Diversity of Indoor Wood Decaying Fungi in Poland

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Results of research on the diversity of wood-rot fungi found in buildings and outdoor wooden engineering structures in Poland are presented in this article. A total of 47 species and genera of wood-rot fungi from Basidiomycota (19 brown rot fungi, 28 white rot fungi) and 1 genus from Ascomycota (1 fungus that does not cause wood decay) were found in damaged buildings. The greatest number of wood-rot fungi was reported on outdoor wooden engineering structures (33 species), followed by unoccupied residential buildings (30 species). The lowest diversity was found in occupied residential buildings (20 species). A total of 34 species and genera of fungi were found in all examined structures, out of which 17 species caused brown rot, 16 caused white rot, and 1 did not cause wood decay.

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INTRODUCTION

Due to its high load-bearing capacity, insulation, and low carbon footprint, wood is an important material used in construction. However, if not properly preserved, it is subject to degradation by a variety of biotic components. Fungi are one of the main causes of degradation of wooden buildings (Schmidt 2007). House-rot fungi do not specialize exclusively in wood degradation of buildings. They are saprotrophic fungi inhabiting dead wood in forests or outdoors, and they colonize building materials in structures due to favorable conditions for their development (Lloyd and Singh 1994). These conditions usually occur due to flawed design, mistakes made during construction, or improper use. House-rot fungi attack wood in structures according to their temperature and moisture content preferences (Schmidt 2006). For example, fungi that decompose fallen trees and tree stumps are observed in damp and cool basements.

According to the classification presented by Blanchette (2000), taking into account the macroscopic appearance of wood biodegradation, three types of decomposition caused by fungi associated with these decompositions have been distinguished: white rot - caused by fungi that degrade cellulose, hemicelluloses and lignin; brown rot - caused by fungi that degrade cellulose, hemicelluloses and do not degrade lignin; and soft rot - caused by fungi that degrade cellulose and hemicelluloses but only at surface level.

In the Northern Hemisphere, the most commonly used wood for structural timber is derived from coniferous trees. Brown rot fungi causes the most economic damage to European and North American buildings (Schmidt and Huckfeldt 2011). Because of progressive decay, wood attacked by fungi loses its original properties. The mechanical strength of structural timber is reduced, resulting in major building failures or disasters.

The terms house-rot fungi and dry-rot fungi are used exclusively for wood-destroying fungi in buildings. Fungi destroying stored wood and structural timber outdoors constitute a separate group. Due to differences in the classification of fungi destroying structural timber indoors and outdoors dating back to the 1930s (Skupieński 1937), species destroying structural timber indoors, structural timber outdoors, and stored wood are all referred to as "house-rot fungi". The first classification of house-rot fungi in Poland was presented by Ważny (1951); this classification was modified several times (Ważny 1957; 1958; 1963; 1970; 1983). Its latest version (Table 1) was published in 2001 (Ważny 2001). Publications by other authors, which appeared in later years (Krajewski and Witomski 2012; Karyś 2014), did not introduce any changes to the Ważny (2001) classification. Thus, despite being published over 20 years ago, the last update of the classification of house-rot fungi by Ważny (2001) is still considered up to date and accurate in Poland. This classification includes the location of damage, developed on the basis of reliable field studies.

Only the most important species are discussed in national monographs on wood-destroying fungi indoors and outdoors. Thus, the list of house-rot fungi in domestic monographs is limited to 8 to 13 species. In contrast, 6 to 26 species of house-rot fungi are discussed in foreign monographs (Table 1). A higher number of species discussed in foreign monographs is connected, among other things, with more frequent use of hardwood in housing construction (Andres *et al.* 2019).

Table 1. House-rot Fungi from Basidiomycota Discussed in Poland Monographs (Andres *et al.* 2019)

