Testing of biocidal properties of thermal insulation system during material life cycle

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Abstract. With the growing number of realized thermal insulation systems, fast growing number of buildings with facades attacked by microorganisms occurs. Such surface attack can occur even in the first years after thermal insulation completion, and it can be a serious problem in a very short time. Problem is both in realization and maintaining of thermal insulation, and directly in the used material. The paper presents results of laboratory experiments on resistance to biological attack, carried out for five commercial materials available on the Czech market. Before the experiments, materials were subjected to accelerated ageing for 4 and 10 years. Resistance testing comprises regulated application of algae and mould strains on samples and incubation in a defined environment. Materials resistant after ageing simulation of the longer time period were found as well as materials susceptible to attack already after completion of a facade set.

1. Introduction

Currently there is a growing number of buildings, where the facade surface is attacked by microorganism biofilm growth. This phenomenon directly connects to the trend of thermal insulation of buildings. Biofilms on facades are taken mainly as an aesthetic problem, however, it is primarily a technological and healthy risk [1, 2, 3].

Microorganisms get on the facade surface from the air. Under suitable conditions, the microorganisms reproduce creating visible coloured films (biofilms). Biofilm composition depends on climatic conditions and a lot of other factors, among them humidity is the most important. As nutrients serve microparticles of organic matter brought with dust or contained in plaster [1]. Possibilities and degree of building deterioration by microorganisms depend mainly on the chosen material, performance of problematic details, building location, insolation, type of surrounding vegetation, pH of adjacent soil and, last but not least, on operation and way of using the building [2].

The principal condition for the growth and reproduction of microorganisms on building facades is humidity. Mainly at thermally insulated buildings, there is moisture occurrence in upper layers of thermal insulation. The reason is water condensation on the building surface, which is not heated up by the heat escaping from the building. On the north- and north-west building sides also water from rainfalls contributed to the moisture content in the given material. The sun in these places does not dry the surfaces, as well as no biocidal effects of UV radiation can have an impact [2, 4].

There are many facade materials on the market, however, not all of them are resistant to biological components. Methods for testing of facade system resistance to biological components are not embodied in the Czech standards. Based on current regulations and experiments from other countries, screening methods were developed to evaluate the material resistance to algae and moulds. These methods were
verified on real samples. Methods include mainly macroscopic observation of algae and mould growth on building materials in defined conditions.

In practice, it is found out that facade materials lose their properties with time, mainly by weather conditions. The retaining time of biocidal properties differs according to the composition and producer of the given material. Therefore, as a suitable tool, a simulation of accelerated ageing precedes complex testing of resistance to biological components. Simulation of accelerated ageing was developed in the Research Institute for Building Materials as a part of a complex method for durability evaluation of fibre-cement composite elements. It includes cyclic changing of dominant factors of the summer and winter seasons in the Czech Republic. Weather mode is patterned on long-term average annual data from 1961 to 2010. A correlation of results from accelerated ageing and long-term storage of samples in real conditions was achieved on a long-term basis.

For the study, five commercial materials available on the market in the Czech Republic were selected, the materials were tested nameless, and exposed to accelerated ageing for 4 and 10 years.

2. Methodology
For sample preparation there were purchased five different sets (kits) of ETICS, from which samples of facade systems were prepared in this composition: plaster, undercoat, glass fabric, reinforcing layer and insulation material – polystyrene. For testing purposes, the samples were cut to dimensions $5 \times 5 \times 2.3$ cm. The samples were tested after 14 days of curing and after accelerated ageing for 4 and 10 years.

Method of accelerated ageing was developed for the equipment (figure 1), where the effect of seasons of the year on tested samples was simulated. One model year takes one week, and it includes summer conditions – heavy rainfall, 10 times. After each rainfall, there is a break followed by radiant heating by using IR lamps. The radiant heat is supplemented with xenon discharge tubes, which create UV radiation. Effect of radiant heat is applied 10 times. Radiant heat output is set to ca. 70°C on the sample surface. The effect of radiant heat and UV radiation is determined by the total average duration in the summer season. This time is divided into 10 parts to change with rainfalls always with a break for a couple of minutes. The model summer season is complemented with the winter season model when the tested material is exposed to freezing at -20°C followed by thawing in water of 20°C. The winter season is defined as one freezing/thawing cycle per year.

