The Assessment of Durability of Discontinuous Roofing: An Experiment on Sandwich Panels

Giuseppe Alaimo [1]
Francesco Accurso [2]

T 22

ABSTRACT

The sustainable development of the construction trade requires a more rational use of the resources used. In light of this, the knowledge of building components and systems durability becomes fundamental in planning the service life of those components and to forestall unexpected deterioration and pathologies. Within the framework of more general research on the durability of building components, which involves various Italian universities, Palermo university has been concerned with discontinuous roofing. After the theoretical study on the reliability of a range of twenty-four technical solutions within the discontinuous roofing class, the sandwich panel, made up of two sides of metallic sheet with expanded polyurethane, was investigated. The research, carried out, in accordance with ISO 15686, concerns the behaviour in time of the sandwich panel, established through the monitoring of its performance characteristics (aspect, weight, colour, thermophysical and mechanical characteristics) when it is subjected to natural and artificial aging using an accelerated aging cycle in a climatic chamber. This was done for typical conditions of the Mediterranean climate. The tests on samples of different sizes, concerned the analysis of colour (light and dark), the measurement of conductivity, thermal resistance and resistance to tensile stress and bending moments. These were carried out on new samples, samples exposed externally and samples subjected to accelerated aging. The results allow the development of correlations between the variations of thermophysical and mechanical parameters and the deteriorations after the first two years of outdoor aging and the first sixty cycles of accelerated aging (rescaling). In such a study, particular attention should be given to the polyurethane interface sheet, in terms of criticality of thermophysical behaviour of the panel and the colour, appearance which compete to imply the quality of the whole building envelope.

KEYWORDS

Sustainability, Maintenance, Durability, Reliability, Sandwich panels.

[1] Università degli Studi di Palermo, Dipartimento di Progetto e Costruzione Edilizia, Palermo, Italy 90128, Phone +39 091 234151, Fax 091 488562, alaimo@unipa.it

[2] Università degli Studi di Palermo, Dipartimento di Progetto e Costruzione Edilizia, Palermo, Italy 90128, Phone +39 091 234151, Fax 091 488562, ing.accurso@alice.it

1 INTRODUCTION

Durability deals with the maintenance of performances associated with a component at the beginning of its working life and the ways in which performance decays in time. Important aspects required to achieve building quality are maintenance planning and control of resources which will be used in all phases of the building process.

This paper presents the results of a research study on "Methodologies of planning and experimental evaluation of the durability of discontinuous roofing", within a national research program (P.R.I.N.) which involves the University of Palermo, the Polytechnics of Milano and Torino, the Universities of Brescia, Napoli and Catania. They constitute a network of research centres, where, in the last years they have developed experimental methodologies to evaluate the durability on different building components, for a range of environments. The results reached, until now, have been presented at Palermo's Conference on 15 September 2006, they furnish contribution to the international research of the CIB W80 RILEM 175 "Service Life Prediction Methodologies", e ISO TC 59/SC14 "Building Construction".

The roof has always been a fundamental component of the building envelope, and a determinant of the environmental quality of the indoors, because it contributes to controlling energy flows between the interior and exterior of the building. The roofs contribute to maintain the planned environmental conditions, with the control of technological functions of the technical elements of the class. That's why there's a need to make reference to the class of technical elements (classification UNI 8290) and to each technological performance level. Within the National Program, the Research Unit of Palermo is carrying out a study on pitched roofs, through a first phase of functional and technical analysis of a catalogue of technical solutions of the class by performing an assessment of natural reliability. We have chosen sandwich panels, used either as roof or wall elements, as the building components for our research, and of which Italy is a leading manufacturer in the world.

2 THE METHODOLOGY

Based on the latest national and international standards (UNI 11156-2006; ISO 15686), the methodology we have followed consists of evaluation using two distinct and complementary procedures for the two parameters of durability: reliability and service life [Maggi et al. 2000, 2001]. Reliability is estimated through a method that permits a qualitative evaluation following a comparative procedure involving the elements of a catalogue of technical solutions of the class, which is considered out of system and with no intended use [Rejna 1995]. Service life is estimated through experimental tests on samples of technical elements exposed to natural agents and accelerated aging test in the laboratory. The results must be compared to determine the time re-scaling of the performance decay of the component.

