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DAMAGES CAUSED BY MICROORGANISMS IN HISTORICAL BUILDINGS ON THE EXAMPLE OF A MULTI-FAMILY RESIDENTIAL BUILDING

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Abstract

The article discusses the destruction of materials in a historic building caused by microorganisms. The problem is presented on the example of a historic multi-family building in the historic centre of the city of Lublin, Poland. The building is an object which, due to its material value, is under strict conservator's protection. As part of the assessment of the technical condition, among other things, tests were carried out to determine the level of dampness in the masonry walls, and also microbiological tests due to the visible degree of biological corrosion of the wall surfaces. The research was aimed at determining the degree of microbiological contamination of the object. Microbiological and chemical methods (gas chromatography) were used to characterise the material samples. The results indicate that the rooms of the studied building are biologically loaded.

Keywords*: Architectural conservation; Biodegradation of building materials; Conservation management., Sick Building Syndrome, Indoor Air Quality*

Introduction

Microbiological corrosion in construction is the process of deterioration of materials by viable biota, mainly by fungi, mould and bacteria. The losses caused by microbial infestations can be very wide: from damage to the wall structure, increased repair costs, reduced service life of buildings and premature demolition of fungus infested buildings to the detriment effects of humans health [1-3].

Moulds are among the most serious damaging factors when it comes to building materials, due to their common occurrence and poor standards for growth conditions. Primary source of contamination of the building envelope is airborne mould spores. Fungi need external food sources: water, water vapour or organic compounds in order to be able to develop fully [1, 4, 5].

The existence of water in the surroundings is a prerequisite for the sustainability of all the living beings and is also of great significance for the degradation process of materials. This

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parameter is closely related to the technological state of buildings. Moisture may be due to technological reasons (defective building framework, insufficient thermal insulation, partition thickness, lack of or ineffective damp-proofing, leaking roof, etc.) or random incidents (e.g. flooding) [6-8]. Dampness leads to the colonisation of buildings by "biodegrading" micro- and macro-organisms which cause unwanted physical, chemical, and mechanical alterations to buildings. Orientation and severity of biodegradation is determined by chemicals, material composition, porosity, water permeability and nutrient availability [9-11].

Biological materials, such as timber, are made biodegradable by the effects of hydrolytic enzymes, that colonize organisms through the decomposition of cellulose, hemicellulose, and lignin [12, 13]. Macroscopic signs of biodegradation surface faults such as modified texture, fibre cracking, pitting, microbial growth, discoloration, convex plaster and flaking paint can be seen. A dangerous effect on the longevity of buildings is the change in their mechanical properties, enabling strength, i.e. especially important for structural elements [14].

As mould grows in damp or moist indoor spaces, it is possible for people to be exposed to mould and its products, both through direct contact on surfaces and through the air. The most frequently identified moulds are representatives of several genera: *Penicillium*, *Aspergillus*, *Cladosporium*, *Alternalia* and *Fusarium* [15, 16].

The term Sick Building Syndrome refers to an increased level of chemical and biological air pollution that negatively affects the well-being of people living indoors. It is still a not very well understood topic related to health problems, increasingly recognized as a new pathogenic entity [17]. A fundamental precondition for successful analysis of the Sick Building Syndrome issue is a detailed understanding of its causes and the consequences carried for humans [1,2,17,18] therefore it seemed justified to undertake research on this topic.

In this article there is presented a widespread investigation of the old building located in South-Eastern Poland, the city of Lublin. The object is visually stricken with microbiological corrosion. Within the research the masonry moisture tests, microbiological and chromatographic tests were carried out. The results indicate that the building is biologically contaminated, which was confirmed by tests with reference methods (gas chromatography).