![Figure 1. Equipment for accelerated ageing.](image)
Subsequently, the samples were tested to resist growth to green algae and moulds. Methodology for testing resistance to green algae is based on the standard ČSN EN 15458 (672032) Paints and varnishes – Laboratory method for testing the efficacy of film preservatives in coating against algae [5]. For inoculation of samples, a suspension of two algal types was used: *Nostoc commune*, *Stichococcus bacillaris*. The algal cultures were purchased from the collection of autotrophic organisms CCALA Třeboň (492 *Stichococcus bacillaris* Naegeli, 118 *Nostoc commune* Vaucher). The collection strains were cultivated, and inoculation suspension according to the standard with approximate density $10^6$ CFU/ml was prepared. For the purpose of algae cultivation as well as the testing BBM (Bold-Basal/Bristol Medium) is used as the medium [6]. The tested samples were laid on the agar surface in individual Petri dishes. The samples and the agar surface were covered with a thin layer of mixed algal culture with a density of $10^6$ CFU/ml; 10 ml of the culture was used to one Petri dish, the culture was slowly inoculated on the sample, and subsequently, it runs down on agar. The samples were tested in three parallel assessments. Incubation occurred under these conditions: $23\pm2^\circ C$, $1000\pm200$ lx, light regime 16 hrs light/8 hrs dark. The whole test took 35 days. During the test and after the test, the algae growth was visually evaluated on the samples, both at a macroscopic level and with using stereomicroscope. Material resistance degree is described by percentual estimation of the sample covering and by the scale: 0 no growth, 1 slight growth, 2 medium growth, 3 intense growth.

Methodology of testing the resistance to moulds is based on the standard ČSN EN 15457 (672031) Paints and varnishes - Laboratory method for testing the efficacy of film preservatives in a coating against fungi [7], EN 60068-2-10 (345791) Environmental t-sting - Part 2-10: Tests - Test J and guidance: Mould growth [8] and ČSN 72 4310 (724310) Testing of mould proofness of building products and materials [9]. The samples are laid on the surface of Malt agar in individual Petri dishes. The test took place in three parallel assessments. Inoculation mould culture consisted of 6 collection strain types (from CCM Czech Collection of Microorganisms): *Aspergillus niger* CCM 8155, *Penicillium brevicompactum* CCM 8040, *Paecilomyces variotii* CCM F-398, *Alternaria alternata* CCM F-397, *Trichoderma viride* CCM F-728, *Cladosporium cladosporioides* CCM F-348). Suspension is prepared by washing off spores from a sporulated culture with mineral solution ($3$ g NaNO$_3$, $1$ g KH$_2$PO$_4$, $0.5$ g MgSO$_4$, $7$ H$_2$O, $0.5$ g KCl, $0.01$ g FeSO$_4$.7H$_2$O to 1000 ml distilled water, a sterilization 30 min at 0.1 MPa). The spore concentration in the solution should be $1-2 \times 10^6$ spores/ml. Inoculation took place under sterile conditions. The samples are covered by a thin layer of the mixed mould culture. 1 ml suspension was used on the sample surface. Incubation took place under these conditions: temperature $24\pm2^\circ C$ and relative humidity $96\pm2$%. Petri dishes with samples are laid in a sealed cultivation vessel, where the high relative humidity is kept by adding saturated solution Na$_2$SO$_4$. The whole test took 28 days. During the incubation, the cultivation vessel is opened once a week in a biohazard box, air is changed and the state of each sample is recorded. During the test and after the test the mould growth is visually assessed on the samples and surrounding nutrient soil. Mould spores in positive examinations should germinate to 6 days from the start of incubation. The resistance is assessed as follows: fungicide material – mould is not generated, inhibition zone is on the subjacent agar, fungistatic material – mould is not generated on the sample, colonies are not visible even by the microscope, growing on soil, non-resistant material – report 1–5 according to the scale (1 – slight growth, visible only by microscope, scattered colonies, 2 – slow growth – numerous small colonies, up to 25% of the surface, 3 – intensive growth, up to 50% of the surface, 4 – very intensive growth, up to 75% of the surface, 5 – total growth, 100% of the surface).

3. Results and discussion
Test results are stated in Table 1 and 2 and supplemented by photo documentation – figure 2 and 3. From the collected data, it can be concluded that some materials keep relatively good resistance even after accelerated ageing for 10 years, on the other hand, other materials lose their biocidal properties already in the first four years of exposure to climatic conditions. At one material, the problem with resistance to mould attack was recorded already at time = 0.
Table 1. Test results of resistance to green algae.

| Test indication | Growth degree of algal cells on samples (35 days of incubation) | Average covering of observed sample surface by algal cells after test finish (35 days of incubation) /% |
|-----------------|-------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Sample indication | Accelerated ageing | Accelerated ageing |
| 0 years | 4 years | 10 years | 0 years | 4 years | 10 years |
| 1 | 0 | 0 | 1 | 0 | 0 | 5 |
| 2 | 0 | 1 | 2 | 0 | 2 | 20 |
| 3 | 0 | 0 | 1 | 0 | 0 | 1 |
| 4 | 0 | 3 | 3 | 0 | 70 | 70 |
| 5 | 0 | 1 | 2 | 0 | 1 | 30 |