This methodology for the evaluation of service life results is in accordance with the approach designed by ISO 15686 "Building service life planning". The assessment of reliability proceeds through the evaluation of the four components of reliability:

Functional reliability which, through the functional analysis, individualizes the distribution of the functions inside the solution, on which the degree of fatigue of the element depends on its operation;

Executive reliability which, through the technical analysis, verifies the degree of executive correspondence in comparison to the design;

Inherent reliability which concerns possible dimensional changes of the component during the phases of the exercise due to the different thermal and humidity stress of the functional elements;

Critical reliability which considers physical-chemical compatibility between adjacent materials of a different nature, and which constitute the technical solution.

The global reliability expresses in qualitative and comparative terms the degree of probability that the technical solutions have to last in time, whereas its complementary to 1 expresses the risk of failure during the service life. The estimate qualitative of reliability, both in global terms and of its components, offers useful information on the choice of maintenance procedure. Allowing by means of comparison, assessment of technical solutions other than those studied, both to estimate the reliability of a solution data and to plan new solutions of data reliability. The method permit to express reliability on the basis of its components: functional, inherent and critical reliability refer to planning choices and their complement of 1 expresses the risk failure for errors in the planning phase; executive reliability concerning activity in the construction phase and its complement of one expresses the risk failure for errors committed in that phase.

3 THE RANGE OF TECHNICAL SOLUTIONS

A range of 24 technical solutions were evaluated, which also included representative solutions by local builders. As well, “innovative” solutions were studied and compared to "traditional" constructions. The technical solutions of the repertoire (some are illustrated in Figure 1), have been characterized by: type of seal element; nature of load bearing structure; presence of insulation and ventilation layers.

The type of seal element (in small or large elements) can be made of brick (plain roofing or channel tiles), cement, fibrous concrete, metal or sandwich panel. The load bearing seals can be mixed with brick and reinforced concrete, of prestressed concrete or with timber and metal. The innovative solutions are those which use sandwich or composite panels, insulated and ventilated. These are also used in residential building.

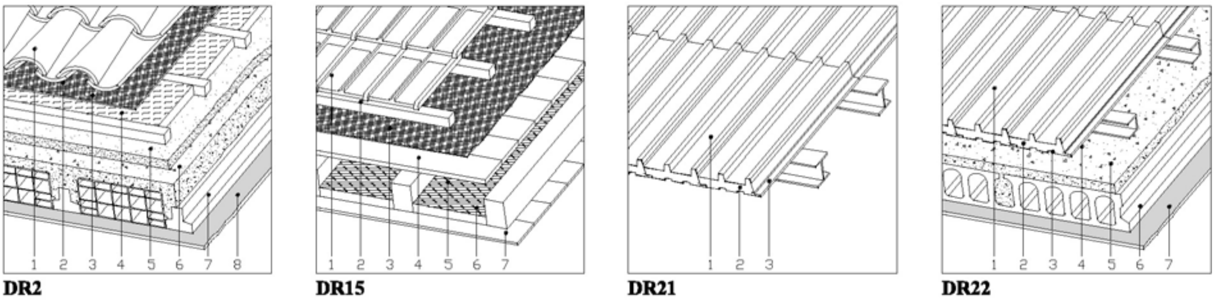


Figure 1. Some technical solutions of the repertoire.

4 THE EXPERIMENTS, SAMPLES AND PARAMETERS

The following parameters and properties were recorded for each sample: aspect; weight; colour; thermo-physical properties; mechanical properties. Such characteristics were determined for samples aged outdoors and in the laboratory using destructive and not-destructive tests, in the following manner:

1) not-destructive tests: aspect (using visual and measurement methods); weight; difference of colour; measurement of thermal conductivity and thermal resistance on the whole sample.
2) destructive tests: mechanical characteristics (traction, shearing and bending); thermo-physical properties (thermal conductivity and thermal resistance on PUR sections).

The original panel was made of two pre-painted galvanized steel skin, with a thickness of 0.45 mm, and an insulated core of expanded polyurethane, with a thickness of 40 mm. The specimens cut from the panel were of sizes 100 x 100 mm, 100 x 250 mm and 100 x 1000 mm are differentiated by colour in bright (White-grey) and dark (Siena red).

