2.9 Test methods for the durability evaluation of pitched roof[1]

The research carried out by the Unit of Palermo, “Planning and experimental evaluation methodologies of discontinuous roofing class durability”, becomes part in the more general picture of evaluation and control of the technological quality of complex products for the building and in particular of durability, fundamental to reach the quality in building (ISO 8402, UNI 10838), cause it regards maintenance over time of the performances owned at the moment of the entrance in exercise and the modalities in which them decay during time.

For the research result fundamentals the normative contributions, in international field of CIB W80/RILEM 175 (Service Life Methodologies) and ISO TC59-Buildings Construction, with the ISO 15686 Building and Constructed Assets Service Life Planning, and in national field UNI11156 - 2006, “Evaluation of durability in buildings components” approved recently.

2.9.1 Objectives of the experiment

The aim of the experiment is to study the behaviour over time of solutions for sloping roofs, in particular sandwich panels with double sheets and an insulating core, in order to test the methods for predicting the service life of these components.

The roof is a system made of many functional elements, each one defines the performances that it must furnish (watertight, thermal insulation, mechanical strength, etc.).

The configuration of a discontinuous roofing results from different factors interdependent among them: functional factors; climatic; contextual; formal; specific of the seal.

The group of functional elements, every with its own physical and chemical characteristics and the mutual position, determines the behaviour of the roof.

The main requirements that concern the class of the discontinuous roofing and particularly the coverage realized with metallic (UNI 10372) elements are: mechanical strength and stability, phase displacement and damping, thermal insulation, control of surface condensation, sound-proofing, watertight, resistance and reaction to the fire, stain resistance, resistance to frost and thermal shock, resistance to ultraviolet radiation, resistance to biological agents, resistance to weathering.

A repertoire of 24 technical solutions has been studied, which includes also representative solutions of the local uses, as well as solutions "innovative" to study it and to compare its characters in comparison to those "traditional".

Another objective is to study the influence that the different colour of the external surface can have on the deterioration in the performance of sandwich panels and their component parts, as a result of the effects of aging.

2.9.2 Description of the tests method

The methodology follows the evaluation with two distinguished and complementary procedures of the two parameters of durability: reliability and natural durability.

Reliability is estimated through an object and functional analysis that permit a qualitative evaluation followed by a comparative procedure lead among elements of a catalogue of technical solutions of the discontinuous roofing class, which is considered out of system and with no intended use.

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[1] Giuseppe Alaimo, Francesco Accurso, Università degli Studi di Palermo, Dipartimento di Progetto e Costruzione Edilizia.

Natural durability is estimated through experimental tests on samples of technical elements exposed to natural agents and accelerated aging test in laboratory.

We choose sandwich panel, as the building components for our research[2].

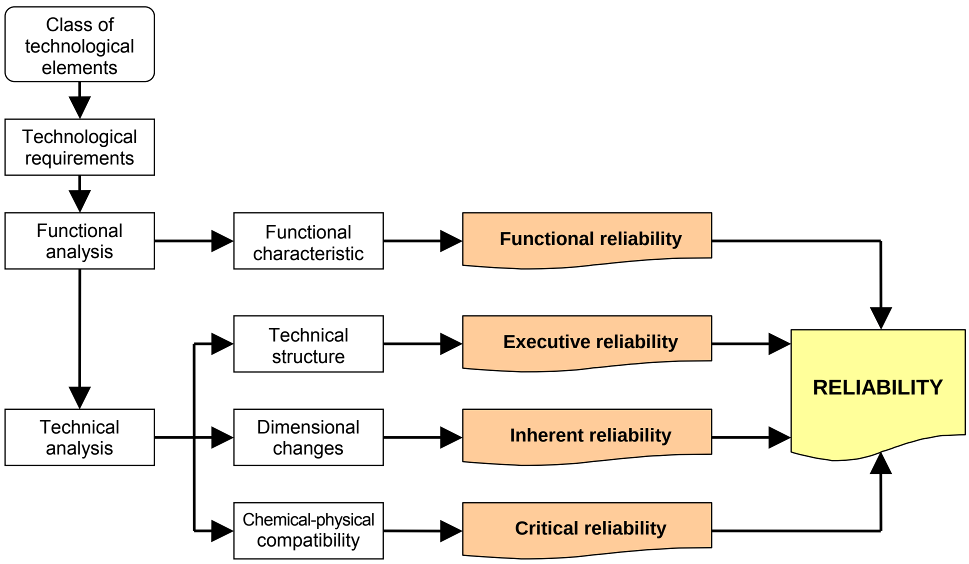
The reliability has been evaluated by the method proposed from Rejna [1995], inserted in the UNI 11156:2006, based on the functional and technical analysis of the element, proceeds through the evaluation, with precise criterions of judgment, of the four components of the reliability (fig. 2.9.1):