The species	Skupieński (1937)	Orłoś (1950)	Ważny (1951)	Kochman (1951)	Orłoś (1952)	Ważny (1957)	Ważny (1958)	Ważny [(1963)	Ważny (1970)	Ważny (1983)	Kozarski (1992)	Grzywacz (1997)	Kozarski (1997)	Zyska (1999)	Ważny (2001)	Krajewski, Witomski (2012)	Karyś (2014)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19
Alutaceodontia alutacea (Fr.)	○																
Antrodia sinuosa (Fr.) P. Karst.	●										●	●	●			●	
Antrodia xantha (Fr.) Ryvarden				●	○												
Armillaria mellea (Vahl.) P. Kumm. *s.l.*	○																
Ceriporiopsis mucida *	●																
Coniophora arida (Fr.) P. Karst.					○												
Coniophora fusispora *					○												
Coniophora puteana *	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Cylindrobasidium laeve (Pers.)			●	○	○	●	●	●	●	●		●		●	●	●	●
Daedalea quercina (L.) Pers.	●	○				●	●		●	●	●	●	●	●	●	●	●
Donkioporia expansa (Desm.) *			○														
Fibroporia vaillantii (DC.) Parmasto	●	●	●	●	●	●	●	●	●	●				●	●		●
Fomitopsis pinicola (Sw.) P. Karst.											●		●				
Gloeophyllum abietinum *	●																
Gloeophyllum sepiarium *	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19
Gloeophyllum trabeum (Pers.) Murrill											●	●	●				
Laetiporus sulphureus (Bull.) Murrill											○						
Leucogyrophana pinastri *	○	○	○														
Meruliporia incrassata *					○												
Neoantrodia serialis (Fr.) Audet						●		●	●	●		●		●	●	●	●
Neolentinus lepideus *	●	●	●		○	●	●	●	●	●	●	●	●	●	●	●	●
Phlebia serialis (Fr.) Donk			●			●											
Phlebiopsis gigantea (Fr.) Jülich			●	○	○	●	●	●	●	●	●	●		●	●	●	●
Serpula himantioides (Fr.) P. Karst.		○															
Serpula lacrymans (Wulfen) J. Schröt	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Serpula tignicola (Harmsen) M.P.	○	○	○														
Tapinella panuoides (Fr.) E.-J. Gilbert	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●
Trametes versicolor (L.) Lloyd	●					●	●		●	●	●	●		●	●	●	●
Trechispora nivea (Pers.) K.H. Larss.	○																

(● - species described (macro- and microstructures) in the publication, ○ – species mentioned in the publication); * *Ceriporiopsis mucida* (Pers.) Gilb. & Ryvarden, *Coniophora fusispora* (Cooke & Ellis) oke, *Coniophora puteana* (Schumach.) P. Karst, *Donkioporia expansa* (Desm.) Kotl. & Pouzar, *Gloeophyllum abietinum* (Bull.) P. Karst, *Gloeophyllum sepiarium* (Wulfen) P. Karst, *Leucogyrophana pinastri* (Fr.) Ginns & Werebus, *Meruliporia incrassata* (Berk. & M.A. Curtis) Murrill, *Neolentinus lepideus* (Fr.) Redhead & Ginns

However, the diversity of indoor wood-decaying fungi is much higher, as evidenced by numerous articles presenting the results of field studies carried out in Europe. Alfredsen *et al.* (2005) presented a list of 31 species and genera of indoor decay fungi in southern Norway. Schmidt (2007) published a list of 74 species and genera of wood-infesting fungi in buildings in Germany. Fraiture (2008) reported a list of 101 species and genera of indoor wood-decay fungi in Belgium. Irbe *et al.* (2008) presented a list of 23 species of wood infesting fungi in historic buildings in Macedonia. Vampola (2008) published a list of 40 species of indoor wood-decay fungi in the Czech Republic. Schmidt and Huckfeldt (2011) reported a list of 117 species and genera of indoor wood-decay fungi in Germany. Irbe *et al.* (2012) presented a list of 46 species and genera of fungi destroying the exterior of wooden buildings in Latvia. Haas *et al.* (2019) reported a list of 40 species of fungi infesting wood in buildings in Styria (Austria).

Interesting results on the biodiversity of fungi found in buildings in France were presented by Slimen *et al.* (2020). The authors of the study, using multidisciplinary analytical tools, identified in the 18th century wooden building fungi causing brown and white rot, in particular *S. lacrymans* and *Coprinellus* aff. *radians* and numerous species of fungi belonging to the *Ascomycota*.

Gabriel and Švec (2017) analyzed data on the occurrence of wood-decaying fungi in the Albania, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Latvia, Norway, Poland and Romania. The most abundant fungi causing deep wood decay in buildings in the indicated countries, except Norway, were *S. lacrymans* and *C. puteana*. In Norway, however, *A. vaillanti* (currently *F. vaillantii*) was the dominant wood-decaying species.

Materials that are used in newly constructed and renovated buildings should improve the management of humidity and thermal comfort, which should reduce the incidence of indoor fungal growth and in particular that of white and brown rot agents. However, some conceptual and design solutions that do not consider the regional climate, the tendency to shorten the construction time to the bare minimum, and the use of old technologies (wet construction systems with high water requirements/consumption) encourage the development of indoor fungi. These characteristics of the modern construction industry, which increase the risk of fungal infestation, have prompted the authors of this publication to conduct a survey study on the diversity of indoor and outdoor wood-decay fungi. This work reviews the diversity of indoor wood-decay fungi in Poland and compares the results with other European studies.