Table 2. Test results of resistance to moulds.

| Test indication | Growth degree of moulds on samples (28 days of incubation) | Average covering of observed sample surface by mould growth after test finish (28 days of incubation) /% |
|-----------------|-------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Sample indication | Accelerated ageing | Accelerated ageing |
| 0 years | 4 years | 10 years | 0 years | 4 years | 10 years |
| 1 | 2 | 2 | 3 | 10 | 20 | 30 |
| 2 | 1 | 3 | 4 | 2 | 30 | 60 |
| 3 | 1 | 1 | 3 | 1 | 2 | 30 |
| 4 | 1 | 4 | 5 | 2 | 75 | 90 |
| 5 | 1 | 3 | 2 | 1 | 25 | 20 |

Figure 2 shows photos of the sample 2 after finishing individual tests. This sample proves average results; however, it can be seen that in the test with moulds after accelerated ageing for four years already, a noticeable mould attack occurs. In figure 3, we can see a relatively large growth of algae and mould at the sample 4 already after four years of accelerated ageing, this sample proved biocidal properties at time = 0.
Testing of facade systems across the Czech market confirmed real-life experience that a lot of materials do not meet announced properties or they lose them after a very short time. There were found materials resistant even after accelerated ageing for a longer time as well as materials prone to attack already after realization of a facade set.

Within a choice of suitable material during realization of thermal insulation, it is very difficult to predict expiration of biocidal properties of facade systems without material testing, therefore, the European commission for standardization prepares the standard „Assessment of the resistance of insulation products against mould development“ (WI = 00088439) that should be issued in the next year. This standard is based on experts’ knowledge and on already standardized methods for other materials. It includes mainly methods ASTM C1338 [10], ASTM G21 - 96 [11] and other methods arising from them.

Verdier et al. [12] present a summary of individual methods of testing resistance to moulds with a comparison of selected experimental parameters – microbial strains, humidity, inoculation technique, incubation conditions, incubation duration. In conclusion, he states that although these tests ensure sustainable and accelerated microbial growth and provide a view of material resistance, in reality, they differ from a real condition of building material exposure to the environment. Within interpretation, it
is really necessary to take it into consideration, yet the test results provide us with important data on material behaviour and, last but not least, it is possible to compare the resistance of different materials. In literature [13], testing of resistance to moulds in combination with accelerated ageing is described in the scope of using biocomposites from agricultural materials. Accelerated ageing, in this case, represents exposure to unfavourable conditions 30°C and 90% RH for three months. Besides visual assessment, also digital image correlation (DIC) with the aim to accelerate evaluation and increase objectivity rate is employed. Regarding the fact that plant materials are the topic, natural contamination of materials with moulds is used.

Parracha et al. [14, 15] describe tests of various ETICS systems with a purpose to compare mould growth on the surface and other properties, mainly moisture transport properties (capillary water absorption, water vapour permeability, water absorption under low pressure, and drying kinetics), thermal conductivity, surface properties (colour, gloss, and roughness). The results show that deeper knowledge of correlation among ETICS properties can effectively contribute to the effective assessment and long-term durability of these systems.

In the first study [14], Parracha deals with the correlation of hygrometric properties – capillary absorption and drying capacity with testing of mould growth at 7 ETICS sets. One group of samples was inoculated by Aspergillus niger, Penicillium funiculosum and Aureobasidium pullulans and the second one was retained with natural contamination. Incubation took place under these conditions: temperature 22±1°C and 70±5% RH. The samples showed no growth for four weeks, after that, a growth occurred, mainly at samples with insulation layer from cork. The fact that at no ETICS a growth occurred on the surface after four weeks of testing the author explained by a presence of biocide in the surface layer.

The newest study [15] describes testing of 12 various ETICS sets to above mentioned technological properties and tendency to moulds. The samples are inoculated only by Aspergillus niger and Penicillium funiculosum. The incubation took place under these conditions: temperature 22±1°C and 70±5% RH. The results of resistance to moulds are similar to the first paper. In both studies [14, 15], new produced systems are examined that had not been exposed to any type of ageing or weather effects, therefore, it is necessary to complete it in the following research. The author stated that although the ETICS samples showed no or small growth of moulds at the end of test, according to further observations, it turned out that some of them are more sensitive to attack. It supports the necessity of regular maintenance of ETICS, including testing of a biological attack.