- functional reliability, through the functional analysis, indentifies the distribution of the functions inside the solution, on which the degree of fatigue of the element depends during its operation;
- executive reliability, through the technical analysis, verifies the degree of executive correspondence in comparison to the design intensions;
- inherent reliability concerns the possible dimensional changes of the component in phase of exercise;
- critical reliability considers physical-chemical compatibility between material adjacent of different nature constituent the technical solution.

The propensity to the global reliability (fig. 2.9.2) expresses in qualitative and comparative terms the degree of probability that the technical solutions have to last in time. Such values result from the arithmetic average among the correspondents values of reliability of the four components.

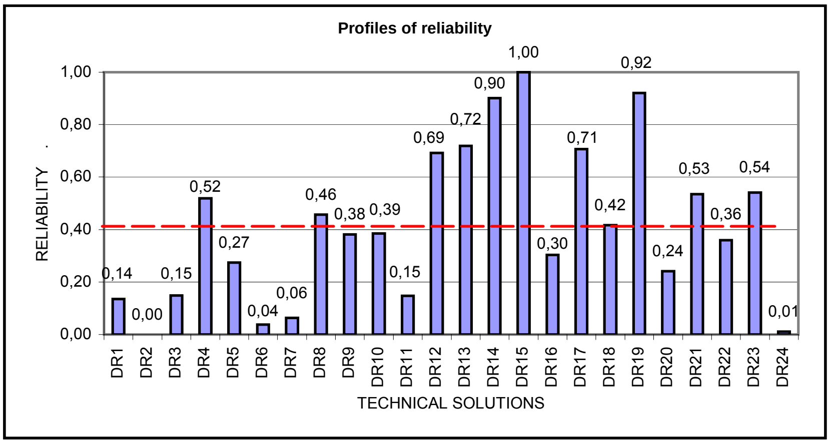
On the basis of the range of the fixed values, it is possible to perform with comparison: the design of a solution of given reliability, or to esteem the reliability of a given solution, different from those to the repertoire.

Fig. 2.9.1 - Methodology for the assessment of reliability



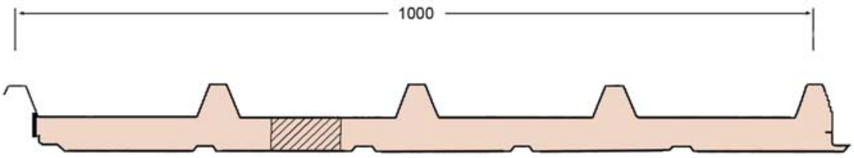
[2] For this reason have been developed the contacts with AIPPEG (Associazione Italiana Produttori Pannelli ed Elementi Grecati) that kindly has offered its collaboration.

Fig. 2.9.2 - Histograms of propensity to reliability of technical solutions



The study has been conducted on samples of measures 100x100, 100x250, 100x1000 mm, cut by standard panels as in fig. 2.9.3.

Fig. 2.9.3 - Cross-section of whole panel and cutting of specimens



The typical panel is constituted by a double metal skin of pre-painted galvanized steel and from an insulating core of polyurethane expanded (PUR) and thickness of 40 mm.

The colours of external surface are: White Grey and Siena Red.

Tab. 2.9.1 - Characteristics of samples

		Type 1 (roof)	Type 2 (wall)
Outside metal skin	Colour	Siena Red	White-Grey
	Side A	Pre-painted galvanized steel (0,45 mm) with polyester (25μ)	Pre-painted galvanized steel (0,45 mm) with polyester (25μ)
	Side B	Primer (5μ)	Primer (5μ)
Foam		40 mm PUR	40 mm PUR
Inside metal skin	Colour	White-Grey	White-Grey
	Side A	Pre-painted galvanized steel (0,35 mm) with polyester (25μ)	Pre-painted galvanized steel (0,45 mm) with polyester (25μ)
	Side B	Primer (5μ)	Primer (5μ)

Necessary methodological preamble to the experimental phase for the program of accelerated aging cycle, is the definition of the reference frame of the agents - actions - effects[3] and therefore of the correspondents deteriorations that they can rise up in the components on the basis of the specific climatic context.