EXPERIMENTAL

The study was conducted in late 2019 and early 2020 to review the list of house-rot fungi found during mycological and building inspections. Mycological and mycological-construction experts associated with the Polish Association of Building Mycologists (PABM) took part in the research. All members of this group had appropriate, certified specialist knowledge and skills in the field of building mycology. Mycological and mycological-construction experts PABM took part in the research, after obtaining informed consent from the PABM Main Board. Participation in the research process was voluntary. The applied research procedures were compliant with the principles of ethics contained in the Code of Ethics for Research Workers - Polish Academy of Sciences.

In order to efficiently collect research results from PABM experts, a data entry form was created and made available to experts online. The data entry form consisted of 21 species of fungi selected based on current publications discussing the occurrence of house-rot fungi in Europe. The species were selected based on the frequency of their occurrence in Central-Western European buildings and based on observations made during mycological and building surveys in Poland. Before providing data on the frequency and location of the fungus species, the experts could read a note containing the technical name, a synonym of the current Latin name, and a brief description of morphological structures of the fungus (macro- and microscopic). When filling out the form about the frequency of occurrence, the experts had to choose one of the following options: very often (more than 50% of observations), often (up to 50% of observations), rarely (up to 25% of observations), occasionally (up to 5% of observations), or not found. Additionally, there was an open question in which the respondent experts could provide names of observed fungal species that were not included in the form.

After determining the frequency of occurrence of a given species, the expert could indicate the type of structure in which they found morphological structures of the fungus. When answering this question, one or more answers could be chosen from: occupied residential buildings (RB), unoccupied residential buildings (URB), other buildings: sheds, wood shelters, *etc*. (OB), structural timber outdoors (STO) and other locations: mines, abandoned churches, railroad ties, *etc*. (OL).

The following was stated in a description, which immediately preceded the data entry form: Sending back the completed form is tantamount to the respondent expert being in possession of appropriate photographic documentation and/or desiccated fungi samples of the observed fungal species.

The experts taking part in the study were tasked with providing percentage values for the frequency of occurrence of given fungal species in controlled structures. The data for filling in the form by the experts came from mycological research they conducted during their inspections of fungus-damaged buildings.

The frequency of occurrence of given fungal species, presented in Table 2 (column 3) and Table 3 (column 8), was determined according to Eq. 1,

$$f = \frac{(\overline{x_{<5\%}}+\overline{x_{5-24,9\%}}+\overline{x_{25-49,9\%}}+\overline{x_{\geq 50\%)}})}{\sum_1^n(\overline{x_{<5\%}}+\overline{x_{5-24,9\%}}+\overline{x_{25-49,9\%}}+\overline{x_{\geq 50\%)}})} \quad (1)$$

where f is the frequency of occurrence of given fungal species, $\overline{x_{<5\%}} \dots \overline{x_{\geq 50\%)}}$ is the weighted arithmetic mean based on values indicated by experts, and n is the number of observed fungal species and genera (n = 48). The frequency of occurrence of fungal species in given object categories was determined in a similar fashion (Table 2, columns 4 through 8).

Statistical error was calculated using the statistical calculator provided on the NETSTEL Software website (naukowiec.org) assuming a confidence level of α = 0.95 and a fraction size of 0.5 (in the absence of information on the distribution of the statistical characteristic in the studied population).

The names of fungi are provided according to systematics updated on a regular basis in the Index Fungorum database (2022).

RESULTS AND DISCUSSION

Based on the results of an internet query, the number of PABM experts actively performing expert reports in 2019 was determined to be 100. For the assumed confidence interval (α = 0.95), it was calculated that collecting 81 questionnaires research forms from mycological and mycological-construction experts would guarantee a study statistical error of 5%. The study involved 73 experts, so the statistical error was 6%. All questionnaires were filled out correctly, *i.e.*, there were no logical errors. The results of the questionnaire are presented in Table 2. The table shows the total frequency of fungal occurrence in the inspected objects divided into object categories, in which fungal morphological structures were detected. The fungi were sorted in descending order based on the total frequency of occurrence in buildings.

The study conducted focused on large Basidiomycota fungi (macromycetes), i.e. with fruiting bodies larger than 5 mm. Therefore, a number of micromycetes (*e.g.* from Ascomycota) found in the fungus infested buildings were not presented in the results of the study.

