DURABILITY ASSESSMENT OF BUILDING MATERIALS EXPOSED TO ATMOSPHERE AGENTS BY TESTING IN SIMULATED ENVIRONMENT

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A b s t r a c t
The paper presents the idea of durability valuation of building materials and elements subjected to the influence of atmospheric environment during their exploitation based on the laboratory tests carried out with the use of climatic chambers and ageing chambers. The special ageing stand for simulating climate influences and testing of building materials is presented. The apparatus works as a rotational chamber for accelerated ageing. Samples are installed inside and are subjected to artificial climatic factors, such as: sun radiation, rain and low temperature. Moreover, the results of study on method for definition of simulated climate program in the aging chamber for an examplary are natural climate of Upper Region are commented. Additionally, the results of examplary aging and durability tests for noise barriers are presented.

S t r e s z c z e n i e
Artykuł prezentuje problematykę oceny trwałości materiałów i elementów budowlanych poddanych w czasie eksploatacji oddziaływaniom środowiska atmosferycznego, na podstawie testów laboratoryjnych wykorzystujących komory klimatyczne oraz komory starzeniowe. Przedstawiono klimatyczną komorę starzeniową do symulacji oddziaływań klimatycznych i testowania trwałości materiałów budowlanych. Skomentowano wyniki prac nad metodyką ustalania programu klimatu symulowanego w komorze starzeniowej dla przykładowego klimatu naturalnego Górnego Śląska. Ponadto przedstawiono wyniki przykładowych testów starzeniowych akustycznych ekranów drogowych wraz prognozą ich trwałości.

K e y w o r d s: **Weathering; Simulated environment; Accelerated ageing tests; Durability assessment.**

1. INTRODUCTION

The durability of buildings elements and materials exposed to weather conditions is essential to their functioning in their usage period. This problem relates to, e.g. such elements in buildings like: renderings and plaster claddings, roofing, windows, etc. Due to different properties and behavior of the individual components of the building on climate impacts, the issue of durability is difficult to clearly define. However, there are various approaches to assess the resistance and durability of building elements according to their structure. For traditional facade materials, such as ceramic brick or plaster claddings, the effects of moisture and temperature variations are essential, especially the passes through temperature of 0°C and the cyclicity and volatility of these effects contributing in consequence to defects. Whereas in concrete and reinforced elements, the effect of gas atmosphere is important, such as: carbon dioxide and chlorides, in corrosion and carbonation processes. Due to the complexity of the durability issue, there are no clear methods for its determination in relation to various materials. In case of resistance it is easier because it means the direct resistance of material structure, that is a casual resistance to certain degradation effect, i.e. resistance to low or high temperature and its changes, moisture resistance, UV resistance, abrasion resistance, etc. In case of durability, the additional important factor is lime. In other words, durability is the resistance to the impact repeated many times over the usage of building material. This feature depends not only on the material and its properties, but also on the environment aggressiveness. Materials resistant in an ordinary environment may not have this feature in aggressive environment. Usually, the durability is understood as time, in which user's requirements are met. Given the complexity of factors determining the resistance, its determination becomes not an easy problem to solve [1,2]. It is proved by numerous evaluations and prediction methods, in many cases capturing the problem in an approximate manner and using simplified models [3,4]. Helpful in this regard are comparative studies of aging processes, long-term in real conditions and short-term, shortened or accelerated, in simulated conditions [5-9]. Such tests are conducted based on the appropriate procedures [1,10-12] in specially prepared positions [13,14].

2. LONG-TERM AND ACCELERATED AGING TESTS

Most reliable tests results for determining the behavior of materials subjected to degradation processes induced by atmosphere factors, give long-term aging tests carried out in natural conditions for a period of several years. Such tests have been conducted for many years. For example, in the 50's in Fraunhofer's laboratory in Holzkirchen, tests on resistance to aging of outside barriers of buildings, were conducted. In UK in the 60's, Butterworth was studing the behavior of ceramic materials for 9 years [15]. In the early 80's, Motohashi and Nireki studied the durability of outside layers of walls [16]. At the same time in Sweden, H.Brolin performed durability tests of doors and windows in natural climate [17], whereas in Brazil, the PVC and polyrethane reinforced with glass fibers boards [9] were tested for 48 months. Whereas, in the early 2000's in Hong Kong, the adhesion of façade files were tested [18]. In Poland, the example of aging tests in natural environment are tests of facing and roofing at the Building Research Institute in Warsaw [19] or enamel-coating research at the Institute of Paints and Varnishes in Gliwice. These are just a few examples of long-term studies. The disadvantage of such studies is their long duration. Therefore, now scientists endeavour to apply for durability on the basis of short-term tests, so called accelerated aging tests [7-9] replacing long-term degradation processes in natural conditions. One of test types is the simulation of climate factors in climate chambers. The most commonly used factors are: moisturizing and drying, heating and freezing, UV and infrared radiation, and also chemical solution of i.e. acids. Currently on the market there are available numerous ready prepared positions for testing durability of different products on specific effects, particularly on the effect of solar radiation, moisture and low temperature. Such devices are used in various industries, including testing construction products. Commonly known are climate chambers for testing frost resistance, but also climate chambers are used for testing resistance to moisture and temperature and aging chambers (Xenotests) for testing resis-