On the samples (new, aged in external and in laboratory) destructive and non-destructive tests have been conducted to check the following parameters and characteristics: aspect; weight; colour; thermo-physical characteristics (thermal conductivity and thermal resistance); mechanical (traction, shearing and bending) characteristics.

[3] For term definitions please refer to the glossary of CIB W86 *Building Pathology*.

NATURAL AGING

The samples of sandwich panel has been exposed outdoor starting from March 2004, directed toward South and with slope of 30° in comparison (fig. 2.9.4a). Before the exposure, edges of the specimens have been protected with a special polyurethane paint.

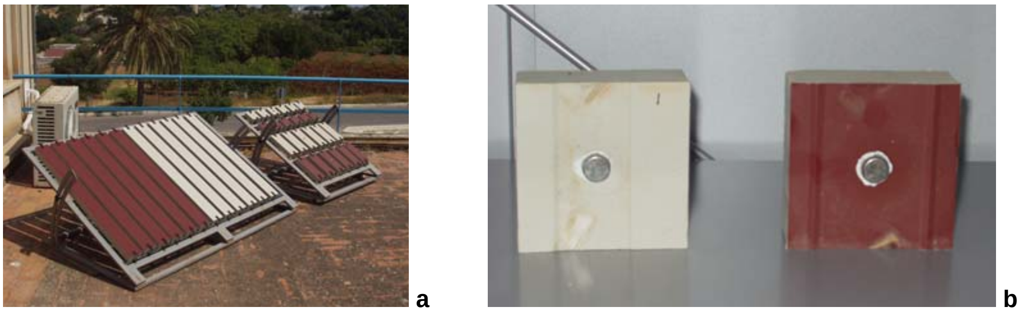
On some samples programmable data-loggers have been applied (fig. 2.9.4b), in order to record the superficial temperatures reached (exposed and shade side) during the exposure.

The collected data, between March 2004 and March 2006, allowed us to find the real course of the maximum, minimum and averages temperatures reached on the surface of the samples in Palermo during different seasons of the year.

The definition of the characteristics and the parameters (type, intensity, length) of the climatic context constitutes fundamental preamble for the definition and the debugging of the accelerated aging cycle to use in the climatic chamber.

To such purpose a weather stations have been located nearest to the site of exposure of the specimens and climatic data of last ten years have been processed .

Fig. 2.9.4 - The exposure in outdoor and temperature micro-loggers

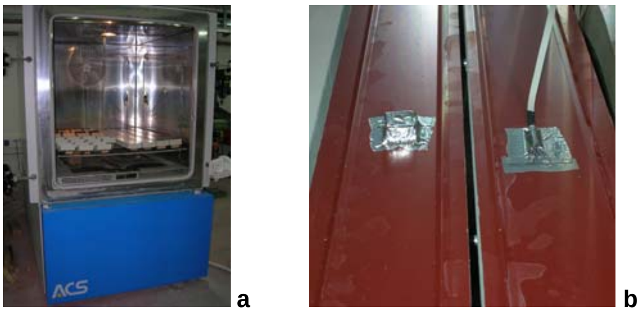


ACCELERATED AGING

From the analysis of the collected data and from the course of the different climatic parameters, four representative seasons of the climatic context of Palermo city are recognized, and particularly: one "summer season" (dry heat); one "autumn season" (rain); one "winter season" (cold); one "spring season" (warm dampness).

For every season the characteristic values of the four principal parameters have been recognized: temperature, relative humidity, rain and solar radiation.