5 NATURAL AGING

The samples were exposed outdoors, directed toward South and with slope of 30° (Figure 2a). Before the exposure, the edges of the specimens were protected with a special polyurethane paint. On some samples, we applied some programmable data-loggers (Figure 2b), in order to record the surface temperatures reached (exposed and shade side) during the exposure. The collected data, between March 2004 and March 2006, have been used to determine trends of the maximum, minimum and averages temperatures reached on the surface of the samples in Palermo with the different seasons of the year.

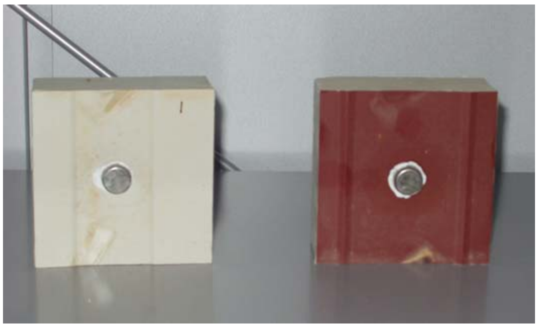

a

b

Figure 2. a: The samples exposed in outdoor; **b**: Temperature data-logger.

6 ACCELERATED AGING

The aging of samples was done inside a climatic chamber (Figure 3) that reproduces the principal climatic agents: rain, sunlight, high and low temperatures, variations of relative humidity. A necessary methodological preamble to the experimental phase included the definition of the range of weathering agents - actions - effects [Daniotti 2000] and corresponding deteriorations that can arise in the specimens. The artificial cycle (Figure 4a) has been developed on the basis of the specific climatic context of Palermo, and with the results of values measured outdoors, after initial calibration (Figure 4b).

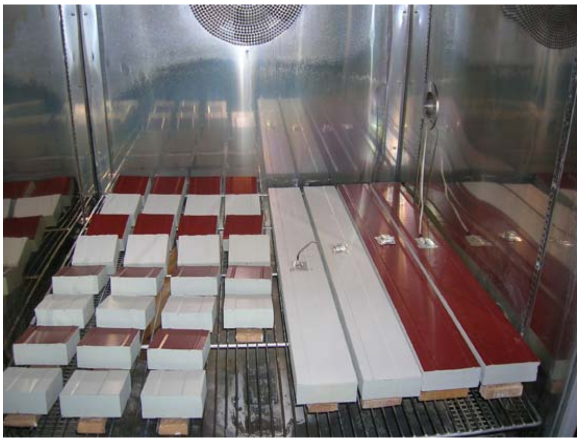


Figure 3. Samples inside of the Climatic chamber with temperature data-loggers.

The weathering accelerated cycle had a duration of 12 hours and consisted of the following phases:

Phase 1 - The samples were sprinkled with water at a temperature of about 20°C for 3 hours. In this phase the relative humidity inside the chamber was 95%;
Phase 2 - Temperature of the chamber was brought to 2°C for 1.5 hours;
Phase 3 - The samples were submitted to the action of warm dampness (T = 35°C, RH = 87%) for around 3.5 hours. This phase was preceded by a transition sub-phase of about 1.5 hours;
Phase 4 - In this phase the samples were exposed to the light produced by the UV lamp that together with the elevated temperature served to simulate the action of dry heat. The temperature was brought to around 80°C and the RH to 56% and maintained for about 2.5 hours.

The artificial aging has been conducted over 120 cycles corresponding to about 1500 hours of accelerated aging.