Materials and methods

Description of facility

The object, where the survey was carried out, is a detached building at 1 Czechowska Street in Lublin, Poland on a plot of land no. 11/7 (Figs 1 and 2). The building has two floors, a partial basement, previously (before the fire of 1999) with a usable attic. The building has a gable roof of a wooden, rafter and purlin structure. Partially covered with metal sheet (fragment above the southern elevation), the remaining part covered with tar paper. The building was constructed using traditional technology, its construction and partition walls are made of solid brick with cement-lime mortar. External cement-lime plasters smooth, repaired and rubbed down with cement mortar. Gutters and downpipes made of galvanised sheet. Partly above the basement: brick vaults and wooden ceilings and contemporary thick-ribbed ceilings of Teriva type. Ceilings for overground storeys were made of wood with a blind ceiling. Floors in rooms are wooden on joists, in some rooms there is oak parquet on a blind floor. In rooms, on most walls there are gypsumboards, in staircases there are cement-lime plasters with emulsion paintings and oil varnishes. Currently, the building is not heated. The window and door frames have been partly replaced, and the historical "Polish type" windows and single- and double-leaf panel doors have been preserved. On the southern elevation, there is a balcony with a structure

based on cantilever steel beams, and the "balcony plate" is covered with wooden planks. The building is located directly on a wetland adjacent to the Czechówka river. On the eastern side, a reinforced concrete retaining wall was erected behind the building, on which the adjacent slope is based.

Fig. 1. View of south-west elevation

Fig. 2. View of the east elevation

Research methods

Within the research both evaluation of the technical status of the building envelope was conducted and the quality of the indoor air was evaluated. Evaluation of the building envelope covered determination of the masonry moisture, indoor air investigations covered microbiological evaluation of the fungi presence and chromatographic determination of the compounds present in the air with the particular emphasis on the Volatile Organic Compounds (VOC) that in microbiologically stricken objects are the fungal metabolites.

Moisture tests on masonry

Masonry samples for moisture content determination were taken from two selected rooms in which microbial load tests were then carried out for comparison. The rooms were characterised by an unpleasant odour and visible efflorescence on the surfaces of the partitions. One of the rooms was located in the basement (room 1), while the other (room 2) was on the ground floor of the building. The tests were carried out in January 2019. The average humidity in the tested rooms was respectively 42% and 61%.

In case of the room 1 the walls were made of red bricks on cement lime mortar, with visible masonry structure without plasters. In case of the room 2, the partition walls were made of solid bricks on cement-lime mortar. In the tested flat on the ground floor (room 2), on the external walls there is a widespread infestation of finishing materials, paintings, linings by mould fungi, on wall surfaces in most of the rooms in the floor zone there are considerable damages of paintings and plasters caused by considerable dampness of this zone.

A total of 8 boreholes were drilled - six in the basement (room 1) and two in a (room 2) on the ground floor. Three samples were taken from the east wall of the basement, two samples from the north wall of the basement and one sample from the west wall (Fig. 3).

The method for moisture content determination is specified in PN-EN ISO 12570 standard [19].

The testing apparatus included: A dryer capable of maintaining a drying temperature of at least 105°C with an accuracy of ± 2°C and a relative humidity of less than 10%; in the case of hot and humid air or low drying temperature, it may be necessary to provide drying air to ensure the appropriate relative humidity. A balance capable of weighing the test samples with an uncertainty of not more than 0.1% of their weight.

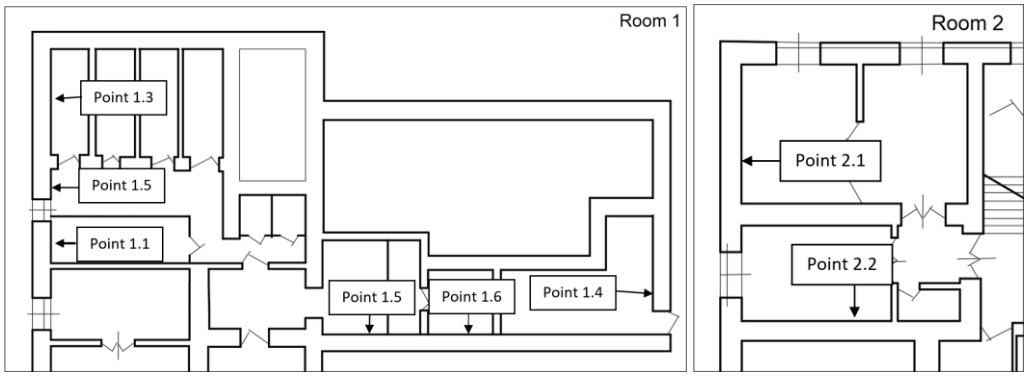

Fig. 3. Schematic views of room 1 and room 2 showing the positions of the measurement boreholes