Fig. 2.9.5 - Climatic chamber and temperature loggers

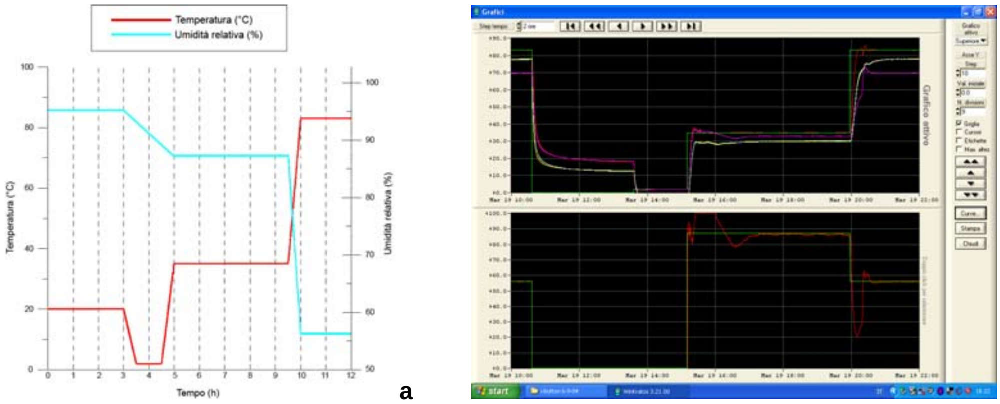


Tab. 2.9.2 - Accelerated aging cycle structure

Phase	Parameter		
	hour	T (°C)	RH (%)
Rain	3.0	-	-
Cold	1.5	2	-
Warm dampness	5.0	35	87
Dry heat	2.5	83	56
Total	12		

At the end of this phase, kept account of other factors of influence like the slope of the samples, the superficial colour, the changes of temperature in the last decade and the existing normative on the thermal shock, we reach the following definitive cycle of accelerated aging (tab. 2.9.2, fig. 2.9.6a).

Fig. 2.9.6 - Accelerated aging cycle: theoretical and experimental



The climatic chamber simulates the principals climatic agents: rain, solar radiation, temperatures, humidity, through an unity of control that allows to program the sequence desired of the agents, the intensity and the duration.

Once fixed the duration of the cycle of accelerated aging (12 hours), the length of each phases result consequently. It is necessary to remember that in the real cycle, between a phase and the following one there are transitory ones, in which temperature and humidity inside in the room before reaching the fixed values, employ a certain time. Nevertheless, for reasons for opportunity such transitions (of the general duration of around 2 h) have been inclusive in the general duration of the cycle (fig. 2.9.6b).

TESTS AND RESULTS

The tests, non-destructive (superficial aspect, weight, colour, thermal characteristics on the whole sample) and destructive (traction resistance, bending and shearing, thermal characteristics on the section of PUR), have been made on: samples before the aging process; external aged samples after 1 and 2 years; artificially aged samples after 30, 60 and 120 cycles corresponding to 360, 720 and 1440 hours of accelerated aging.

At the end of every phase of aging are been performed on the samples test turned to appraise the characteristics and parameters changes, in comparison to the samples virgin.

Every test have been conducted at least, on a number of three specimens.

SUPERFICIAL ASPECT

The analysis of the aspect don't show substantial differences among the aged samples in external to 24 months and those aged in laboratory up to 60 cycles. Superficial stain and punctual oxidations are primarily developed.

After 120 cycles the samples, also for their limited dimensions, have shown deformations of the form: increase of thickness of 1-2 mms and separations among metal skin and PUR along the edges that as expectation constitute critical points where this degradation have departed despite the protective paint (fig. 2.9.7).

From the comparison among the detected effects a temporal correspondence can be hypothesized between the 60 cycles of accelerated aging and the 24 months of external exposure .

Fig 2.9.7 - Detachment among PUR and metal skin

WEIGHT

The sandwich panels in their complex can be considered impermeable. Nevertheless the vapour and, with it, water can migrate inside the insulating layer in polyurethane causing some dimensional variations that influence the shape, the weight and the same performances of the component.

From the comparison of the results among natural aging and accelerated aging a meaningful analogy emerges both qualitative and quantitative among the variations of weight of the samples, very limited and more for the dark samples.

Also under such aspect the effect of the first two years of outdoor aging it results entirely comparable with that caused by the first 60 cycles of aging in the climatic chamber.