Figure 1.
Sample aging chambers [20], description in text

tance to light. The example of aging devices are such chambers as: Solar Climate Chamber by Atlas (Fig. 1a), UV Test aging chamber (Fig. 1b), Suntest XLS Camera (Fig. 1c) and XXL, Xenotest, SEPAP 12-24 chamber and others [20].

These devices are designed for accelerated aging tests with simulation of natural solar radiation. Light sources used in chambers as metal halide lamps give a spectrum very similar to natural sunlight in the entire spectral range (UV, visible light, infrared) or selective UV radiation spectrum. The range of application of these devices include primarily tests of paints and varnishes, plastics, construction materials, bituminous and plastic roofing materials, and technical textiles, i.e. geotextiles. These chambers are characterized by a selective action in relation to selected climate effects. Different position combining all major climate effects is a climate chamber for accelerated aging tests at the Civil Engineering, Silesian University of Technology in Gliwice, founded in 90's in collaboration with the Institute of Durability Research in Trondheim, Norway, and recently upgraded in the frameworks of the research project [21]. In country, the centers for this type of research is the Building Research Institute (ITB) in Warsaw and Technical University in Łódź. The ITB institute conducts resistance tests on variable thermal and moisture conditions, tests on color durability and test of façade coatings [19]. For testing façade coatings' resistance with dispersion paints on accelerated action of atmosphere factors, an UVCON device is used, designed to UV irradiation and condensation of water vapor. The samples are subjected to 50 cycles, each of which consists of radiation at a temperature of +60°C and condensation of water vapor of 4 hours each. Color durability is tested on XENOTEST devices [19]. In the climate VOTSCH chamber, coatings and plasters are tested on the action of 10 thermal and moisture cycles. A single test cycle consists of 10 hours at +30°C and 12 hours at -20°C. By the way of above mentioned methods, a large number of methods without climatic simulation, so called direct and indirect, based on the measurements of quantities related to durability, such as: porosity, adsorption, resistance and others, should be mentioned. The example of the most popular in this area are frost resistance studies.

3. SIMULATION POSITION OF AGING PROCESSES

The subjected climate chamber is a position to aging simulation in the atmospheric environment. On the position, materials such as: plasters and facade factures, windows and other building products exposed to atmospheric factors can be tested. In the chamber, materials are subjected to alternating, cyclical influence of simulated climatic factors, such as: low temperature, rain and solar radiation. The position consists of four chambers (Fig. 2), from which the essential one is central rotary chamber with four display walls with the size of 1.5×2.4 m for mounting test bodies. The other three chambers cooperate with the central chamber and simulate the dominant climatic factors.

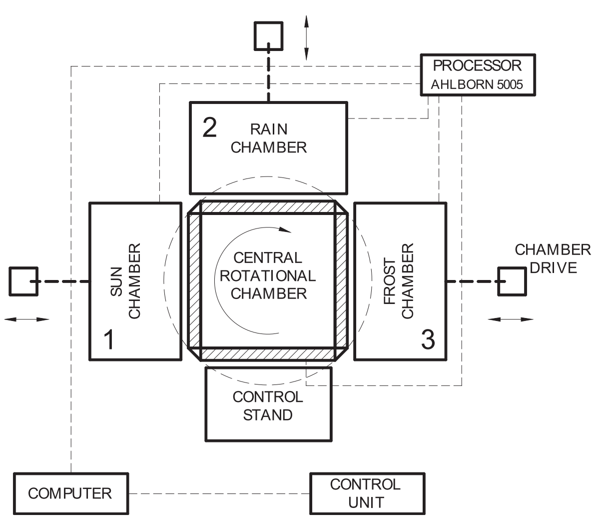

Figure 2.
Position to simulate aging processes, schedule and view from the side of "rain" and "frost" chamber [21]

The "sun" chamber gives radiation in the spectral range close to natural one. Visible radiation in the range of wavelength 400÷700nm allows the system of 20 metal halide lamps with power of 8kW generating temperature up to +75°C. An additional system of ultraviolet radiants with wavelength of 185 and 255 nm imitates UV radiation.