The experts provided a total of 48 types of fungi (43 species and 5 fungi recognized to genus): 47 species and genera of wood-degrading Basidiomycota (including 41.7% brown rot fungi and 58.3% white rot fungi) and 1 genus from Ascomycota (Table 2). The highest species diversity of wood-rot fungi was found on outdoor structures (STO) - 33 species. The second location in terms of diversity was unoccupied residential buildings (URB) - 30 species. The lowest diversity was found in occupied residential buildings (RB) - 21 species.

Table 2. Total Frequency of Fungal Occurrence in Control Sites and Locations of Fungal Morphological Structures

Genera and Species Name	Rot	Frequency (%)	Locations (%)				
			RB	URB	OB	STO	OL
1	2	3	4	5	6	7	8
Serpula lacrymans (Wulfen) J. Schröt	B	24.8	8.0	8.66	5.75	0.0	2.33
Coniophora puteana (Schumach.) P. Karst.	B	14.1	2.2	4.44	2.98	2.23	2.23
Fibroporia vaillantii (DC.) Parmasto	B	13.8	4.1	4.14	3.80	1.73	0.0
Phlebiopsis gigantea (Fr.) Jülich	W	7.8	0.9	1.71	2.43	1.71	0.98
Antrodia sinuosa (Fr.) P. Karst.	B	6.4	1.5	2.07	1.38	0.86	0.52
Serpula himantioides (Fr.) P. Karst.	B	5.3	0.8	1.67	1.12	0.84	0.83
Gloeophyllum sepiarium (Wulfen) P. Karst.	B	4.4	0.5	0.55	0.83	1.92	0.55
Neoantrodia serialis (Fr.) Audet	B	4.2	0.5	1.01	1.01	1.16	0.43
Tapinella panuoides (Fr.) E.-J. Gilbert	B	3.6	0.6	1.09	0.76	0.66	0.44
Cylindrobasidium laeve (Pers.) Chamuris	W	3.3	0.7	0.85	0.85	0.43	0.43
Gloeophyllum trabeum (Pers.) Murrill	B	2.1	0.2	0.40	0.50	0.70	0.30
Gloeophyllum abietinum (Bull.) P. Karst.	B	1.9	0.3	0.36	0.36	0.48	0.36
Antrodia xantha (Fr.) Ryvarden	B	1.6	0.3	0.53	0.27	0.27	0.18
Neolentinus lepideus (Fr.) Redhead & Ginns	B	1.3	0.1	0.15	0.25	0.55	0.20
Asterostroma cervicolor (Berk. & M.A. Curtis)	W	0.7	-	x	-	-	-
Daedalea quercina (L.) Pers.	B	0.6	0.0	0.12	0.06	0.24	0.15
Schizophyllum commune Fr.	W	0.6	0.0	0.00	0.00	0.30	0.25
Leucogyrophana pinastri (Fr.) Ginns & Weresub	B	0.4	0.1	0.10	0.10	0.10	0.00
Coprinus spp.	W	0.4	x	x	x	-	-
Peziza spp. (division: *Ascomycota*)	-	0.3	-	x	-	-	-
Rhodonia placenta *	B	0.3	0.0	0.11	0.11	0.06	0.06
Trametes versicolor (L.) Lloyd	W	0.3	0.0	0.00	0.03	0.25	0.12
Laetiporus sulphureus (Bull.) Murrill	W	0.2	-	-	x	-	-
Armillaria mellea (Vahl.) P. Kumm. *s.l.*	W	0.1	-	-	x	-	-
Chondrostereum purpureum (Pers.) Pouzar	W	0.1	-	x	-	x	-
Coniophora arida (Fr.) P. Karst.	B	0.1	-	-	-	-	x
Donkioporia expansa (Desm.) Kotl. & Pouz	W	0.1	0.0	0.05	0.00	0.00	0.02
Hyphodontia ssp.	W	0.1	-	x	-	x	-
Hypholoma fasciculare (Huds.) P. Kumm.	W	0.1	-	-	-	x	-
Fuscoporia contigua (Pers.) G. Cunn.	W	0.1	-	x	-	-	-
Fomitopsis pinicola (Sw.) P. Karst.	B	0.1	-	x	-	-	-
Mycena galericulata (Scop.) Gray	W	0.1	-	-	-	x	-
Pholiota spp.	W	0.1	-	-	-	x	-
Pleurotus spp.	W	0.1	-	x	-	-	-
Pluteus spp.	W	0.1	-	-	-	x	-
Stereum hirsutum (Willd.) Pers.	W	0.1	0.0	0.00	0.00	0.05	0.05
Trechispora farinacea (Pers.) Liberta	W	0.1	-	x	-	-	-
Trichaptum fuscoviolaceum (Ehrenb.) Ryvarden	W	<0.1	-	x	-	-	x
Daedaleopsis confragosa (Bolton) J. Schröt.	W	<0.1	-	-	-	x	-
Heterobasidion annosum (Fr.) Bref *s.l.*	W	<0.1	-	-	-	-	x
Pseudomerulius aureus (Fr.) Jülich	B	<0.1	-	-	-	x	-
Pycnoporus cinnabarinus (Jacq.) P. Karst.	W	<0.1	-	-	-	x	-
Rhodofomes roseus (Alb. & Schwein.) Kotlaba &	B	<0.1	-	x	-	-	-
Stereum rugosum Pers.	W	<0.1	-	-	-	x	-
Trametes gibbosa (Pers.) Fr.	W	<0.1	-	-	-	x	-