COLOUR

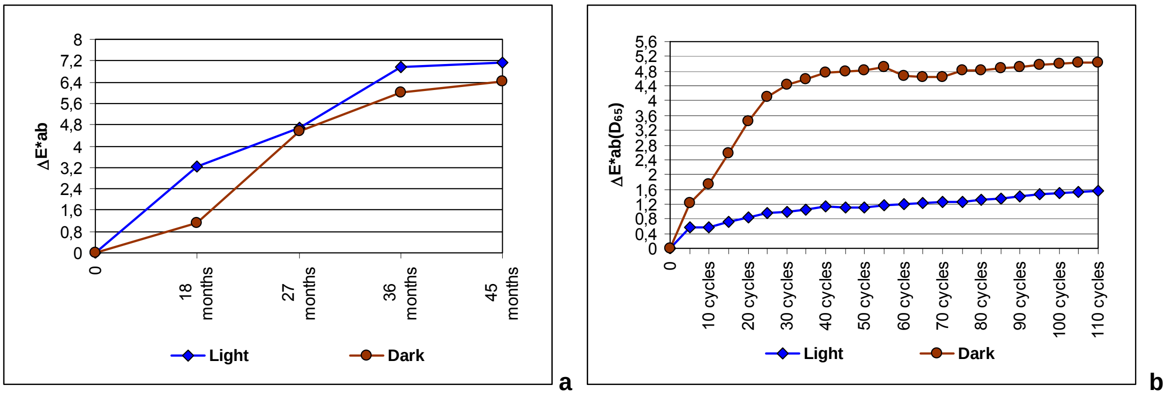
The colour was monitored periodically, on day one and after 18, 27, 36 and 45 months outside.

The results show a colour shift in terms of ΔE. The light and dark samples can be compared.

In fact, after about 45 months both sets of samples show ΔE values of between 6 and 7 units. However, after 18 months the light coloured samples already show a marked tendency to change colour compared with the dark ones (ΔE equal to about 3 units compared with 1.13 for the dark samples).

In the same way, after 27, 36 and 45 months this tendency persists, but the difference between the values is less clear-cut.

Fig. 2.9.8 - (a) Natural aging; (b) Accelerated aging



The equipment used to simulate aging is a Solarbox 1500e fitted with a Xenon lamp and a filter of 280nm.

In this case samples from the same production batch were used, but 100x100 mm in size.

The measurements were carried out using a colorimeter and a spectrophotometer, with D_{65} as illuminant to simulate day light.

Each cycle is made up of the following phases:

4 hours of UV (800 W/m²) at a temperature of 65°C;
4 hours of condensation with the lamp switched off and T= 55°C;

repeated three times in the 24 hours. Measurements were taken every 5 cycles up to a total of 110 cycles, equivalent to 2640 hours of exposure in total.

Shifts comparable to the variation in color recorded on the exterior can be observed from the measurements carried out with the colorimeter. In particular on the Siena Red samples, where there is a variation of about 5 units after 110 cycles (equivalent to 2640 hours of aging in total). Smaller variations have been recorded for light colored samples.

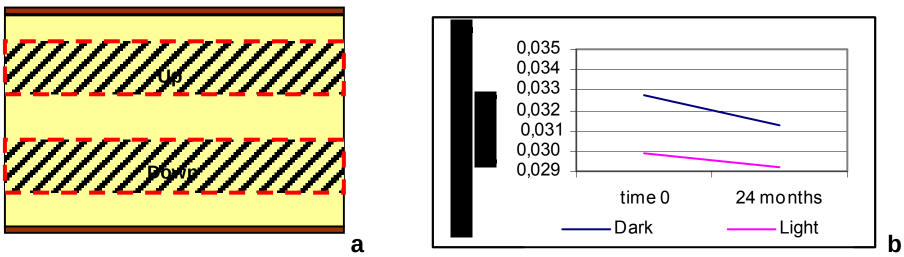
The measurements were repeated using a spectrophotometer, for the purpose of evaluating aspects of the aging phenomenon that are not verifiable with the colorimeter.

THERMO-PHYSICAL CHARACTERISTICS

The measure of the thermal conductivity of building materials in stationary state was made, according to the standard UNI/CTI 7745 "Determination of the thermal conductivity with the method of the warm plate with mark ring".

Measures have been conducted both on the whole samples and on the polyurethane sections (using from the core of every samples two sections of the thickness of 10 mm) (fig. 2.9.9), to the purpose to evaluate the influences of the external metallic elements and the interfaces with polyurethane.