The first stage of the study involved collecting the samples and then weighing them to an accuracy of 0.01g using Adventure Pro Type AV264CM. The n ext stage consisted in drying the samples for 48h at 105°C to constant weight and then weighing of dried samples. The last stage was weighing of the measuring vessel itself in order to make correct calculations.

Microbiological method

Microbiological method of indoor air quality assessment can be divided into traditional (mycological) and molecular method.

Mycological assessment involves macroscopic and microscopic observation of collected and cultured microorganisms, determination of moisture content in collected samples, and evaluation of the efficiency of ventilation and other sanitary systems. This method is based on detecting mold fungi in air samples or swabs, calculating the number of colonies, and determining the species or genus. Traditional techniques include [2]:

- the Koch sedimentation method,
- the cascade method, which is based on the flow of contaminated air through small openings.

The collision method was used for this study. This method is based on the fact that the air flowing at high velocity, which hits the surface of the medium, is forced to change its direction of motion rapidly, resulting in the microorganism falling out of the air current and settling on the surface of the medium. Petri dishes of the medium are incubated, the number of colonies on each plate is counted, and then the number of colonies in 1 m^3 of air is calculated.

The cascade impactor (Fig. 4) is a device used to determine the specific size distributions of any aerosol-forming dust. Using appropriately shaped aerosol guide channels, dust of different diameters is deposited at different locations.

Six petri dishes with Sabouraud's medium were placed in the cascade impactor and air was drawn for 10 minutes using a pump. The impactor was placed in the centre of the room 1 and room 2 at a height of 1 metre. The plates were then located in a greenhouse at 27°C with incubation time of the samples set for 2 weeks. The cascade impactor (Fig. 4) is an appliance for determining specific size distributions of aerosol-forming dusts. With use of appropriately shaped aerosol guide channels, dust of different diameters is deposited at different locations [18, 20].

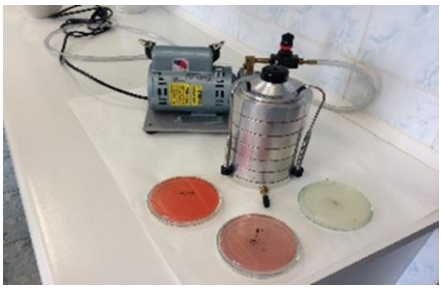

Fig. 4. The cascade impactor and Petri dishes

Gas chromatography

Together with microbiological evaluation, chemical composition examination of the indoor air was conducted to detect the possible microbial metabolites presence. For examination of the chemical trace in building it was applied the microextraction technique on SPME fibres. It was used Supelco PDMS, DVB and CAR fibers, which were placed for 60 minutes in rooms 1 and 2 to absorb fungal metabolites in the air. Afterward fiber were analysed by gas chromatography coupled with a mass spectrometer GC-MS TraceUltra – PolarisQ, Thermo with chromatographic column Equity 5MS from Supelco, length 30m, internal diameter 0.25mm, phase thickness 0.25µm. Helium flow through column was 1.2ml/min with purity 99.999%. For particular fiber was applied specific column temperature program (Tab. 1).

In spectrometer ion source temperature (filament) was 220° and detector - Full Scan 35-350 m/z. For data analysis was used Xcalibur 1.4 with NIST 08 willey8 [21] with comparison library.

Table 1. Analysis programme for SPME fibers

Parameter	PDMS	DVB	CAR
Dispenser (Blue Sky Restek 1mm in splitless mode)	2 min at 250°	2 min at 220°	2 min at 300°
Program	2 min at 40°, slope 8°/min to 150°, slope 15°/min to 250°, 5 min at 250°	2 min at 40°, slope 8°/min to 150°, slope 12°/min to 270°, 5 min at 270°	2 min at 40°, slope 8°/min to 150°, slope 15°/min to 300°, 5 min at 300°
Transfer line (auxalillers)	250°	220°	300°

Results

Test results for the masonry moisture

As a result of the tests concerning the humidity of partitions, the mass moisture content of individual elements was obtained. These values were related to data from literature in which the moisture levels were quantified from dry to damp states presented in Table 2.

