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Innovative Environment-Friendly Interior Finishing Technologies Resistant to Mold Growth

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Abstract. *Excessive mold development in interior spaces can be the cause of health problems in their users, as well as of a decrease in the comfort of use of internal spaces. The aim of our study was the development of a service that can ensure the long-term elimination of the cause and effects of mold in buildings by using new compositions of materials and finish application techniques. For this purpose, the most mold-resistant variants of construction material compositions and the technology of their application were selected. The study features an analysis of 18 variants of samples taken from climatic boards with various building finishes, which were tested for resistance to three species of mold: A. versicolor, Ch. globosum and P. funiculosum, under different climate and humidity combinations. The results of the study pointed to the most effective anti-mold technology. One comprehensive solution that can improve the conditions of the use of interior spaces is an external wall interior thermal insulation application system that employs silicate and lime sheets.*

Keywords: *Mold, Durability, Interior Finishing, Silicate and Lime System.*

1 Introduction

Fungi and the remediation of living quarters have been a problem that has accompanied mankind for many years. Exposure to harmful biological agents in the interior environment of living quarters has been identified by the WHO as a significant health risk. There is mounting evidence that mold growth in damp buildings is an important risk factor in the development of respiratory diseases. Air contamination by biological agents is associated with moisture and inadequate ventilation. A WHO study (2007) showed that there is a significant number of European homes that can be affected by mold and damp. Available publications indicate that in European Union Member States, the problem of mold or damp affects 10% of social housing (over 14 million cases) (Bonnefoy *et al.* 2003).

Worldwide observations indicate that in newly-built buildings, over 60% of mold problems apply to bathrooms, up to 40% to kitchens and only a few percent in other rooms. The dynamics of the indoor microclimate are related to the finishing materials and the organisms

themselves, which can in turn affect the materials. For example, porous substances can retain moisture and provide a reservoir for it, creating spaces with high humidity that are convenient for mold growth in otherwise dry indoor conditions. Molds are an extensive taxonomic group. Some of them need small amounts of organic nutrients and can grow on plasters, walls and construction materials in places with increased humidity (Fedorczak-Cisak *et al.,* 2019; Fedorczak-Cisak *et al.,* 2020; Radziszewska-Zielina and Śladowski, 2017). Molds develop actively at elevated mass humidity values, which differ between the species of mold and type of material (Gutarowska, 2010). Molds cause the biodegradation of building materials, reduce the aesthetics of the interior, destroy stored products and adversely affect the well-being and health of people and animals. They develop on surfaces, forming variegated mycelium deposits, the coloration being usually caused by numerous conidial spores (Gutarowska and Piotrowska, 2007). The second important factor affecting mold growth is the pH of a material. In particular, the alkaline nature of materials *e.g.* a high pH value of around 12-14, has been observed to show a lack of active growth of mold, which resulted from the existence of conditions unfavorable to the development of these microorganisms (Andersson et al., 1999). Excessive development of molds in utility spaces has been observed to cause health problems. The disease factor, in the form of spores, mycelium or metabolites, enters the human body by inhalation, ingestion or through the skin. The effects of these factors are not always immediate, many of them are revealed after a longer period of time (WHO 2009; Nielsen *et al.* 1999; Guo *et al.* 2004).

Control of the occurrence of molds in buildings and its reduction requires a holistic approach to the construction and occupancy process, taking into account the aspects of thermal insulation, heating, ventilation and proper finishing of materials, as well as the proper maintenance of indoor spaces (Radziszewska-Zielina *et al.* 2020). The use of comprehensive solutions consisting of the improvement of thermal and humidity conditions in an indoor space can lead to the elimination or reduction of the causes of fungal infestations. Using an internal insulation system comprised of Epatherm silicate-lime slabs is one such comprehensive solution.

2 Materials

Several dozen samples were prepared in laboratory conditions, using various finishing materials (mortars, thin coat plasters, paints (KFI, etf, acrylic (ap), latex (lp), emulsion (ep)), while the base consisted of silicate and lime sheets of varying thickness (from 15 to 100 mm). The proposed thermal insulation sheets include silicone in their composition, which gives them hydrophobic properties, making them more resistant to dampness and therefore the development of microorganisms (Hippelein and Rügamer 2004). The resistance of the analyzed sheets to the effects of molds was also a result of the existence of conditions that are unfavorable to the development of these microorganisms, particularly stemming from the alkaline character of the proposed set of materials, *e.g.* their high pH value of 12-14. In addition, based on laboratory studies, a lack of application differences was observed in the case of using these material compositions in atmospheric conditions, i.e. in temperatures ranging between 5˚C and 30˚C, with a relative air humidity of 40% to 80%. The materials used in the system are mineral products, composed of lime, quartz sand and water, which

results in a lack of toxins or other substances that are not allowed in construction.