1	2	3	4	5	6	7	8
Trametes ochracea (Pers.) Gilb. & Ryvarden	W	<0.1	-	-	-	x	-
Trametes trogii Berk.	W	<0.1	-	-	-	x	-
Volvariella bombycina (Schaeff.) Singer	W	<0.1	-	x	-	x	-

B - brown rot, W - white rot; RB - residential buildings used, URB – unused residential buildings, OB – other buildings, non-residential building (shed, wood shelter, *etc.*), STO – structural timber outdoors, OL – other locations (mines, unused churches, railroad sleepers, *etc.*), x - occurrence species entered by experts (fungi outside the list of 21 species included in the questionnaire) for which it was not possible to determine the percentage occurrence in each category based on the research results.
* *Rhodonia placenta* (Fr.) Niemelä, K.H. Larss. & Schigel*, *Rhodofomes roseus* (Alb. & Schwein.) Kotlaba & Pouzar

Thirty-four species and genera of fungi were found in buildings (RB, URB, and OB), including 33 wood-rot fungi (51.5% brown rot fungi and 48.5% white rot fungi). A total of 87.3% of fungal species and genera observed in buildings were brown rot fungi, 12.3% were white rot fungi, and 0.4% did not cause wood decay (concerns *Peziza sp*. fungi, which are not classified as wood destroying fungi).

Table 2 (columns 4 through 8) can be used to track which buildings were most frequently infested by given fungal species. In the case of species entered by experts (fungi outside the list of 21 species included in the questionnaire), Table 2 does not show their percentage occurrence in each category but only indicates these categories by "x". The other locations category (OL), which was filled out by experts, proved to be the most diverse. Experts indicated following locations: structures on forested land, mines, lumber yard stores, railroad sleepers, and others.

The results of field investigations published in the form of articles generally present a much broader spectrum of wood-rot fungi in buildings than it is described in monographs. There are relatively few national publications (articles) on the species diversity of house-rot fungi because for over 40 years, no data on the occurrence of wood-decaying fungi in buildings were published in Poland. Few publications refer to selected areas of Poland (Ważny and Czajnik 1973; 1974a; 1974b; Konarski 1974) or focus on a specific category of objects (Ważny and Czajnik 1963a; Ważny *et al.* 1999; Andres 2011). Only the publication by Ważny and Czajnik (1963b) provides data for the entire country on wood rot fungi in buildings (Table 3). In the publication from the 1960s (Ważny and Czajnik 1963b), a list of 26 species was provided (including 61.5% brown rot fungi and 38.5% white rot fungi), whereas the experts taking part in the study provided a total of 33 wood rot fungi. In addition to the increase in diversity, it can be concluded that the proportions of species causing brown rot and white rot of wood have slightly changed. In the 1960s, the total frequency of observations of brown rot fungi in buildings was 95.4%. In this study, the total number of observations of brown rot fungi was 86.7%. The obtained results could have been significantly influenced by the revitalization programs implemented in the country after 2004 (after Poland's accession to the European Union) and since 2015 widely implemented under the Municipal Revitalization Programs (Ministry of Development Funds and Regional Policy). These programs are aimed at, inter alia, counteracting the degradation of the urban structure of cities and striving for reconstruction of cities' historical identities. As part of integrated revitalization projects, the following are renovated: historical market squares, tenement blocks, and 19th century postindustrial complexes (according to nomenclature adopted in this publication: RB, URB and OB). The observations of the authors of this article confirm that buildings intended for revitalization are often heavily damaged, and due to the high moisture inside of them, favorable conditions for the development of white rot fungi occur.