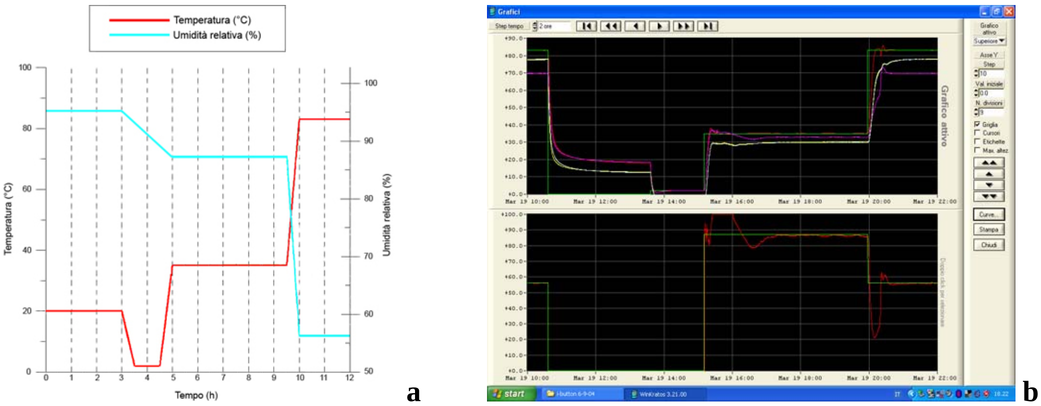


Figure 4. a: Theoretical accelerated aging cycle;
b: Experimental accelerated aging cycle (by Winkratos software).

The tests, destructive (thermal and mechanical properties) and non-destructive (aspect, colour, weight), were performed on the initial samples at time zero; the external aged samples after each year and after every 30 cycles for samples aged in laboratory.

7 RESULTS AND CONCLUSIONS

Surface Effects
Both with natural aging and accelerated aging, a slow evolution of degradation was observed. Initially, the phenomena of chromatic and yellowing alterations of the metallic surface were observed. Then the appearance of local oxidation marks, and with the increase of cycles, the formation of blisters and cavities in the foam, thus variations of shape at the interface foam-metal skin. After 120 cycles cracks on the interface appeared, which is certainly a critical point, both for thermo-physical and mechanical behaviour.

Tensile tests
The test has the purpose of evaluating the tensile strength of the polyurethane foam (Figure 5a,b) and its adhesion to the metallic support (ETAG 016-1, UNI EN 1607, EN 14509).

The specimen showed an improvement of the traction resistance up to 60 cycles, subsequently such tendency is reversed with the increase of cycles (Figure 6a).

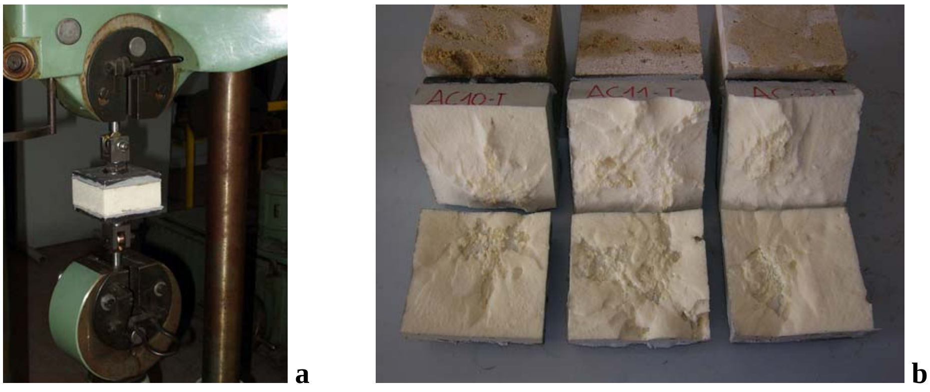


Figure 5. a: Tensile test; **b**: Type of failure (PUR).

It is important to underline the relationship found between the tensile strength, the percentage of uncovered metal skin (Figure 6b) and the length of the aging. The aging causes in fact an increase of the percentage uncovered after the failure. This effect was more accented in the dark samples. From comparison of the effects of the two types of aging in this type of tests, a correspondence can be noticed between the effects of 60 cycles and those of 2 years of natural exposure.

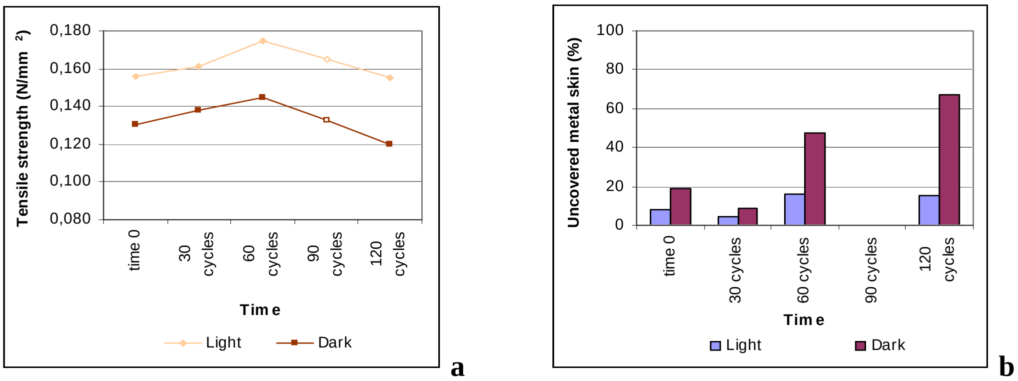


Figure 6. **a**: Tensile test; **b**: Metal skin after the failure (accelerated aging).