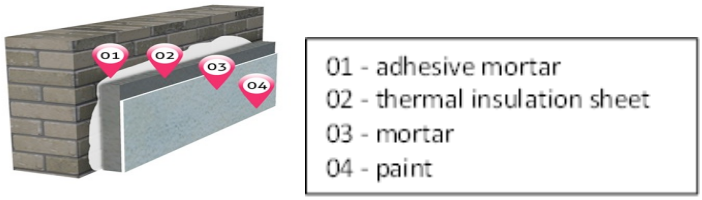

Figure 1. Layers of the proposed interior thermal insulation application system (www.eximreno.eu).

45 compositions of material and ready-made application solutions with different construction finishes (Table 1) were examined in the study:

Table 1. Material samples and technologies of their application and finishing.

No	Thickness [mm]	Finishing	No	Thickness [mm]	Finishing
1	15	factory	**24**	30	priming etg + mortar m-eti + lp
2	15	priming	**25**	30	priming etg + mortar m-eti + ap
3	15	priming, mortar m-eti	**26**	30	priming etg+thin coat plasters 5w1+ap
4	15	priming, mortar bs	**27**	30	priming etg+thin coat plasters 5w1+lp
5	15	priming, thin coat plasters ekp	**28**	30	priming etg+thin coat plasters ekp+etf
6	15	priming, mortar m-eti, KFI+priming KFV	**29**	30	priming etg + white mortar + gypsum
7	20	factory	**30**	30	Priming, mortar, lime paint KFI
8	20	priming etg	**31**	40	priming etg + mortar m-eti
9	20	priming + mortar m-eti	**32**	50	factory
10	20	priming etg, mortar m-eti, etf	**33**	50	priming etg + mortar m-eti
11	20	priming etg + mortar m-eti + ap	**34**	50	priming etg + mortar m-eti
12	25	factory	**35**	50	priming etg + mortar m-eti + etf
13	25	priming	**36**	50	priming etg + mortar m-eti + ep
14	25	priming, mortar m-eti	**37**	50	priming etg + mortar + ap
15	25	priming, mortar bs	**38**	50	priming etg + glue
16	30	factory	**39**	50	priming etg + thin coat plasters ekp
17	30	priming etg	**40**	50	priming etg+thin coat plasters 5w1+etf
18	30	priming, thin coat plasters ekp	**41**	50	priming etg+thin coat plasters 5w1+ap
19	30	priming etg + mortar m-eti	**42**	50	priming etg+thin coat plasters 5w1+lp
20	30	priming etg + mortar m-eti + etf	**43**	50	priming etg + Knauf + ap
21	30	priming etg + mortar m-eti + ep	**44**	50	priming+thin coat plasters KnaufMP75
22	30	priming etg + thin coat plasters 5w1+ etf	**45**	60	priming etg + mortar m-eti
23	30	priming etg+ thin coat plasters 5w1+ep			

3 Methods

3.1 Resistance to Molds

The study used 18 sets of 45 samples taken from climate boards with different construction finishes, which were treated with three species of mold: *Aspergillus versicolor*, *Chaetomium globosum* and *Penicillium funiculosum* in 9 climate combinations. The test was performed in compliance with American standards (ASTM C1338-08; ASTM International E104-02; ASTM International D6329-98). According to this document, stable humidity conditions are

provided by saturated solutions of selected inorganic salts, while the temperature is provided by external devices. In this study, a refrigerator chamber and an incubator were used. Radio-controlled thermohygrometers in an environmental chamber were used for the control. The conditions of the experiment and the means of ensuring them in the environmental chambers have been presented in the Table 2.

Mycological tests were carried out based on prepared spore suspensions of three selected molds with a density of 10^6/ml in two types of media (sterile distilled water and a liquid medium), which were sprayed on the test samples. The inoculated materials were placed in environmental chambers with humidity, which were then placed at three temperatures (Table 2). In total, 18 sets of 45 samples with different finishes were used in the study. A mycological evaluation of the cultures was performed after two days of incubation - 0 - determining the recovery of mold without the influence of climatic conditions. Further assessments of the size of the cultures were performed at 1 and 2 weeks of incubation. Cultures were extracted from the samples through a 1 cm^2 smear of the top layer of the sample and, after the disinfection of the surface, scraping the material from a depth of 0.5 cm on a surface of 1 cm^2. The cultures were cultivated on two media: Malt Extract LAB-AGAR™ (MEA) and Rose Bengal LAB-AGAR™ (RBA) in triplicate. When assessing the susceptibility of materials to mold, a total of over 20,000 cultures were assessed, while the total number of records in the database was about 82,000 in total, nearly 823,000 mold colonies were counted. The results were subjected to a statistical analysis.