Table 2. Permissible values for moisture in masonry [22]

Degree of moisture	Test results (%)	Degree of moisture in masonry
I stage	0-3%	walls with acceptable humidity
II stage	3-5%	walls with higher humidity
III stage	5-8%	walls with average moisture
IV stage	8-12%	heavily soggy
V stage	>12%	wet walls

Basement walls moisture

Table 3 presents data containing information about the level of moisture of the examined walls of the basement (room 1). Below the table there are placed the photographs (Fig 4a and b) showing the walls that were sampled.

Table 3. Summary of the test results of the dampness level in room 1walls

Point	Location	Test results (%)	Degree of moisture in masonry
1.1	Basement-east wall	11.97	IV stage-walls heavily soggy
1.2	Basement-north wall	19.86	V stage- wet walls
1.3	Basement-west wall	20.02	V stage-wet walls
1.4	Basement-east wall	19.37	V stage-wet walls
1.5	Basement-east wall	19.76	V stage-wet walls
1.6	Basement-north wall	20.01	V stage-wet walls

Examples of photographs of moistened masonries in the basement.

Fig. 5. Dampness and biological corrosion – moulds

Fig. 6. Visible dampness and loss of joints and bricks, crystallisation of building salts

In all cases examined, the degree of dampness was exceeded, with the basement walls showing the highest dampness. Such a high level of moisture, which persists for a long period of time, is the reason for significant corrosion of masonry materials - bricks and joints are heavily degraded. Locally, the damage does not concern only the surface of walls and plasters, but the degradation causes damage to deeper structures of bricks. In the parts of the masonry where the moisture is not so high, the corrosion related to building salts is visible. Both types of corrosion are accompanied by the development of microorganisms, moulds and algae.

Ground floor walls moisture

Table 4 presents data containing information about the level of moisture of the examined walls of the room 2. Figures 5 and 6 present the walls that were sampled.

Table 4. Summary of test results for the degree of dampness in the interior walls (room 2).

Point	Location	Measurement results (%)	Dampness of masonry
2.1	East wall	0,71	Stage I - walls with acceptable humidity
2.2	South wall	1,19	Stage I - walls with acceptable humidity

Basing on the moisture tests of the walls inside the building, the following observations were found: walls of the ground floor, in 2 measurement points walls with acceptable moisture content were found on the surface painted in the ground floor room on the eastern wall, visible biological corrosion - moulds, most probably the surface was previously covered with glue paint, which became an excellent medium for the development of microorganisms, and increased humidity in the room favours their development.

Results of microbiological analysis

A number of fungal species were found as a result of microbiological investigations. Their list is given in Table 5.

Table 5. Identified fungi species

Room 1	Room 2
Penicillium chrysogenum	*Mucor racemosus*
Mucor racemosus	*Aspergillus fumigatus*
Aspergillus fumigatus	*Aspergillus ochraceus*
Aspergillus flavus	*Alternaria alternata*
Aspergillus ochraceus	*Cladosporium sphaerospermum*
Aspergillus Niger	*Fusarium sporotrichioides*
Aspergillus ustus	*Penicillium chrysogenum*
Penicillium expansum	*Cladosporium cladosporioides*
Stachybotrys chartarum	
Alternaria alternata	
Cladosporium cladosporioides	
Cladosporium sphaerospermum	
Chaetomium globosum	
Fusarium sporotrichioides	
Cladosporium herbarum	
Alternaria alternata	

Fungal species were identified visually after comparison with reference samples.

As a result of the cascade impactor tests, it was possible to determine the number of fungal colonies at each impactor level along with the average number of colonies in each room tested. A summary of these data is shown in Table 6.