Kvande et al. [16] describe the testing of ETICS in Norway with regard to system defects. A part of laboratory experiments is also accelerated ageing of materials, both exposure to natural weather conditions and testing by means of laboratory equipment. In the equipment, it is possible to revolve the samples among four climatic zones. Exposure is always 1 hr in each climatic zone in the given order. These factors affect the samples: UV and IR light of various intensity and wavelength, heating up to 63°C, freezing at -20°C and thawing at 20°C, water sprinkling 15 dm³/(m²h). The purpose of this accelerated ageing is to compare the properties of various materials. Tests, therefore, do not provide exact data on lifetime expectancy expressed with a number of years. Detailed research of this method and other methods of accelerated ageing is done by Jelle [17], the method is always chosen by the material and climate. The described methods correspond with the method used for our purposes.

4. Conclusions
The aim of the study was to evaluate five commercial facade sets across the Czech market with respect to resistance to biological attack. The materials were tested after their preparation and they were subjected to accelerated ageing for 4 and 10 years before the testing. Tests of resistance were carried out by means of controlled application of algal and mould strains on the samples and incubation in a defined environment. Some materials were resistant to accelerated ageing for a longer period, some of the materials prone to attack already after a facade set preparation. The results confirmed experience from real life that a lot of materials do not meet the declared properties, or they lose these properties
after a very short time. According to our methodology, accelerated ageing of materials appears to be a suitable supplementary method for testing the resistance of such materials.

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References
[1] Wasserbauer R 2001 Biological deterioration of buildings (in Czech) 1. ed (Praha: ABF, Nakladatelství ARCH) p 257
[2] Büchli R and Raschle P 2004 Algae and fungi on façade (in Czech) 2. ed (Ostrava: Nakladatelství MISE, s.r.o.) p 108
[3] Flannigan B, Samson R A and Miller J D 2001 Microorganisms in home and indoorworkenvironments: diversity, health impacts, investigation and control (BocaRaton [Fla.]; CRC Press) p 529
[4] Adan O C G and Samson R A 2011 Fundamentals of mold growth in indoor environments and strategies for healthy living (Wageningen: Wageningen Academic Publishers) p 523
[5] ČSN EN 15458 (672032)2015 Paints and varnishes – Laboratory method for testing the efficacy of film preservatives in coating against algalae(Praha, Úřad pro technickou normalizaci, metrologii a státní zkušebnictví) p 16
[6] Kukletova I and Chromkova I 2019 Proposal of methodology for testing the resistance of building materials against mold infestation IOP Conf. Series: Materials Science and Engineering 583 012029
[7] ČSN EN 15457 (672031) Paints and varnishes - Laboratory method for testing the efficacy of film preservatives in a coating against fungi
[8] ČSN EN 60068-2-10 (345791) 2008 Environmental Impact Testing - Part 2–10: Tests - Test J and Instructions: Mold Growth (Praha,Český normalizační institut) p 36
[9] ČSN 72 4310 (724310) Testing of mould proofness of building products and materials (in Czech)
[10] ASTM C1338 2014 Standard test method for determining fungi resistance of insulation materials and facings (ASTM International) p 3
[11] ASTM G21 - 96 2015 Standard practice for determining resistance of synthetic polymeric materials to fungi (ASTM International) p 6
[12] Verdier T, Coutand M, Bertron A and Roques CH 2014 A review of indoor microbial growth across building materials and sampling and analysis methods. Building and Environment 80 pp 136–149
[13] Viel M, Collet F, Lecieux Y, François M, Colson V, Lanos C, Hussain A and Lawrence M 2018 Resistance to mold development assessment of bio-based building materials Composites Part B doi: https://doi.org/10.1016/j.compositesb.2018.09.063
[14] Parracha J, Cortay A, Borsoi G, Veiga R and Nunes L 2020 Evaluation of ETICS Characteristics that Affect Surface Mould Development Current Topics and Trends on Durability of Building Materials and Components Serrat C, Casas J R and Gibert V (Eds) URL https://www.scipedia.com/public/Parracha_et_al_2020a
[15] Parracha J L, Borsoi G, Flores-Colen I, Véiga R, Nunes L, Dionísio A, Gomes M G and Faria P 2021 Performance parameters of ETICS: Correlating water resistance, bio-susceptibility and surface properties, Construction and Building Materials 272 121956
[16] Kvande T, Bakken N, Bergheim E and Thue J V 2018 Durability of ETICS with Rendering in Norway – Experimental and Field Investigations, Buildings 2018 8(7):93 https://doi.org/10.3390/buildings8070093
[17] Jelle B P 2012 Accelerated climate ageing of building materials, components and structures in the laboratory J Mater Sci 47 pp 6475–6496 https://doi.org/10.1007/s10853-012-6349-7