Table 2. Conditions of the experiment.

Temperature [ºC]			Relative Humidity (%)		
Categories	**climatic conditions**	**Value**	**Categories**	**climatic conditions**	**Value**
Low	refrigerator chamber	2.6 ±1.0	Low	silicate	44.5 ± 11
Low		3.9 ± 0.6	Medium	magnesium nitrate	80 ± 1
Low		4.7 ± 1.0	High	potassium chloride	92 ± 1
Medium	room temperature	22.1 ± 1.4	Low	silicate	53 ± 1
Medium		21.8± 1.2	Medium	sodium nitrite	77 ± 1
Medium		22.6 ± 1.3	High	potassium nitrate	96 ± 1
High	laboratory incubator	36.4 ± 0.3	Low	silicate	23 ± 8
High		36.9 ± 0.2	Medium	sodium nitrite	57 ± 6
High		36.0 ± 0.3	High	potassium sulfate	86 ± 2

3.2 Statistical Analysis

The authors used one-way analysis of variance (ANOVA) to analyze the relationship between the number of mold colonies (dependent variable) and the tested variant sample "plate number" (grouping variable). The dependent variable was measured in various configurations. An ANOVA test was performed for the following configurations of experimental conditions. Afterwards, Fisher's multiple comparison tests were conducted for all identified relationships between the dependent and grouping variables, in order to detect differences between the means. A default significance level of 0.05 was adopted. The dependent variable was measured in configurations that were selected based on an analysis of the literature and the observations made during the seed test. It was found that the samples most exposed to mold fungi were those with average temperature "TEMP = SR" and high humidity "RH = WYS"

(Pasanen, 2000) conditions. The statistical analysis took into account the results after the maximum incubation time of samples from inoculation, i.e. after a period of two weeks of incubation in the above climatic conditions, "Culture = 2". A suspension in the spore medium in the MEB medium "IV = P" was selected, at which a higher number of spores was obtained relative to the spore suspension in sterile water. Spore collection from the sample surface was carried out using two methods (selected for analysis): a swab from the sample surface "V = W" and a sample groove to the depth "V = S". RBA "VI = R" medium was selected for analysis because of the low amount of impurities/infection. It has been proved that filamentous fungi depend on the presence of organic matter in the environment, they can even use house dust as a source of nutrition in conditions of high humidity (Buchmiet and Żakowska, 2009). Primary colonizers of building materials include xerophilic species that also develop in dry conditions, *e.g.* fungi of the genera *Penicillium* and *Aspergillus* (Gutarowska and Piotrowska, 2007). The dependent variable analysis was performed separately for three species of molds: "VII = A" - *A. versicolor*, "VII = P" - *P. funiculosum*, "VII = Ch" – *Ch. globosum*.

4 Results

One of the assumptions of the project was to develop a method of long-term mold removal in variously used internal spaces, one that could be introduced to the construction market. Over the course of laboratory research, material compositions with the greatest resistance to mold growth were selected and then various methods of applying them in actual construction conditions were analyzed. An analysis of the method of base surface preparation for the application of the system's sheets was performed, as well as that of their finishing depending on the type of internal space and the manner of its use. A significant relationship was found between the variable dependent number of colonies and the sample number (p value <0.05).

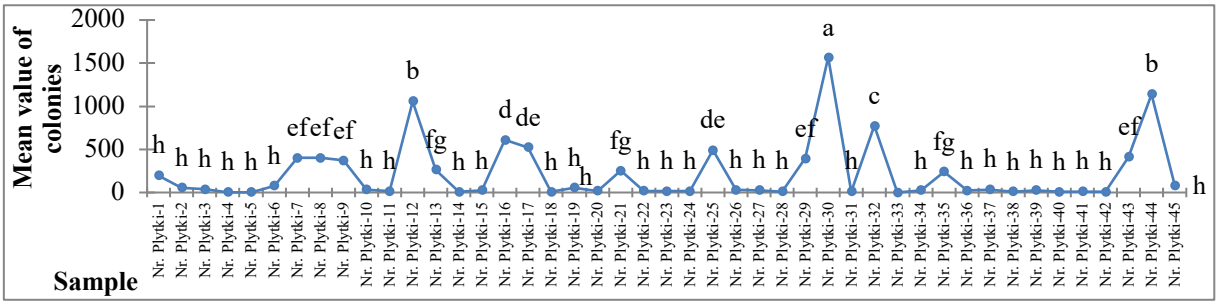

Figure 2. Experimental setup (sampling - Scraping, *A. niger*), TEMP = SR, RH = WYS, Culture = 2, IV = P, V = S, VI = R, VII = A.