The "rain" chamber simulates rain and wind. Water spraying system enables multipoint sprinkling system connected to a horizontal noozle system giving air streams. The number of given water and air blowers are regulated by the amplitude, frequency and speed. The 'frost' chamber lowers the temperature of tested elements surfaces to -25°C.

The position's performing belongs to short-term aging test methods, accelerated with climate simulations. The basic test is 100 cycles which corresponds to the period of 2.5 years in natural climate conditions in upper Silesia. Test duration is 4-6 weeks. A full aging cycle is equivalent to single revolution of central chamber and takes 4×50-60 minutes. The position is automatically controlled and test parameters are given on a special programmer. During the operation of position, the aging tests were conducted for such components as: exterior traditional and thin-layered plasters, facade insulation systems, gypsum blocks, polymer concrete railway traction weights, lining made of sandstone, cellar concrete for footing sleepers and road noise barriers. Tests concerned mainly the resistance assessment of atmospheric factors, but also test methods of façade cleaning and study of impact of weather on acoustic properties, were performed. The longest performed test consisted of 5×100 cycles.

4. CLIMATIC SIMILARITY IN THE AGING CHAMBER

Climate, simulated in the chamber, interacts with a particular similarity with respect to natural climate. Knowledge of this similarity is the basis for prediction of materials properties. In order to determine simulated climate in the chamber, a characteristic of an averaged meteorological year was developed on the example of the climate of the Silesia region [21]. For this study, as well as observation and measurement data from the meteorological station (mimic) in Katowice-Muchowiec were used comprising 10-year period (2000-2009). Data was prepared as monthly averages which are general characteristic of the Averaged Meteorological Year (AMY). On this basis, individual characteristics of: temperature, sunlight, rain and wind with average and extreme values for each position of the aging position of climate chamber, were determined. Based on the IMGW data analysis, characteristics of simulated climate (CSC) were determined, such as: temperature, sunlight, rainfall and wind speed for different climate chambers. For each chamber, two parameters were determined: the intensity and duration of action while maintaining the similarity of characteristics by adopting relative values, so called reference values.

Creation of characteristics of CSC simulated climate started with climate characteristic in the 'frost' chamber. The action of this climate chamber was taken as the dominant due to the main degradation effect determining the resistance. To maintain the similarity of CSC extreme conditions in regard to averaged AMY, the transfer of such parameters was admitted as: the average minimum negative temperature (-19.9°C) and number of days with the phenomenon of freezing and thawing (41 days). Based on the research experience [22,23], it shows that, among the atmosphere factors effecting building materials, the most essential is the effect of temperature and number of passes through the temperature of 0°C [24] determines the resistance to atmosphere factors. Based on the work of Pihlajavaar on prediction of time of use of materials subjected to outside exposure [24], stability can be estimated on the basis of annual number of days in which there was a pass through the temperature of 0°C with the full cycle of freezing-thawing. For example, in 2000 year for Katowice region, in the temperature characteristic of outside climate, N_{TR} = 62 passes through 0°C occured (Fig. 3).

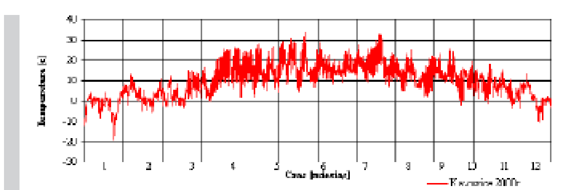

Figure 3.
Examplary annual temperature changes in natural climate for the region of Upper Silesia in 2000 year [21]

For example, in simulated environment of the chamber operating at a frequency of 5 cycles per day, the number of passes through 0°C is 5. In terms of the work of the position it corresponds to N_{TS}=1800 passes. Relating these values to number of passes through 0°C in the meteorological year, the coefficient of acceleration in relation to natural environment can be assessed :