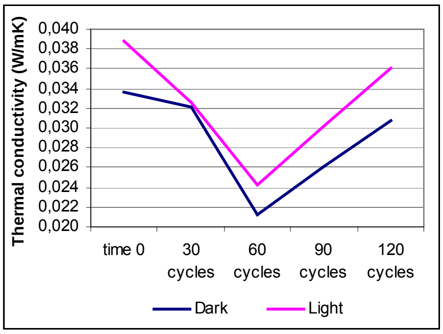
Fig. 2.9.9. Sections of PUR and change of conductivity (natural aging)



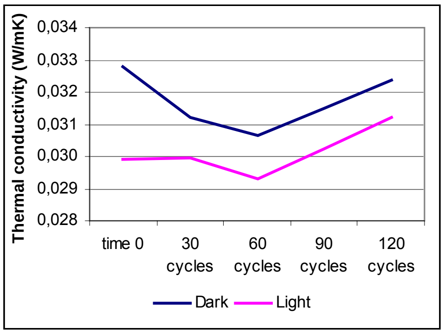
During 24 months of external exposure the conductivity of the samples has substantially been constant, both in the whole samples and in the sections of PUR.

In general the thermal conductivity of the whole samples results greater than PUR sections, cause the lower contact resistance due to the cover sheets glued to the PUR.

Fig. 2.8.10- Change of conductivity in the whole sample and in the PUR sections (artificial aging test)



a



b

There is a substantial constancy among the measures on the samples "Up" with those on the samples "Down".

The results of the tests in climatic chamber show an analogous behaviour from the qualitative point of view among the whole samples (fig. 2.9.10a) and the sections of PUR (fig. 2.9.10b) both for the samples White Grey and for those Siena Red.

Also in this type of tests after the 60 cycles an inversion of tendency is observed with a substantial constancy of the thermal conductivity both in the first year of natural aging, and in the first 30 cycles of accelerated aging.

MECHANICAL STRENGTH

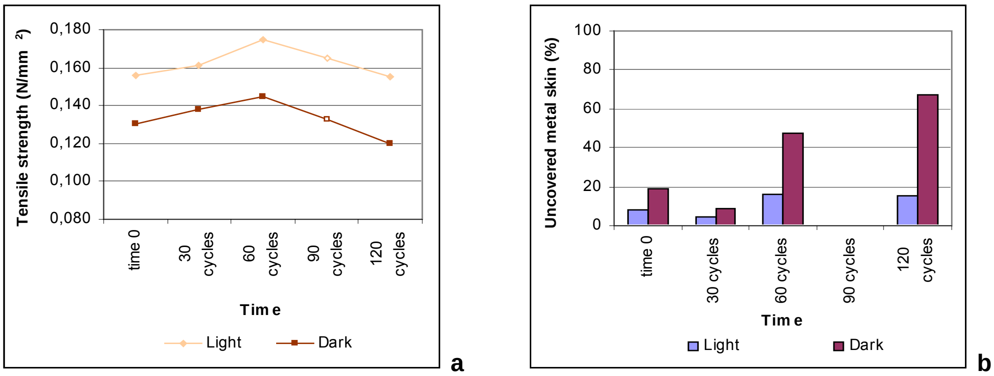
The test (fig. 2.9.11) has the purpose to evaluate the tensile strength of the polyurethane foam and its adhesion to the metallic support (ETAG 016-1, UNI EN 1607, EN 14509) and show an improvement of the traction resistance up to 60 cycles, subsequently such tendency is reversed with the increase of cycles (fig. 2.9.12a).

Fig. 2.9.11 - Tensile test and type of failure (PUR)

It seems us interesting to underline the relationship found among the tensile strength, the percentage of uncovered metal skin and the length of the aging. The aging causes in fact an increase of the percentage uncovered after the failure, effect more accented in the dark samples (fig. 2.9.12b).

From the comparison among the effects of the two types of aging, also in this type of tests a correspondence can be noticed among the effects of 60 cycles and those of 2 years of natural exposure.

Fig. 2.9.12 - Tensile test and uncovered metal skin in tensile failure (artificial aging test)



PREDICTING THE USEFUL LIFE OF A PANEL WITH THE FACTORIAL METHOD USING PERFORMANCE GRIDS

The factor method proposed by ISO 15686-2 allows an estimate of the service life of the component (ESL) to be made, starting from a known reference value (RSL).

In its various applications the method has proved to be affected by a high level of subjectivity, which has limited its use, although up to now it is the only one provided for by the international regulations.

One possible application of the factor method involves the preparation of performance grids for the attribution of coefficients to different factors, which can be used by designers who want to use the factorial method to determine the duration of a component.