For the experimental system (sampling - Scraping, *A. versicolor*), the analysis of multiple comparisons includes all samples in which the average number of colonies does not exceed 82.67 in one homogeneous class, H (this corresponds to sample 45). Samples in a homogeneous class H showed the highest resistance to *A. versicolor*. Samples 30, 44 and 12 proved to be the least resistant to *A. versicolor*, etc. (Fig. 2). Compared to variants not resistant to *A. versicolor*, samples in the G-F class also showed fungistatic activity against the

tested mold (Fig. 2). In the case of samples treated with *P. funiculosum*, variants for which the average number of colonies does not exceed 31. 33 (this limit is determined by sample No. 5) were observed to be the most resistant (Figure 3). Analysis of samples exposed to *Ch. globosum* found no significant difference between the samples (p value 0.52). Thus, all samples were observed to behave homogeneously (well) under the selected experimental setup (Fig. 4).

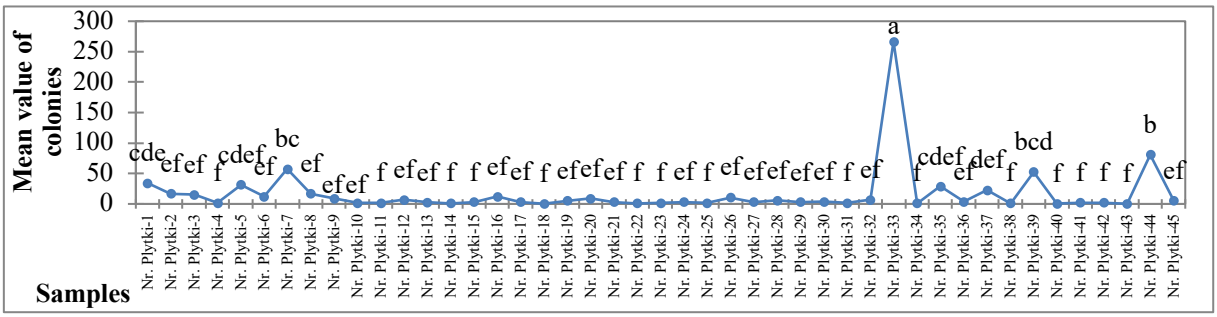

Figure 3. Experimental setup (sampling - Scraping, *P. funiculosum*), TEMP = SR, RH = WYS, Culture = 2, IV = P, V = S, VI = R, VII = P.

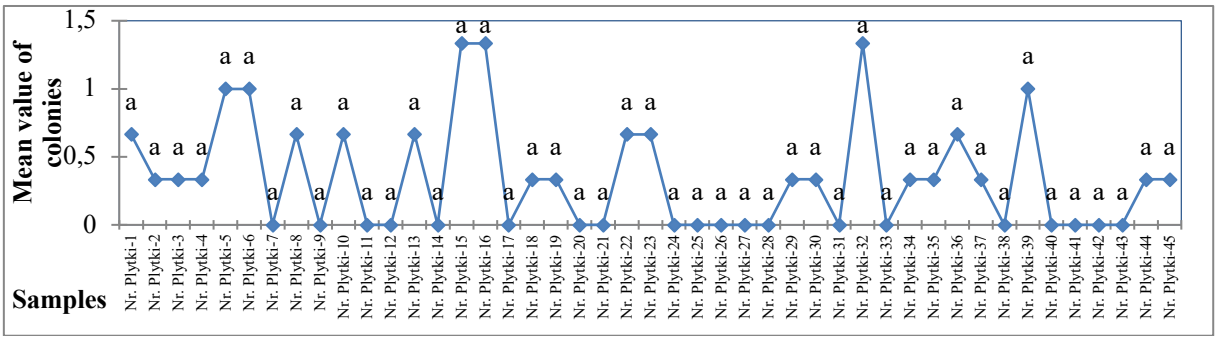

Figure 4. Experimental setup (sampling - Scraping, *Ch. globosum*)