An analogue behaviour was observed, from a qualitative point of view, between the resistance to traction and thermal conductivity and thus a decrement of the characteristic up to 60 cycles and a successive reversal of the trend with an increasing number of cycles.

Thermal conductivity

Measurements have been conducted both on whole samples and on the polyurethane sections (extracted from the core of every samples two sections with a thickness of 10 mm) (Figure 7a), with the purpose to evaluate the influences of the external metallic elements and the interfaces with polyurethane.

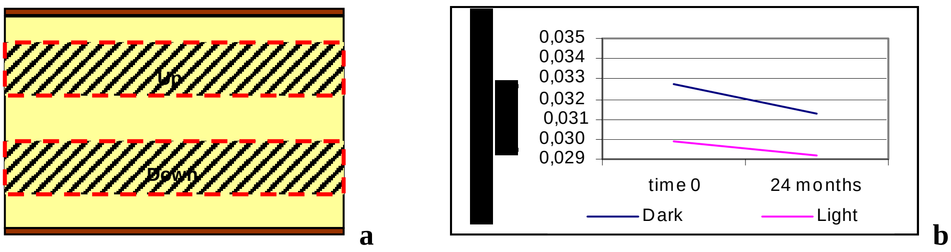


Figure 7. a: Sections of PUR; **b**: Change of conductivity (natural aging).

For up to 24 months of external exposure the conductivity of the samples remains substantially constant, both in the whole samples and in the sections of PUR (Figure 7b). In general the changes in thermal conductivity of the whole samples are greater than the changes in the PUR sections, because of the lower contact resistance due to the cover sheets glued to the PUR.

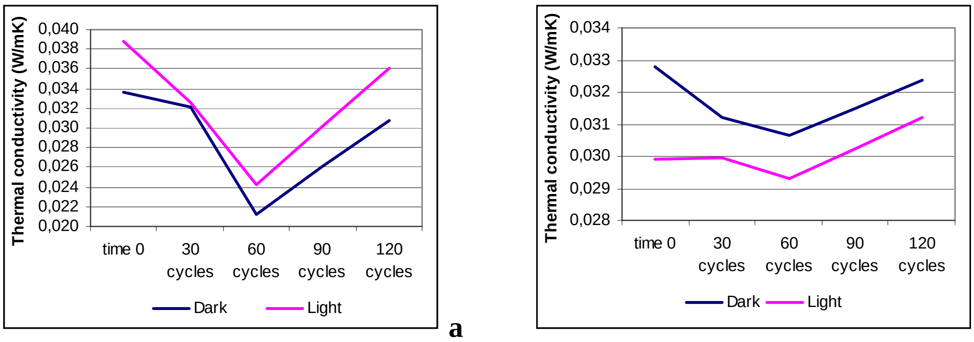


Figure 8. Change of conductivity – **a**: whole samples;
b: sections of PUR (light and dark samples -accelerated aging).

There is a substantial consistency among the measurements on the samples marked "Up" with those of the samples marked "Down". The results of the tests in the climatic chamber show an analogous behaviour from the qualitative point of view among the whole samples (Figure 8a) and the sections of PUR (Figure 8b) both for the samples White Grey and for those Siena Red.

Also in this type of tests after 60 cycles, an inverse relationship is observed with substantial consistency, involving the thermal conductivity both in the first year of natural aging, and in the first 30 cycles of accelerated aging. Definitively, the results show a significant qualitative relationship between variations of thermo-physical and mechanical parameters and a corresponding trend between the observed degradations after the first two years of external aging and the first 60 cycles of accelerated aging (re-scaling).