$K_A = N_{TR}$ (real) / N_{TS} (simul) = 1800 / 62 = 29.0 times

The above result depends on the number of cycles and therefore the number of passes through 0°C of chamber's operation during one day. In continuous mode, the acceleration can reach values of 40 times. Usually, accelerations of 20-30 times are accepted. On this basis, it was accepted that simulated test with the same amount of freezing-thawing cycles as in AMY, corresponds to natural conditions during one year (1 natural year of AMY contains N cycles of freezing-thawing). Therefore, it was accepted that one meteorological year for Silesia corresponds to 41 cycles of aging test. The length of freezing, so the time of operation of "frost" chamber, was determined based on the condition of achieving the minimum reference temperature (-15.9°C for AMY) on the surface of tested materials. This time was determined empirically by measuring the kinetics of freezing (Fig. 5a). The minimum reference temperature was reached after about 30 minutes. A similar approach was adopted in determining climate characteristics in the "sun" chamber. For this effect, parameters were determined which were connected with heating during summer months, such as: the average maximum temperature during the day on cloudless days and solar radiation intensity on a vertical surface.

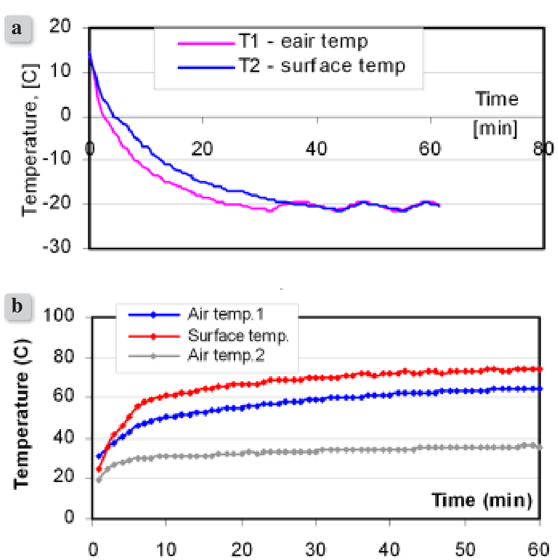

Figure 4.
a. Characteristics of the chilling kinetics in the "frost" chamber [21] b. Characteristics of heating kinetics in the "sun" chamber [21]

To maintain the similarity, the operation of chamber was accepted from the condition of maintaining extreme solar temperature of the outside air (1) on the vertical surface of the elevation.

$$t_s = t_z + \frac{A \cdot I_c}{\alpha_z} \qquad (1)$$

where: t_z – temperature of outside air, A – radiation absorption coefficient, I_c – total solar radiation intensity, α_z – heat transfer on the outside coefficient.

The values of solar radiation intensity on horizontal surface were converted to the component onto a vertical surface using individual components known in such transformations: direct, diffused and reflected radiation [25]. In this way, values of 744-909 W/m^2 were obtained (Fig. 5a). Combining these values in expression (1) with the outside air temperatures, solar temperatures were achieved ranging from +18°C in January to +42°C in July (Fig. 5b).

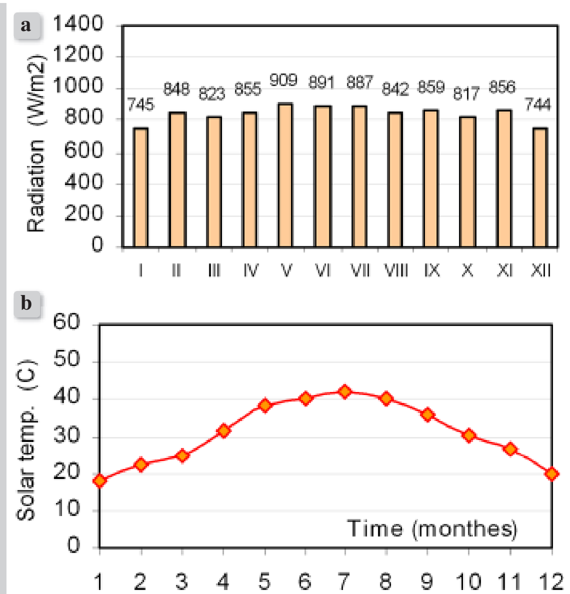

Figure 5.
Data on Silesian climate from 2000-2009: a) radiation intensity on vertical surface, b) solar temperatures [21]

A radiation absorption coefficient "A" was adopted for both plasters and concrete, i.e. with the value of A=0.65. Knowing that the outside air temperatures are average values, the solar temperature for the operation of the 'sun' chamber was adopted for the maximum temperature, i.e. +36.4°C, which gives, with the component of solar radiation, corresponding value of +59.5°C. The length of chamber's operation was determined empirically by measuring heating kinetics of exposed surface (Fig. 4b).

