted in various works [GASPAR, 2002; GASPAR, 2009; EMÍDIO, 2012 and GALBUSERA, 2013]. Therefore, some principles were stated, the more relevant ones being highlighted:

- The maximum value for the average of the relation FM/GM is 1.05 (FM indicates the values obtained through the factor method and GM refers to the values achieved through the graphical method);
- The results achieved through the factor method should be coherent with the expected reality. Therefore, the maximum was set as twice the reference service life (42 years) and the minimum as 15% of the same value (3.15 years);
- the main objective of the various iterations is to maximize the number of cases contained in the interval of 0.85 and 1.15 for the FM/GM relation.

Table 2. Description of the criteria applied to each scenario

Scenario	Description of the criteria
1	This scenario takes into account the average predicted service life value obtained through the graphical method (22 years). For each year of difference between the average service life associated to each sub-factor and the average predicted service life, the coefficient *k* is increased or reduced by 0.05, in relation to 22 years. If the average obtained for one variable is equal to 22 years (difference of values equal to 0) or the sub-factors have scarce representation of cases in the sample, the *k* coefficient takes the value of 1.0.
2	The criteria applied in this model are similar to the methodology used in scenario 1, but now based on the values of the averages obtained through the degradation curves for each sub-factor. In this context, the model takes into account the average service life value obtained from the average degradation curve - Figure 1 (20 years). Considering the difference between the average service life of the degradation curves associated to each sub-factor and the stated value, *k* is reduced or increased by 0.05 for every year of difference in relation to 20 years.
3	In this scenario, a weighting value of 1.0 is attributed to all the sub-factors, analysing the neutral behaviour of the model.
4	In this model, the values adopted are based on ISO 15686 standard (2000): 0.80 for unfavourable situations, 1.2 for favourable situations and 1.0 for current situations or for variables with a difficult evaluation.
5	The criteria adopted are similar to the principles used in scenario 4. The values attributed to the *k* sub-factors are 0.90, 1.0 and 1.1. This range is tighter than the one proposed in scenario 4 so as to analyse the model´s sensibility to small variations and the contribution of this variation on the sub-factors quantification.
6	This model is based on the results of the previous scenarios and considers the physical meaning and the influence of each variable. It consists on an optimized attribution of the *k* values, obtained by manual iterations, to the various sub-factors.

7. Results and discussion

Table 3 illustrates the statistical indicators obtained through the analysis of the considered scenarios, after the factor method application. The results that do not fulfil the expressed criteria are marked in red, while the most relevant values are highlighted in blue. The best weighting coefficients combination was reached with scenario 6, which emerged from an optimization of the values that were changed so as to obtain the best possible fit to the sample. This scenario was the one that reproduced the best results and, therefore, validated the applicability of the methodology.

Table 3. Statistical indicators obtained through the analysis of the considered scenarios

Scenario		1	2	3	4	5	6
FM/GM average <1.05		1.12	0.81	1.13	1.18	1.17	1.02
Standard deviation		0.464	0.349	0.634	0.573	0.582	0.439
Standard deviation average in relation to 1.0		0.30	0.34	0.37	0.38	0.36	0.29
Amplitude of results	Factorial method (years)	31.9	21.5	20.9	37.6	26.4	20,4
	Graphical method (years)	34.2	34.2	34.2	34.2	34.2	34,2
Extremes values obtained in the factor method	Maximum = 42 years	47.1	32.5	41.8	49.9	43.0	33,5
	Minimum = 3.15 years	15.3	11.0	20.9	12.3	16.6	13,1
FM/GM ≥ 0.85 (≥50%)		74.7%	30.8%	65.2%	72.5%	71.4%	67.8%
FM/GM ≥ 1.50 (< 10%)		12.8%	5.1%	14.7%	17.9%	15.0%	9.2%
0.85 ≤FM/GM ≤ 1.15		41.4%	19.4%	38.5%	37.7%	38.1%	47.3%

Statistically, scenarios 4 and 5 led to the worst results, not fulfilling many of the defined criteria. A possible reason for these results is that some sub-factors included few elements that were not statistically representative. Scenario 1 features the second best outcome in terms of the statistical percentage of elements with a ratio FM/GM included in the range 0.85 and 1.15 (41,4%), but did not fulfil several of the registered requirements.

Scenario 2 shows better results, with only one criterion not satisfied (FM/GM ≥ 50%), although it presents a low percentage of cases within the range 0.85 and 1.15 (19,4%) and the influence of some variables was not clearly evaluated due to the small number of claddings with these characteristics in the sample. Likewise, scenario 3 did not reproduce globally satisfactory outcomes, as two of the indicators did not respect the defined criteria. This scenario was only considered with the purpose of studying the neutral behaviour of the model and, therefore, does not have a physical meaning.

The adjustment and the manual optimization process of the values in scenario 6 have led to the best results and the fulfilment of all the requirements, giving due emphasis to the highest percentage of elements featuring a ratio FM/GM between 0.85 and 1.15 (47.3%). The estimated service life value obtained for this scenario through the factor method is identical to the one calculated through the average degradation curve (approximately 20 years). The results can be considered satisfactory, considering the variability of the conditions influencing the degradation of ETICS systems, and showed that the optimized weighting coefficients should not be too close to the ones achieved through a neutral model (scenario 3 - standard conditions) nor too removed from 1.0, in order to validate the credibility of the values and, simultaneously, minimize the deviations (Table 4).

Table 4. Values obtained in scenario 6

Factors	Sub-factors		Service life average obtained through the graphical method	Final *k*
A1 - Type of system	*k*1	Traditional	22	1,000
	*k*2	Strengthened	24	1,150
	*k*3	Ceramic	29	1,200
A2 - Colour	*k*1	White	21	1,100
	*k*2	Light colours	21	1,000
	*k*3	Dark colours	27	1,300
	*k*4	Other	23	1,350
B1- Type of finishing	*k*1	Rough	22	0,800
	*k*2	Smooth	23	1,000
	*k*3	Other	29	1,150
B2- Protection level	*k*1	Peripheral profile	26	1,125
	*k*2	Wainscot	23	1,100
	*k*3	Other	20	0,795
C1- Execution level	*k*1	Adequate	22	1,000
	*k*2	Inadequate	6	0,800
E1 - Orientation of the facade	*k*1	North	21	0,905
	*k*2	South	25	1,025
	*k*3	East	23	1,000
	*k*4	West	22	1,000
E2 - Distance from the sea	*k*1	< 1 km	-	0,800
	*k*2	Between 1 and 5 km	22	0,975
	*k*3	> 5 km	22	1,100
E3 - Humidity exposure	*k*1	High	22	1,000
	*k*2	Low	22	1,125
E4 - Exposure to wind/rain action	*k*1	Severe	23	0,800
	*k*2	Moderate	20	0,900
	*k*3	Mild	22	0,900
E5 - Pollution exposure	*k*1	High	20	1,000
	*k*2	Low	23	1,100
G1 - Ease of inspection	*k*1	Yes	22	1,100
	*k*2	No	22	1,000

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