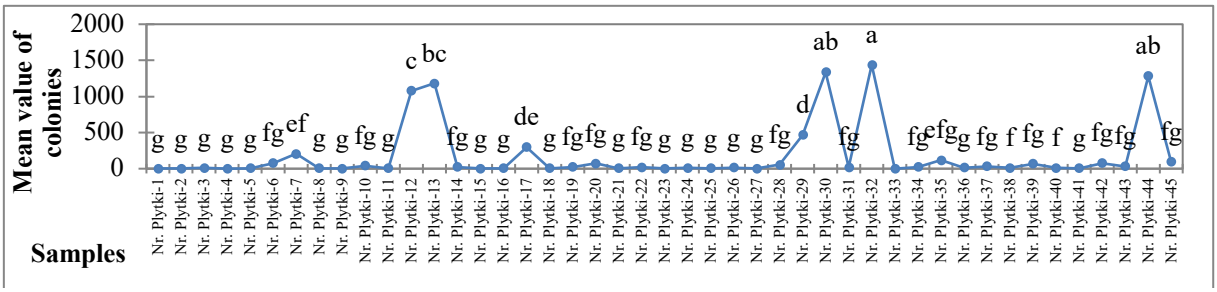

Figure 5. Experimental setup (sampling - Swab, *A. niger*), TEMP = SR, RH = WYS, Culture = 2, IV = P, V = W, VI = R, VII = A.

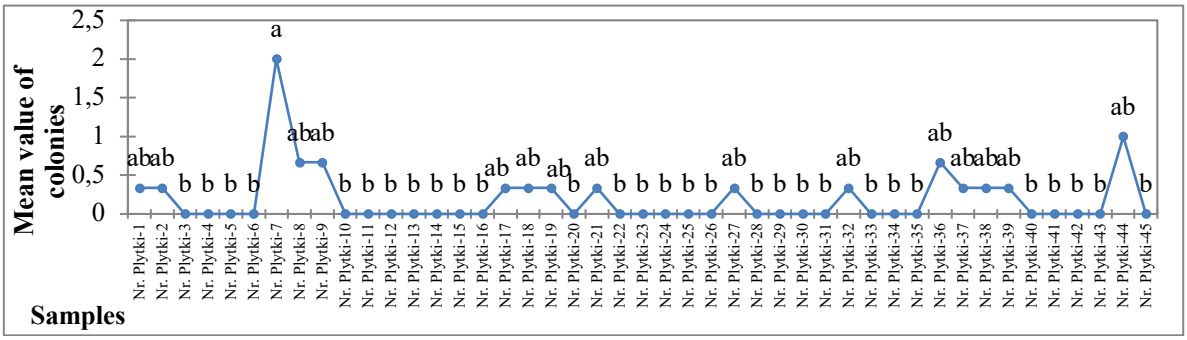

Figure 6. Experimental setup (sampling - Swab, *Ch. globosum*).

For the experimental system (sampling - Swab, *A. versicolor*), multiple comparison analysis classified all samples resistant to *A. versicolor* into one homogeneous class, G. The limit of the most resistant samples is determined by option No. 35 (Fig. 5). Additionally for the experimental system (sampling - Swab, *P. funiculosum*), multiple comparisons analysis determined the variants that were the least resistant to the action of *P. funiculosum*, which include variant No. 33. The remaining samples were within homogeneous classes B or C (not presented in figure).

Sample No. 7 was found to be the least resistant to *Ch. globosum* in this experimental setup, which is a separate class. For the remaining samples, no significant differences were observed, placing them all in the B homogenous class (Figure 6).

5 Conclusions

A review of the obtained results has shown that all building materials can be a convenient substrate for the growth of molds that contribute to their destruction. Therefore, it is necessary to know the susceptibility of currently used construction materials to colonization by these microorganisms, as well as the factors that facilitate this process.

Most often, the presence of mold was observed on samples numbered 7, 8, 9, 12, 13, 16, 17, 30, 32, 33, 44. Differences between the ability to grow mold in laboratory conditions were observed in inorganic materials (gypsum, plaster). The reason for these differences in fungal growth may have been the presence of additional sources of nutrients that stimulate said growth, e.g. in the form of dust or a microbial medium.

The results show that variants number 35 and 40, which are characterized by high vapor permeability (water vapor diffusion coefficient = 3), prevent the development of mold on their surface. Climatic boards, which have silicone in their composition, which gives them hydrophobic properties, will be more resistant to moisture, and thus to the development of microorganisms.

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