The reference maximum solar temperature was obtained after 35-45 minutes. To maintain the similarity of solar radiation in the chamber, metal halide lamps of 400 W were used, giving the radiation spectrum closest to the sunlight in the ultraviolet range of 200-380 nm, visible light of 380-780 nm and infrared light. The characteristics of rainfall were brought to the water quantity effecting vertical surface at AMY. For this effect, the amount of wind-driven rainfall was determined, corresponding to annual rainfall amounts on the horizontal surface in windy days [596.6 mm]. As it is known, the slanting rain depends on the wind speed. Such dependence is determined by various formulas. British standard BS 8104:1992 [26] defines the relationship:

$$r_v = \frac{2}{9} \cdot V \cdot r_h^{8/9} \qquad (2)$$

where: V – wind speed perpendicular to the wall in m/s, r_h – rainfall on the horizontal surface in mm/h,

Another way to determine wind-driven rain was proposed by Künzel [27]:

$$R_s = r_s \cdot v \cdot R_N \qquad (3)$$

where: R_s – slanting rainfall on the wall surface in mm/h, R_N – rainfall on the horizontal surface in mm/h, r_s – coefficient of barrier position on the height, usually r_s = 0.2 s/m, v – wind speed at 10 m above terrain in m/s.

The amount of wind-driven rain was assessed on the basis of relationship (3) giving greater values. It was accepted that during the test simulating 1 natural year (41 cycles in chamber), the amount of water flow corresponds to the average amount of rainfall on the building walls. Because it is difficult to define the unambiguous wind speed causing wind-driven rains, as it depends on the size of raindrops, the rainfall for the average wind speed of 2.8 m/s was accepted. Thus, the amount of water given in a single annual test on the wall surface is 335 mm, or 8.1 mm (dm^3/m^2) for 1 cycle. Wind is characterized by the largest random character. The evidence is that the daily distributions of the wind durations with various speeds and distributions of probability (Fig. 6) varies for each month. It shows that the fan blows characteristics should be multi-state or at least two-state due to the occurance of wind gusts (V_{av}=11.3 m/s). The lower speed of fan blows corresponds to average annual speed of wind (V_{1av}=2.8 m/s), whereas higher speed to average speed of wind gusts (V_{2av}=11.3 m/s).

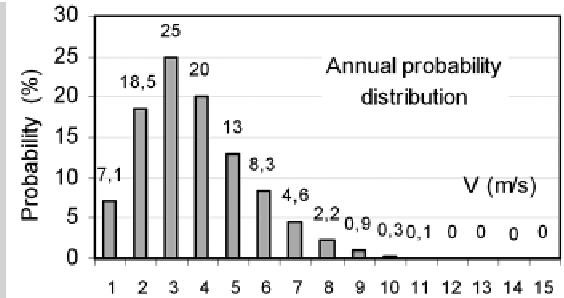

Figure 6.
Probability distribution of wind speed for average meteorological year [21]

As the number of passes to average speed V_{1av}=2.8 m/s to average speed of gusts is very small (below 20 over 10 years), therefore the more appropriate is two-state characteristics with values of V_1=0.0 m/s for no-wind and V_2=V_{av}=2.8 m/s. Due to the negligible share of no-wind per day (1.7 h), such characteristics could be adopted as single-stated. Determining climate characteristics for individual chamber, the climate program for the whole position was adopted. The carried out analysis of climate date of sample average meteorological year allowed to determine which climate parameters are essential for determining climate program for aging chamber. This way, a methodology was created allowing to define the parameters of simulated climate for any geographical area and thus to determine the climate program in aging chamber [20]. For the climate of Upper Silesia region, 100 cycles in the chamber correspond to the period of 2.5 years in natural conditions.

5. AGING TESTS

One of the recent and continuing aging studies are tests of noise barriers for the impact of weather on acoustic properties of sound absorption [28]. Panels used in road barriers must comply with standard requirements. They are usually tested in laboratory conditions excluding the impact of weather conditions. In order to recognize how such factors influence acoustic properties and durability of panels, the aging and acoustic tests were conducted. Based on measurements, characteristics of sound absorption (Fig. 8) were determined in frequency function and sound absorption rates.