Table 6. Fungal colonies number at each cascade impactor level

Room 1		Room 2	
Level 1	146	Level 1	3
Level 2	174	Level 2	11
Level 3	uncountable	Level 3	10
Level 4	53	Level 4	45
Level 5	196	Level 5	19
Level 6	23	Level 6	16
Average	118,4	Average	17,3
CFU	470	CFU	550

According to the standard PN-EN 13098:2007 the acceptable number of CFU in the rooms should be less than 500cfu/m^3. It is not possible to calculate the total number of fungal colonies in each room, because at level 2 of the cascade impactor in room 1 the number of colonies is uncountable. In addition, an average of each room is needed to calculate the CFU.

Results of chemical analysis

The most common compounds found using chemical method in the basement and ground floor were listed in Table 7. Compounds were recognized by the TIC (total ion current) method as well as by the characteristic ion detection method.

Table 7. List of chemical compounds in building detected using SPME technique

Basement		Ground floor	
Retention time	**Compound**	**Retention time**	**Compound**
2.93	Benzene	2.93	Benzene
4.45	Toluene	4.46	Toluene
6.35	Ethylbenzene	6.3	Ethylbenzene
6.52	m-p-xylene	6.5	m-p-xylene
7	o-xylene	6.99	o-xylene
7.19	2-metylocyklopentanon	4.04	1-ethyl-5-methyl-cyclopentene
8.02	1-butoxy-2-propanol	5.07	Hexanal
9.88	2-octene	5.4	n-butyl acetate
9.93	Cineol	7.73	Sabinene
9.9	Limonene	7.89	α-pinene
9.92	Eucalyptol	8.81	3-carene
6.97	Styrene	8.86	Phenol
7.89	Methoxymethyl-benzene	8.96	6-methyl-5-heptan-2-one
9.07	Pinene (beta)	9.05	5.5-dimetylo-2-heksan
9.5	delta-carene	9.5	Carene (isomer)
9.79	p-cymene	9.55	1.4-dichlorobenzene
10.03	1-3butynyl-1.3cyclopentadiene	9.78	p-cymene
10.71	Dihydro myrcenol	9.9	Limonene
11.12	3-buthyl-2.5-dibuthyl pyrazine	10.48	Terpinene (isomer)
11.4	2.3-dimethyl 1-pentanol	10.7	Menthane-8-ol (isomer)
12.63	Acetic acid benzyl ester	11.09	p-mentha-1.4-diene
12.8	Linalyl acetate (lavender oil)	11.27	Linalol (isomer)
13.09	Camphene	11.35	Nonene-1-ol
13.14	p-menthane-3-on	11.56	Benzene-ethanol
13.29	10-undecanol	12.99	Naphthalene
13.45	p-menthane-1.2-diol	12.53	Acetic acid phenyl methyl ester
13.6	2-fenoksy-etanol	12.74	l-menthol (isomer)
13.69	Menthyl-acetate	12.86	1.2.4-trivinyl-cyclohexane
13.81	Carvacrol	13.1	2.6-dimethylphenol
14.19	delta-3-carene (isomer)	13.3	3-decen-1-ol

Discussions

Examined rooms in the basement were characterised by the increased moisture of the masonries. Visual observations of the brickworks indicating states of the increased humidity were confirmed by the laboratory measurements. In all cases it exceeded the value of 12%mass moisture which classified all of them as V stage-wet walls. The height of the influence of the dampness reaches 1.0m of the wall height. The damage concerns both external and internal walls, which proves the lack of vertical and horizontal insulation. Water penetrating the wall structure is most probably of ground (and most probably of river origin with content of aggressive corrosive compounds) and atmospheric origin. The building does not have an effective and unobstructed rainwater drainage (gutters and downpipes, band drainage), and the band around the building (made in the last period of use) is shaped in a way which does not

enable draining water "from" the building to the outside. Rainwater directly penetrates the basement walls and the ground floor. The influence of dampness is also visible on the walls of the ground floor. Crumbling plaster and peeling paint indicate the negative influence of moisture on the structure. The structure of basement walls locally shows crumbling of materials (bricks and mortar) and development of biological corrosion.