The performance characteristics to be considered are those stated on day one by the producers and by the regulations that refer to that particular product (resistance to tensile stress, resistance to compression, permeability to water, density).

The method requires the indication of the RSL of the component as a starting point and subsequently the adjustment of each of the factors from A to G.

For the purpose of decreasing the subjectivity of the method, performance classes have been provided for each factor. Each performance class corresponds with a coefficient that can be greater than 1 to indicate an improvement in performance compared with the standard condition, or less than one if worsening conditions of the performance of the panel are referred to.

Although this method is of absolutely general validity, it was applied to the sandwich panel, starting from a reference value for its useful life of 10 years and introducing the necessary adjustments for each factor.

In the case of factor A (Quality of the component), seven sub-factors were provided, but since these factors do not have the same importance with regard to the duration of the component, it is necessary to attribute a different importance to each of them. Using the comparison of pairs matrix method and comparing the various sub-factors two by two, it was possible to attribute a weight of importance to each of the factors considered. The conclusion of this was that the characteristics of resistance to tensile stress and compression are the most important.

Tab. 2.9.3 - Performance grid relative to the factor A

Code	Sub-factor	Factors levels	Score
A1	Traction resistance	R_{tr} < 100 KPa	0,90
		100 ≤ R_{tr} ≤ 120 KPa	1,00
		121 ≤ R_{tr} ≤ 150 KPa	1,10
		R_{tr} > 150 KPa	1,20
A2	Compression resistance	R_{tr} < 120 KPa	0,90
		120 ≤ R_{tr} ≤ 150 KPa	1,00
		151 ≤ R_{tr} ≤ 175 KPa	1,10
		R_{tr} > 175 KPa	1,20
A3	Density	δ < 34 Kg/m^3	0,90
		34 ≤ δ ≤ 37 Kg/m^3	1,00
		δ > 37 Kg/m^3	1,10
A4	Water permeability	≥ 300 Pa	0,90
		≥ 600 Pa	1,00
		≥ 1200 Pa	1,10
A5	Colour changing	ΔE_{ab}^* > 8	0,80
		5 ≤ ΔE_{ab}^* ≤ 8	0,90
		ΔE_{ab}^* < 5	1,00
A6	Quality	FPC (ISO 9000)	0,80
		ETA	0,90
		CE marking of products	1,00

Tab. 2.9.4 - Performance grid relative to the others factors

Code	Factor	Factors levels	Score
B	Quality of project	Any certificate	0,90
		According to best practice indications	1,00
C1	Quality of construction	Any certificate	0,90
		According to best practice indications	1,00
C2	Quality of construction: laying team	Not specialized	0,90
		Specialized	1,00
D	Indoor environment	Very aggressive	0,70
		Aggressive	0,80
		Middly aggressive	0,90
		Low aggressive	1,00
		Not aggressive	1,10
E	Outdoor environment	Industrial and marine	0,70
		Industrial	0,80
		Marine	0,90
		Urban	1,00
		Rural	1,10
F	Conditions of use	Environment with bumps against hard body	0,80
		Environment with bumps against soft body	0,90
		Environment with no frequent bumps	1,00
		Environment with rare bumps	1,10
G	Level of maintenance	High (< 10 years)	0,90
		Medium (10 ≤ t ≤ 20 years)	1,00
		Low (> 20 years)	1,10

In this way, on the basis of the characteristics of the component chosen for the new design, the designer attributes an adequate level, so as to correct the score of factor A.

Similarly, for the others factors, the following grid was constructed in tab. 2.9.4.

At this point it is possible to estimate the useful life of the component (ESL) under the project conditions, using the formula of the factor method:

Tab. 2.9.5 - Assessment of ESL

Component	**Sandwich panel on discontinuous roofing**	
RSL	**10 years**	
Factor	**Level**	**Score**
A	According to technical characteristics	1,18
B	According to best practice indications	1,00
C	Construction in according to best practice indications and by specialized laying team	1,00
D	Not aggressive indoor environment	1,10
E	Urban environment	1,00
F	Environment with rare bumps	1,10
G	High level of maintenance	0,90
ESL	**RSL x A x B x C x D x E x F x G**	**12,83 years**

As can be observed, under the project conditions established, the useful life went from 10 to 12.83 years. With the help of grids similar to the ones presented here, in our opinion, the subjectivity of the method is further reduced.