It should be noted, however, that despite the indicated noticeable differences between the results from the 1960s and the current state of fungal infestation in buildings in Poland, both studies had different methodologies for obtaining data.

Table 3. Abundance of (%) Wood-Decaying Fungi in Buildings

Genera and Species Name	PL[a]	DE[b]	DE[c]	BE[d]	NO[e]	AU[f]	PL[g]
1	2	3	4	5	6	7	8
Antrodia spp.	-	3.6	9.4	0.7	18.4	8.2	-
Antrodia sinuosa (Fr.) P. Karst.	9.4	1.6	1.0	-	-	0.2	6.4
Antrodia xantha (Fr.) Ryvarden	0.5	1.5	2.0	0.4	-	1.1	1.6
Antrodia gossypium (Speg.) Ryvarden	0.2	0.1	<0.1	<0.1	-	-	-
Armillaria mellea (Vahl.) P. Kumm. *s.l.*	0.1	-	-	-	-	-	0.1
Asterostroma spp.	-	-	-	4.6	-	-	-
Asterostroma cervicolor (Berk. & M.A. Curtis) Massee	-	2.4	2.4	0.4	0.2	-	0.7
Asterostroma laxum Bres.	-	0.1	0.2	-	-	-	-
Coniophora spp.	-	-	-	7.8	-	1.4	-
Coniophora arida (Fr.) P. Karst.	-	0.3	0.2	0.4	-	-	0.2
Coniophora puteana (Schumach.) P. Karst.	22.	14.6	15.5	0.7	16.3	2.5	14.1
Coprinus spp.	-	3.1	3.5	0.7	0.1	0.4	0.4
Coriolopsis trogii (Berk.) Domański	-	-	-	-	-		0.1
Cylindrobasidium laeve (Pers.) Chamuris	1.6	0.3	0.2	-	0.1	0.2	3.3
Daedalea quercina (L.) Pers.	0.1	-	-	-	-	-	0.6
Daedaleopsis confragosa (Bolton) J. Schröt.	-	-	-	-	-	-	0.1
Donkioporia expansa (Desm.) Kotlaba & Pouzar	0.1	10.0	8.8	15.5	-	1.1	0.1
Fibroporia vaillantii (DC.) Parmasto	1.9	3.1	1.4	-	-	0.8	13.8
Fomitopsis pinicola (Sw.) P. Karst.	0.1	0.1	-	-	<0.1	0.2	0.1
Fuscoporia contigua (Pers.) G. Cunn.	-	1.1	0.9	2.8	-		0.1
Gloeophyllum spp.	-	2.0	0.8	-	-	3.3	-
Gloeophyllum abietinum (Bull.) P. Karst.	-	1.5	1.6	-	-	1.2	1.9
Gloeophyllum sepiarium (Wulfen) P. Karst.	1.6	1.6	1.0	-	2.9	2.8	4.4
Gloeophyllum trabeum (Pers.) Murrill	-	0.7	1.0	0.4	-	0.9	2.1
Heterobasidion annosum (Fr.) Bref *s.l.*	0.1	0.1	0.1	-	-	-	<0.1
Hypholoma fasciculare (Huds.) P. Kumm.	-	-	-	-	-	-	0.1
Hyphodontia ssp.	-	-	-	<0,1	-	0.2	0.1
Hyphodontia microspora J. Erikss. & Hjortstam	-	0.1	<0.1	-	-	-	-
Laetiporus sulphureus (Bull.) Murrill	0.1	-	-	-	-	-	0.2
Leucogyrophana spp.	-	0.3	0.4	0.4	0.2	-	-
Leucogyrophana mollusca (Fr.) Pouzar	-	0.4	0.1	-	2.0	0.2	-
Leucogyrophana pinastri (Fr.) Ginns & Weresub	0.4	1.1	2.3	-	<0.1	0.6	0.4
Mycena galericulata (Scop.) Gray	-	-	-	-	-		0.1
Neoantrodia serialis (Fr.) Audet	1.1	0.3	0.2	-	-	0.5	4.2
Neolentinus lepideus (Fr.) Redhead & Ginns	1.5	0.5	0.5	-	0.1	0.3	1.3
Perenniporia medulla-panis (Jacq.) Donk	0.3	-	-	<0.1	-	-	-
Phlebia serialis (Fr.) Donk	0.2	-	-	-	-	-	-
Peziza spp. (division: *Ascomycota*)	-	-	-	6.0	-	0.3	0.3
Phlebiopsis gigantea (Fr.) Jülich	1.5	-	0.1	-	0.1	-	7.8
Pleurotus sp.	-	0.3	0.2	0.4	-	-	0.1
Porodaedalea pini	0.2	-	-	-	-	-	-
Rhodofomes roseus (Alb. & Schw.) Kotl. & Pouzar	0.1	-	0.3	0.3	0.1	-	<0.1
Rhodonia placenta (Fr.) Niemelä, K.H. Larss. & Schigel	-	1.7	0.6	-	0.1	0.5	0.3