On the other hand in the ground floor rooms (group 2), the walls had an acceptable level I of humidity (below 2%mass). Despite low moisture values determined in laboratory microbial presence was visible on the walls surface in the form of efflorescence and destruction of the wall surface. Additionally it ought to be mentioned that, numerous thermal bridges in the building caused localised condensation of moisture from the air on the surface and in the pores of the walls. Material from these points was not sampled for laboratory investigations. The freezing of the walls in winter was compounded by the lack of heating in the last few seasons.

From the chemical point of view it was difficult to identify that chemical compounds specific to the fungi present. On a laboratory scale it is possible to determine compounds characteristic of individual species. In the studied object, none of the strains was dominant; moreover, the metabolic products of microorganisms depend to some extent on the material on which they develop [22]. A large number of organic compounds were found in Room 1. Among these are compounds that may be associated with microbial contamination, including: hydrocarbons and aromatic hydrocarbons, alcohols, ketones, terpenes [23-26]. It can be listed: 1-butoxy-2-propanol, dihydromyrcenol, 2,3-dimethyl-1-pentanol, 10-undecanol, p-menthane-1,2-diol, 2-phenoxyethanol (alcohols), benzene, toluene, ethylbenzene, m-p-xylene, o-xylene, 2-acetene, styrene, methoxymethyl-benzene (aromatic hydrocarbons), pinene, delta-carene, camphene, delta-3-carene (bicyclic monoterpenes), acetic acid (carboxylic acids), 2-methylcyclopentanone, p-menhtan-3-one (ketones), linalyl acetate, menthyl-acetate (esters), limonene (terpenes), cineol, eucalyptol (cyclic ethers), as well as other organic compounds: P-cymene, 3-buthyl-2,5-dibuthylopyrazine, carvacrol, 1-3 butynyl-1,3-cyclopentadiene. The ground floor premises also showed the presence of a number of compounds (Tab.8), not normally found in rooms with acceptable air quality and not affected by fungal infestation.

The biological examination confirmed the visual assessment of the investigated premises, where biological corrosion was found in the basement. The development of microorganisms was favoured by the damp conditions of the walls, in most cases with a V degree of dampness. Moreover, the lack of ventilation caused accumulation of spores and mVOC (microbial volatile organic compounds) in the indoor air. Comparing the biodiversity of rooms 1 and 2 it must be noticed that in room 1, with higher moisture of the walls more fungi species were found. All species of fungi found in the room on the ground floor (room 2) were also present in the basement (room 1). In the basement, fungi of the *Aspergillus* family are additionally present (*Aspergillus flavus*, *Aspergillus Niger*, *Aspergillus ustus*) as well as *Penicillium expansum*, *Stachybotrys chartarum*, *Chaetomium globosum*, *Cladosporium herbarum*, *Alternaria alternata*. The amount of fungi present in indoor was evaluated using cascade method. In both examined rooms the number of CFU was about 500cfu/m^3 which is the boundary value for this factor. In the basement it was 470 and in the ground floor 550, which means that both rooms are microbiologically loaded, but the level of infestation was lower that visual and hygric evaluation implied. In accordance with PN-EN 13098:2007 standard, the permissible number of CFU in tested rooms should be smaller than 500cfu/m^3.

Sawoszczuk et al. [27] presented a similar research on the product of metabolism of some fungi, where species also occurring in the basement of the studied building were discussed, such as *Alternaria alternata* (on silk), *Aspergillus niger* (on parchment),

Chaetomium globosum (on paper), *Chaetomium globosum* (on wool), *Cladosporium herbarum* (on paper). However, only some compounds occurred in the present study such as, 2-acetene, styrene, limonene, benzene, toluene, ethylbenzene. During the study period, the temperature in the building was low, which was not conducive to spores at that time.

Conclusions

Based on the conducted investigation of the XIX-XX century building raised in the area of the increased moisture influence without suitable water against layers the following conclusions can be drawn:

• The lack of vertical and horizontal water insulation as well as the ineffective rainwater drainage system caused the basement walls to become completely damp (about 20%$_{mass}$). At the basement level, the beginnings of material structure deterioration and signs of biological corrosion were identified.