5.1. Research methodology

Tests were performed for panels filled with mineral wool mats in wooden case (Fig. 7). Acoustic panels were subjected to aging test lasting 150 cycles (Fig. 8). After every 50 cycles, sound absorption by panels was measured in reverberation chamber, before aging test (state 0), after 50 cycles, after 100 cycles and after 150 cycles. Tests were carried out in reverberation chamber according to the Standard [29].

Figure 7.
The view of acoustic panel in aging chamber [28]

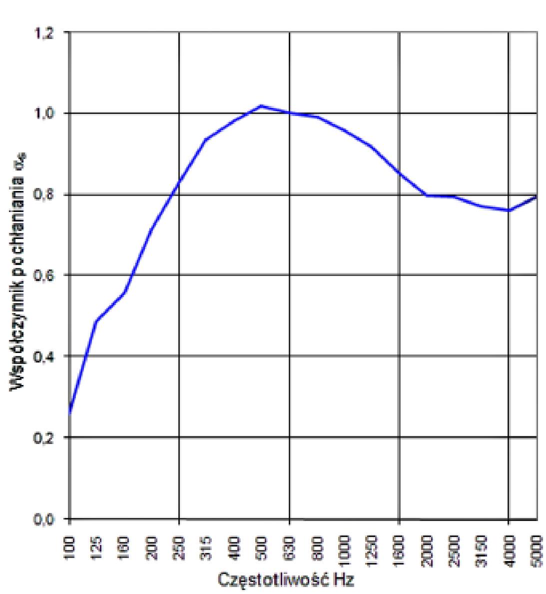

Figure 8.
Sound absorption after 150 cycles of aging [28]

Table 1.
Classes of absorption properties [28]

Acoustic class	DL_{α}, rate
A0	not defined
A1	< 4
A2	4 - 7
A3	8 - 11
A4	> 11

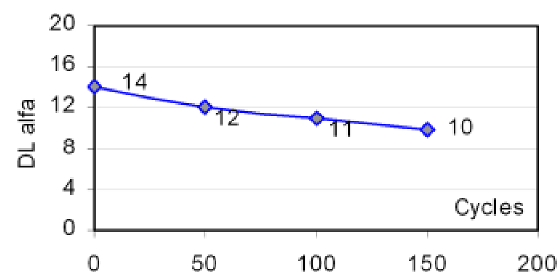

Figure 9.
Results: single rates of DLα sound absorption assessment [28]

On the basis of measurements of reverberation time, a weighted rate of sound absorption α_w (Fig. 8) was determined and also single rate of sound absorption assessment DLα (Fig. 9). On this basis and standard classification, tested screens were qualified into the appropriate class of absorption properties (Tab.1): before test and after 50 cycles to class A4 and after 100 cycles and 150 cycles to class A3.

5.2. Assessment of acoustic panels durability

Durability of noise barriers was based on standard and literature guidelines [1,29] concerning durability prediction. According to British Standard BS ISO 15686-2001 [30], durability is understood as a boundary condition of the use function (Fig. 10).

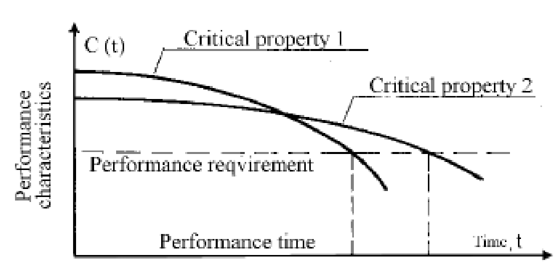

Figure 10.
The principle of determining the performance time acc. to BS ISO 15686-2

In order to estimate the durability time, a mode characteristic was determined on the basis of measured values of DLα rate. On this basis and taking into account the relationship of the aging cycles number with natural conditions, the acoustic panels durability was defined. To determine the use function, a measurable physical characteristic in time function C(t) is needed and also accepted boundary value C_{min} of used property. The property characteristic C(t) can be defined from the regression function from measurements made at intervals. The boundary values are specified by acceptable standard values (e.g. decrease of resistance, weight loss, etc) ore use ones. In case of tested acoustic panels there is difficulty in determining measurable physical characteristics for individual components because there were no macroscopic changes during the aging test. There was no damage, shape changes, losses or color changes. For this reason, the changes of surface morphology at the micro level were taken into account, such as the deposition of carbonate sediments. This effect may explain the measured changes (decrease) in sound absorption during the aging test. For this reason, as a meaningful feature for assessing acoustic durability, the rate of DLα sound absorption assessment rate was adopted. As accepted boundary values, the sectional values of absorption characteristic classes were accepted (Tab.1). This approach is indicative and only possible for obtained results. The exact determination of durability, according to methodology defined by acoustic Standards is difficult to define. Therefore, in order to estimate the durability time for expected classes of acoustic absorption, characteristics of Figure 9 was determined into a regression curve for measured values DLα, as:

$$y = 13.744 \cdot e^{-0.0914x} \tag{4}$$

So, knowing that 100 cycles in chamber correspond to the period of 2-2.5 years in natural conditions, the values for aging cycles are expressed in years. Then, based on Excel spreadsheet, a model curve of exponential type (4) with high determination coefficient $R^2=0.9812$ was adopted. On the basis of obtained curve and values corresponding to the boundaries of absorption, the absorption times of durability were defined:

$y_{0,1} = 0.5$ dB ; $y_{1,2} = 4.5$ dB ; $y_{2,3} = 7.5$ dB ; $y_{3,4} = 11.5$ dB, $t_{0,1} = 36.0$ years; $t_{1,2} = 12.0$ years; $t_{2,3} = 7.0$ years; $t_{3,4} = 2.0$ years.

It shows that acoustic classes may be subjected to decrease in subsequent years, e.g. A4 class lasts for 2 years, A3 and A2 classes for 5 consecutive years, and the lowest class A1 for more than 20 years. These results should be treated as estimates. It was found that exposure in weather conditions causes deterioration of acoustic properties of panels. Acoustic measurements during the aging test showed the decrease of DLα sound absorption assessment rate by 28%. Additional scanning tests showed the impact of aging in the form of calcium carbonate sediments. These sediments may have contributed to changes in acoustic properties of panels.

6. SUMMARY

Above presented position for the simulation of climatic agents is useful in accelerated durability tests of building materials on the effect of aging processes. The position allows to program the parameters of simulated climate as an equivalent of natural climate with an appropriate similarity. For Silesian climate, 100 cycles in chamber correspond to the period of 2.5 years. On this basis, it is possible to predict the performance time based on short-term tests. Positive results are obtained from the analysis of measurable changes of material properties, e.g. acoustic or other physical characteristics reflecting the effect of degradation factors.

REFERENCES

[1] *Ściślewski Z.*, Zasady projektowania budynków i budowli z uwzględnieniem trwałości (Principles to design of buildings with regard to durability), ITB Research Works, Warszawa, 1994 (in Polish)

[2] *Broniewski T., Fiertak M.*; Metodologiczne problemy oceny trwałości materiałów budowlanych (Metodological problems about durability assessment of building materials), II Konf. Nauk.-Tech. "MAT-BUD 98", Kraków-Mogilany, 1998; p.31-42 (in Polish)

[3] *Matsufuji Y., Koyama T., Harada S.*; Service life predictive method of building materials, Durability of Building Materials and Components, Vol.1, Published by E&FN Spon, London, 1996; p.45-53

[4] *Sarja A., Vesikari E.*; Durability design of Concrete Structures, RILEM Report 14, London, 1996

[5] ASTM E632-82. Standard practice for developing accelerated tests to aid prediction of the service life of building components and materials

[6] Dokumenty Unii Europejskiej dotyczące budownictwa – seria 11. Trwałość budynków i okres użytkowania wyrobów budowlanych w ustaleniach technicznych zharmonizowanych z dyrektywą 89/106/EWG (EU Documents about Civil Engineering – Part 11, Durability of buildings and service time of building articles in technical settlements harmonized with 89/106/EU instruction), ITB Research Institute, Warszawa, 2002 (in Polish)

[7] *Litherland K., Oakley D., Proctor B.*; The use of accelerated ageing procedures to predict the long term strength of GRC composites, Cement and concrete research, Vol.11, Pergamon Press Ltd. USA, 1981; p.455-466

[8] *Tokyay M.*; Strength prediction of fly ash concretes by accelerated testing, Cement and Concrete Research, Vol.29, 1999; p.1737-1741

[9] *Uemoto K.L., Flauzino W.D.*; Natural and accelerated ageing of GRP and PVC corrugated sheets, III Int.Conf. on the durability of building materials and components, VTT Symposium, Espoo, Vol.2, 1984; p.135-146