2.9.3 Conclusion

The results, even partial, allow to express some considerations on the behaviour over time of the samples of sandwich panel investigated. After two years of outside exposure characteristics of the external covering (pre-painted metal skin) and the insulating polyurethane core are not so different from those that the component had in origin.

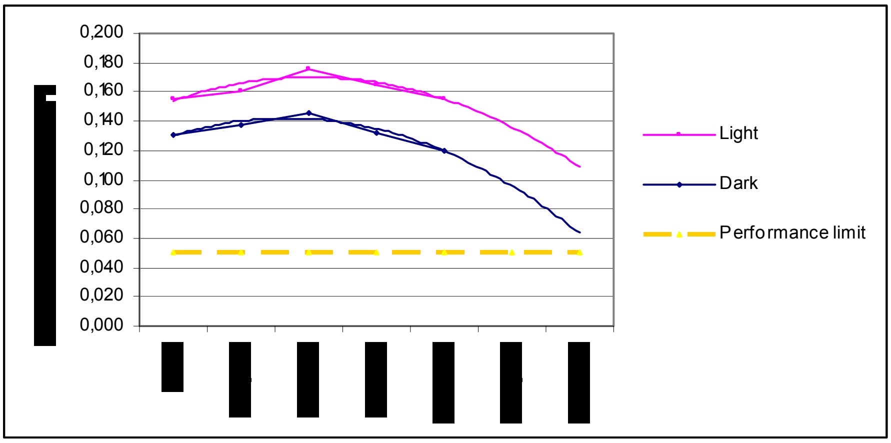
An analogous behaviour is observed, from the qualitative point of view, among tensile strength and thermal conductivity, the decrement of the characteristic up to 60 cycles and a following inversion of tendency with cycles.

Such behaviour somehow could be connected to the variations of weight and to the dimensional gymnastics of the elements of the panel (skin and core) favoured by phenomenon of diffusion and absorption of the vapour in the cellular structure of the polyurethane.

The colour, that deserves more attention from the normative point of view, is the characteristic that has suffered the greatest variations among the observed ones.
The two types of finishing paint from the point of view of colour variation behave in a different way.
Maintenance the project colour during time, cause the frequently use of panel for external roofs or walls, is an aspect that define the quality of the entire construction and deserve an adequate weight between the parameters to put under control.
A more clearly norm could give an important contribution to the final product quality.

As it regards the end of service life of the component, according to the EN 14509 it's achieved when the value of tensile strength is less than 0,050 N/mm^2, as shown from the extrapolation of the diagram of fig. 2.9.13.

Fig. 2.9.13 - Specimen's mechanical strength



It will be useful continue to check the course of the thermal conductivity of the samples exposed in external to assume new elements on the role of the skin-core interface and on the variability of the insulating property. The study could evidence properties of the aged polymer and the gas contained inside the cells to furnish an explanation to the improvement of the characteristics (tensile strength, thermal conductivity) measured in the initial phase of the panel's aging.

2.9.4 References

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2.9.5 Standard test methods

EN 14509 Self supporting double skin metal faced insulated panels

This European Standard specifies requirements and tests for double skin metal faced insulating sandwich panels, which are intended for discontinuous laying in roofs, internal or external walls and partitions within the building envelope.

The durability tests are defined in the Annex B by the change in the tensile strength of a test specimen that is subjected to climatic test for one or more weeks under constant conditions of temperature and humidity.

This standard has been used to choose test specimen (type and dimension), the maximum temperature for accelerated aging tests and mechanical testing procedures (tensile and bending tests).

ETAG 016 Self supporting composite lightweight panels

This guideline covers self-supporting composite lightweight panels with one or both skins made of various materials assembled, with a core which is bonded to at least one of the skins.

The ETAG is divided into four parts, the first part deals with general aspects, the other parts deal with specific aspects relating to a different field of application (Part 2 is specific for use in roofs).

The durability of the panel shall be assessed as decay of performance characteristics after ageing tests, with reference to ISO 15686. The influence of ageing on panels is tested by measuring changes in the tensile strength on different specimen set subjected to climatic test cycles.

The assessment of the performance of panels under the effect of thermal shock, is carried out with an array of infra-red lamps for artificially irradiating the external skin of the test panel, at temperature according to the surface colour. The same procedure has been considered for the accelerated aging test in the climatic chamber but on little specimen cut from the whole panel.