• Despite the odour and efflorescence on the walls, the number of fungal colonies was increased. Calculated number of fungal colonies equalled from 470 to 550cfu/m^3 depending on the room and oscillated around the limit value limited by Polish standards.

• High moisture of the masonry favours the biodiversity; however, even with acceptable masonry moisture and a slightly higher room temperature, the number of fungal colonies was higher.

• Due to the season in which the tests were conducted, the number of fungal colonies may have been lower due to a limited fungal development during winter period and low indoor air temperatures.

• As a result of chromatographic tests, compounds belonging to the mVOC group were detected, most of which are secreted by indoor airborne fungi.

• The problem of mould infestation is common in all historical buildings which were raised without providing a suitable protection against water damage.

References

[1] M. Pierpaoli, M.L. Ruello, *Indoor air quality: A bibliometric study*, **Sustainability, 10,** 2018, Article Number: 3830, doi:10.3390/su10113830.

[2] M. Garbacz, A. Malec, S. Duda-Saternus, Z. Suchorab, Ł. Guz, G. Łagód, *Methods for Early Detection of Microbiological Infestation of Buildings Based on Gas Sensor Technologies*, **Chemosensors, 8**(1), 2020, Article Number: 7, doi.org/10.3390/chemosensors8010007.

[3] S. Siddiquee, S. Al Azad, F.A. Bakar, L. Naher, S.V. Kumar, *Separation and identification of hydrocarbons and other volatile compounds from cultures of Aspergillus niger by GC–MS using two different capillary columns and solvents.* **Journal of Saudi Chemical Society, 19,** 2015, pp. 243–256, doi:10.1016/j.jscs.2012.02.007.

[4] S.U. Morath, R. Hung, J.W. Bennett, *Fungal volatile organic compounds: A review with emphasis on their biotechnological potential,* **Fungal Biology Review, 26**(2-3)**,** 2012, pp. 73–83, doi:10.1016/j.fbr.2012.07.001.

[5] B. Gutarowska, *Metabolic activity of moulds as a factor of building materials biodegradation,* **Polish Journal of Microbiology, 59**(2), 2010, pp. 119–124.

[6] B. Flannigan B, J.D. Miller, *Microbial Growth in Indoor Environments*, **Microorganisms in Home and Indoor Work Environments. Diversity, Health Impacts, Investigation**

and Control, (Editors: B. Flannigan, R.A. Samson and J.D. Miller), Taylor&Francis, London and New York, 2001, pp. 35–67.

[7] M. Piotrowska, Z. Zakowska, *Humidity as a parameter conditioning the development of factors responsible for the biological corrosion.* **Protecting Buildings Against Dampness and Biological Corrosion,** (Editor: J. Karys), Polish Association of Building Mycologists, Breslau, 2011, pp. 89–95.

[8] H. Viitanen, J. Vinha, K. Salminen, T. Ojanen, R. Peuhkuri, L. Paajanen, K. Lahdesmaki, *Moisture and bio-deterioration risk of building materials and structures*, **Journal of Building Physics, 33**(3), 2010, pp. 201–24, doi.org/10.1177/1744259109343511.

[9] T.C. Dakal, SS. Cameotra, *Microbially induced deterioration of architectural heritages: routes and mechanisms involved*, **Environmental Science Europe, 24**, 2012, pp. 36–48, https://enveurope.springeropen.com/articles/10.1186/2190-4715-24-36.

[10] B. Cwalina, *Biodeterioration of concrete*, **ACEE, 4**, 2008, pp. 133–140.

[11] A. Webster, E. May, *Bioremediation of weathered-building stone surfaces*, **Trends Biotechnology. 24**, 2006, pp. 255–260, doi.org/10.1016/j.tibtech.2006.04.005.

[12] J. Ważny, *Microorganisms developing in buildings*, **Protecting Buildings Against Biological Corrosion,** (Editors: J. Wazny, J. Karyś), Arkady, Warsaw, 2001, pp. 52– 90.