1	2	3	4	5	6	7	8
Schizophyllum commune Fr.	0.3	0.1	-	0.4	-		0.6
Serpula himantioides (Fr.) P. Karst.	1.0	2.0	2.6	-	0.5	0.3	5.3
Serpula lacrymans (Wulfen) J. Schröt	52.	25.3	24.0	41.9	16.0	61.	24.8
Stereum hirsutum (Willd.) Pers.	-	-	-	-	-	0.2	0.1
Stereum rugosum Pers.	-	0.1	-	-	-		<0.1
Tapinella panuoides (Fr.) E.-J. Gilbert	2.7	2.9	2.6	0.7	0.8	0.3	3.6
Trametes hirsuta (Wulfen) Pilát	-	0.3	0.2	-	-	0.2	-
Trametes ochracea (Pers.) Gilb. & Ryvarden	-	0.1	-	-	-	-	<0.1
Trametes versicolor (L.) Lloyd	0.1	0.1	0.1	0.4	-	-	0.3
Trechispora spp.	-	1.2	1.4	0.45	-	0.2	-
Trechispora farinacea (Pers.) Liberta	-	1.1	0.4	0.7	-	0.3	0.1
Trechispora invisitata (H.J. Jacks.) Liberta	-	0.1	<0.1	<0.1	-	-	-
Trechispora mollusca (Pers.) Liberta	-	0.4	0.2	<0.1	-	-	-
Volvariella bombycina (Schaeff.) Singer	-	0.1	<0.1	0,2	-	-	<0.1

[a] Ważny and Czajnik (1963b), [b] Schmidt 2007, [c] Schmidt and Huckfeldt, 2011, [d] Fraiture 2008, [e] Alfredsen *et al.* 2005, [f] Haas *et al.* 2019, [g] research 2019-2020.

It should be noted that the conducted research did not aspire to determine the current state of fungal growth in buildings in Poland but to determine any changes in the species composition of fungi currently degrading wood in buildings. The method of data collection, different than in the studies by Ważny and Czarnik (1963b), may have an impact on the obtained results; however, the trend of changes in the diversity of wood-destroying fungi in buildings is clear. The authors realize that the presented research results only approximate the number of species and the frequency of their occurrence in buildings, as not all fungi infested buildings in Poland are submitted for inspection by PABM experts.

The results of the research generally correspond to the outcome of studies on indoor fungi conducted in Europe after 2000. Studies conducted in Germany have shown a high diversity of indoor wood-decaying fungi. Schmidt (2007) reported a list of 74 species and genera of fungi (including 40.5% brown rot and 59.5% white rot fungi), and Schmidt and Huckfeldt (2011) published a list of 117 species and genera of fungi (including 38.9% brown rot and 61.1% white rot fungi) responsible for wood decay in buildings. In the publication of Schmidt and Huckfeldt (2011), the total number of observations of brown rot fungi (2011) in buildings was 57.9%, and white rot fungi was 8.4%. Buildings in Germany were most frequently infested by *S. lacrymans* and *C. puteana*. The analogous frequency of both species was shown by the questionnaire conducted by the authors of this study. The third most frequent fungus infesting wood in buildings in Germany was *D. expansa*, which is occasionally recorded in Poland. In Germany, *F. vaillantii*, *A. sinuosa* and *N. serialis* were present at much lower levels than in buildings in Poland.

In a publication on wood-decaying fungi in buildings in the Czech Republic, Vampola (2008) presented a list of 40 selected species of fungi belonging to Basidiomycota (including 42.1% brown rot fungi and 57.9% white rot fungi). Unfortunately, the frequency of their occurrence in decayed buildings was not given in the paper. The diversity of indoor wood-decaying fungi in the Czech Republic is slightly lower than that in Poland.