Colour
The results of the measurement of colour, in the CIEL*, a*, b* space, show:
• after about two years of natural aging, the light samples have been shown a significant variation of colour (ΔE) and a tendency to yellowing;
• in the samples that were artificially aged, we can see a difference of colour in two ways.

The light samples show a tendency to yellowing and a progressive variation of colour, the dark ones have a more significant variation after 30 cycles and a decrease in this difference with the increase of cycles. Results, for the light samples, are shown in Figure 9.

Between the different aspects investigated, the study of colour assumes particular value, both from an aesthetic and architectonic point of view, on the visible impression, on the individual psychological effects as the "Sick Building Syndrome". Thus, the colour is able to reflect not only the quality of the building product, but also that of the existing environment.

Another important social aspect is the maintenance, in particular that carried out on the aesthetic appearance of buildings in the outskirts of the city, where social decadence is almost always accompanied by the lack of urban and building quality. Therefore, this is an aspect which requires adequate attention also from a normative point of view.

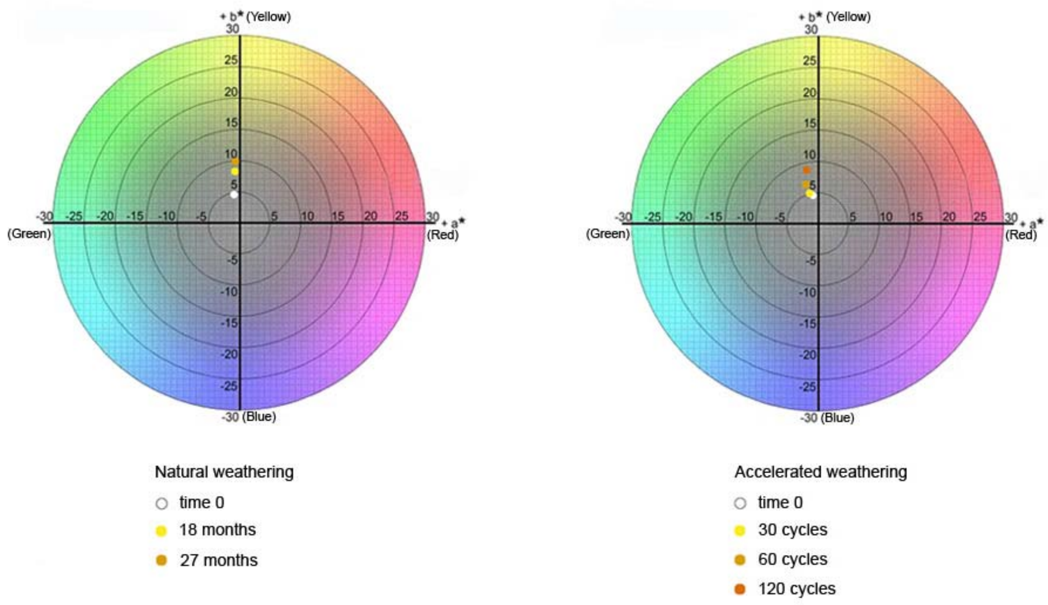


Figure 9. Chromatics diagrams a*, b* for the light samples.

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

REFERENCES

Alaimo G. et al., 2006, Valutazione sperimentale della durabilità di coperture discontinue. Un'applicazione al pannello sandwich, EdiTecnica, Palermo.

Alaimo G., 2004, L'affidabilità funzionale delle coperture discontinue, EdiTecnica, Palermo.

Alaimo G., Accurso F., 2006, La stima dell'affidabilità delle coperture discontinue, EdiTecnica, Palermo.

Maggi P.N. et al., 2000, La qualità tecnologica dei componenti edilizi - La durabilità, Epitesto, Bologna.

Maggi P.N. et al., 2001, La qualità tecnologica dei componenti edilizi - La valutazione della durabilità, Epitesto, Bologna.

Rejna M., 1995, Valutazione della qualità tecnologica utile dei prodotti complessi per l'edilizia, Quaderno DISET vol. 4, Esculapio, Bologna.

ISO 15686-1 (2000) Buildings and constructed assets - Service life planning - General principles.

ISO 15686-2 (2001) Buildings and constructed assets - Service life planning - Service life prediction procedures.

UNI 11156-1-2-3 (2006) La valutazione della durabilità dei componenti edilizi.