[13] R.A. Blanchette, *A review of microbial deterioration found in archaeological wood from different environments,* **International Biodeterioration and Biodegradation, 46**, 2000, pp. 189-204.

[14] V. Luca, O. Corbu, I. Sandu, I. Bucur, *Rimetea, an Example of a Traditional Village from Romania,* **International Journal of Conservation Science, 10**(4), 2019, pp. 689-700.

[15] T. Verdier, M. Coutand, A. Bertron, C. Roques, *A review of indoor microbial growth across building materials and sampling and analysis methods,* **Building and Environment, 80**, 2014, pp. 136–149, doi:10.1016/j.buildenv.2014.05.030.

[16] W. Żukiewicz-Sobczak, P. Sobczak, K. Imbor, E. Krasowska, J. Zwoliński, A. Horoch, A. Wojdyła, J. Piątek, *Fungal hazards in buildings and flats—Impact on the human organism*, **Medycyna Ogólna Nauki o Zdrowiu, 18**, 2012, pp. 141–146.

[17] X. Huo, Y. Sun, J. Hou, P. Wang, X. Kong, Q. Zhang, J. Sundell, *Sick building syndrome symptoms among young parents in Chinese homes*, **Building and Environment, 169**, 2019, Article Number: 106283, doi: 10.1016/j.buildenv.2019.106283.

[18] Z. Suchorab, M. Frąc, L. Guz, K. Oszust, G. Łagód, A. Gryta, et al., *A method for early detection and identification of fungal contamination of building materials using e-nose*, **PLoS ONE, 14**(4): 2019, Article Number: 0215179, doi.org/10.1371/journal.pone.0215179.

[19] * * *, *Cieplno-wilgotnościowe właściwości materiałów i wyrobów budowlanych. Określanie wilgotności przez suszenie w podwyższonej temperaturze*, **PN-EN ISO 12570**.

[20] B. Andersen, et al., *Pre-contamination of new gypsum wallboard with potentially harmful fungal species*, **Indoor Air, 27**(1), 2017, pp. 6–12, doi.wiley.com/10.1111/ina.12298.

[21] * * *, https://www.thermofisher.com [accessed on 09.02.2021].

[22] J. Adamowski, J. Hoła, Z. Matkowski, *Problemy remontowe zawilgoconych monumentalnych obiektów barokowych*, **Renowacje i Zabytki, 1**(13), 2005, pp. 130-138.

[23] K. Fiedler, E. Schütz, *Detection of microbial volatile organic compounds (MVOCs) produced by moulds on various materials*, **International Journal of Hygiene and Environmental Health, 204**(2–3), 2001, pp. 111–121, doi.org/10.1078/1438-4639-00094.

[24] M. Kuske, A.C. Romain, J. Nicolas, *Microbial volatile organic compounds as indicators of fungi. Can an electronic nose detect fungi in indoor environments?* **Building and**

Environment, 40(6), 2005, pp. 824–831, http://www.sciencedirect.com/science/article/pii/S0360132304002434.

[25] S. Garcia-Alcega, et al., *Fingerprinting outdoor air environment using microbial volatile organic compounds (MVOCs)* – A review. **TrAC - Trends in Analytical Chemistry**, **86**, 2017, pp. 75–83, doi.org/10.1016/j.trac.2016.10.010.

[26] I. Sandu, M. Orlenko, M. Dyomin, O. Ivashko, Y. Ivashko, C.G. Lazareanu, K. Paprzyca, I.G. Sandu, P. Sztabinska-Kalowska, *Scientific conservation of the outstanding theaters of the 19th century and their influence on the creation of modern art-space,* **International Journal of Conservation Science, 12**(2), 2021, pp. 361-390.

[27] T. Sawoszczuk, J. Syguła-Cholewińska, *Optimization of headspace solid phase microextraction for the analysis of microbial volatile organic compounds emitted by fungi: Application to historical objects.* J. & del Hoyo-Meléndez, J.M., **Journal of Chromatography A**, **1409**, 2015, pp. 30–45, doi.org/10.1016/j.chroma.2015.07.059..

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