[10] PN-85/C-89037 Metody badań odporności na starzenie. Tworzywa sztuczne (Ageing durability tests. Plastic materials) (in Polish)

[11] PN-73/6701-03 Metoda przyśpieszonego badania odporności na działanie czynników atmosferycznych (Accelerated tests on weathering agents durability) (in Polish)

[12] BN-77/6701-04 Materiały wykończeniowe stosowane w budownictwie. Oznaczanie trwałości barwy metodą przyśpieszoną (Finishing materials in civil engineering. Accelerated tests on color durability) (in Polish)

[13] *Pavlik Z., Jirickova M., Cerny R.*; Semi-scale testing of multi-layered building envelope on the basis of HPC in different climate conditions, Rocznik Inżynierii Budowlanej, No.4, PAN department in Katowice, 2004; p.17-24

[14] *Chiavarini M., Gaggini F., Massa V.*; A new methodology for the accelerated simulation of environmental attacks, Durability of Building Materials and Components, Vol.2, London, 1996; p.1055-1060

[15] *Buttervorth B.*; The recording comparison and use of outdoor exposure tests, Trans. Brit. Ceram. Society, Vol.63, No.11, 1964

[16] *Motohoshi K., Nireki T.*; Investigation into degradation mechanisms for masonry coating systems by microscopic analysis methods, III Int. Conf. on the durability of building materials and components, VTT Symposium, Espoo, Vol.2, 1984; p.241-253

[17] *Brolin H.*; Dimensional stability of entrance doors exposed to natural climate, III Int. Conf. on the durability of building materials and components, VTT Symposium, Espoo, Vol.2, 1984; p.12-20

[18] *Yiu C.Y., Ho D.C., Lo S.M.*; Weathering effects on external wall tiling systems. Construction and Buildings Materials, Vol.21, 2007; p.594-600

[19] *Prokop M.*; Badania odporności materiałów elewacyjnych na przyśpieszone starzenie (Accelerated tests on durability ageing of elevation materials). Materiały Budowlane, No.10, 1999 (in Polish)

[20] www, Internet

[21] *Bochen J.*; Prognozowanie trwałości komponentów budowlanych eksponowanych na czynniki atmosferyczne na podstawie testów przyspieszonego starzenia (Durability prediction of building components exposed to weathering agents on the basis of accelerated ageing tests). PBU-33/RB9/2010 Research Project, Gliwice, 2010-2013 (in Polish)

[22] *Basińska M., Koczyk H.*; Klimat zewnętrzny w badaniach i modelach (External climate in research and models), III Konferencja Nauk-tech. "Fizyka budowli w teorii i praktyce", Łódź, 1995; p.14-21 (in Polish)

[23] *Lichołaj L.*; Wpływ parametrów klimatycznych na zapotrzebowanie ciepła do ogrzewania pomieszczeń (Influence of climatic parameters on heat application for building heating), VII Konferencja Naukowo-techniczna "Fizyka budowli w teorii i praktyce", Łódź, 1999; p.338-345 (in Polish)

[24] *Pihlajavaara S.E.*; The prediction of service life with the aid of multiple testing, reference materials, experience data and value analysis, III Int. Conf. on the durability, VTT Espoo, Vol.2, 1984; p.37-64

[25] *Smolec W.*; Fototermiczna konwersja energii słonecznej (Photothermical conversion of solar energy). Edited in PWN, Warszawa, 2000 (in Polish)

[26] BS 8104 : 1992 British Standard Code of practice for assessing the exposure of walls to wind-driven rain. British Standard Institution, 1992

[27] *Kűnzel H.M.*; Simultaneous Heat and Moisture Transport in Building Components, Fraunhofer Institute of Building Physics, Stuggart, 1995

[28] *Żuchowski R., Dulak L., Bochen J.*; Badania właściwości akustycznych i trwałości paneli akustycznych poddanych starzeniu w warunkach symulowanych (Acoustic properties and durability tests of noise barriers subjected to ageing in simulated environment). NB-4/RB-4/09/RB-9 Research Project, Gliwice, 2009 (in Polish)

[29] PN-EN ISO 354:2005 Akustyka. Pomiar pochłaniania dźwięku w komorze pogłosowej (Acoustics. Sound absorption measurements in reverberation chamber) (in Polish)

[30] BS ISO 15686-2001 Buildings and constructed assets – Service life planning. Part 2: Service life prediction procedures