An equally high diversity in infested buildings in Belgium was found by Fraiture (2008). The author listed 101 species and genera of fungi (including 36.8% brown rot fungi and 63.2% white rot fungi). Additionally, in Belgium, a low percentage of buildings were infected by fungi of the genus *Antrodia sp*., while the incidence of *S. lacrymans* was 41.9%. The total incidence of brown rot fungi in buildings was 73.5%, while the incidence of white rot fungi was 21.2%.

The study of Irbe *et al.* (2012) focused mainly on the deterioration of external wooden elements of buildings in Latvia. A total of 46 genera and species of Basidiomycota fungi were found on wooden buildings in the open-air museum (including 31.8% brown rot fungi and 68.2% white rot fungi). A total of 19 Basidiomycota genera and species were found on religious wooden buildings (including 26.3% brown rot fungi and 73.7% white rot fungi). The percentage share of particular fungal species was not given in the paper. The diversity of wood-decaying fungi in buildings in Latvia is slightly lower than that in Poland.

A study by Alfredsen *et al*. (2005), conducted in Norway, also in the temperate climate zone, but more northerly than Poland, showed a much lower diversity of house-rot fungi. The paper gives a list of 31 species and genera of Basidiomycota fungi (including 62.9% brown rot and 37.1% white rot fungi) infesting wood in buildings. The total number of observations of brown rot fungi in buildings was 87.3%, and that of white rot fungi was 12.7%. The most frequent Basidiomycota causing wood damage in Norwegian buildings were fungi of the genus *Antrodia* and species of *C. puteana* and *S. lacrymans*. It should be noted that in the publication discussed here, the fungi of the genus *Antrodia sp*. include *A. xantha*, *A. sinuosa*, *N. serialis* and *F. vaillantii* because according to the systematics of that time, these species belonged to one genus (*Antrodia*). In Poland, the number of species afflicting buildings was similar to the number specified in Norwegian data; however, the frequency of wood infestation in buildings by *S. lacrymans* and fungi of the genus *Antrodia* (according to systematics adopted in the article above) was higher than that in Norway, whereas the incidence of *C. puteana* in fungus-infested buildings was slightly lower.

Haas *et al.* (2019) reported 74 genera and 40 species of indoor wood-decaying fungi in the federal state of Styria (Austria). The total number of observations of indoor brown rot fungi was 88.0%, and white rot fungi accounted for 5.4%. A total of 6.4% of observations were described as “other genera” and thus could not be assigned to a specific type of wood rot. The highest amount of damage in buildings was caused by *Serpula spp*. The incidence of fungi of the genus *Antrodia spp*. The authors of the publication believe that the high percentage of infestation of buildings by *S. lacrymans* may have its genesis in the large destruction of buildings in this part of Austria during World War II. In Poland, the incidence of *S. lacrymans* in buildings is two times lower than in Styria, whereas the occurrence of the "polypores group" (*A. sinuosa*, *A. xantha*, *F. vaillantii and N. serialis*) is almost three times higher and the incidence of *D. expansa* in affected buildings in Poland is ten times lower.

Bucşa and Bucşa (2009) presented the frequency of occurrence of the main fungal species in historical buildings of Romania (castles, palaces, citadels, churches, *etc*.). The buildings were infected, among others, by *S. lacrymans* (32%) and *C. puteana* (60%), *A. vaillantii* (21%), and *D. expansa* (21%). The conducted research showed a lower percentage of occurrence of fungi in buildings than in Poland and lower diversity. It should be noted, however, that Romanian research concerns historical buildings, which does not necessarily correspond to the general fungal infestation of residential buildings.

Irbe *et al.* (2008), based on studies conducted in Macedonian cultural heritage sites (37 monasteries and churches and one fortress) presented a list of 26 species of wood-decaying Basidiomycota fungi, of which 21 species (80.8%) caused white rot. The most common fungus found was *Lyomyces crustosus*, causing white rot. The total number of observations of white rot in buildings was 81.3%. *S. lacrymans* was not found during the inspection of historic buildings; moreover, this fungus was never found in Macedonia. Among the brown rot fungi, the most commonly occurring genus was *Antrodia spp*.

(6.2%). Comparing the results of the study to the results achieved by Irbe *et al.* (2008), it can be stated that indoor white rot fungi occur more frequently in southern European subtropical climates than in temperate climates.

Caution should be exercised when comparing studies conducted in different European countries on fungal diversity in buildings, as they used different testing procedures to determine the diversity and prevalence of fungi in buildings, as well as different categories of buildings analyzed.

CONCLUSIONS

1. Despite the changes in the method and technology of construction and renovation of buildings, the most important species most frequently found in fungus-infested buildings in Poland are brown-rot fungi: *S. lacrymans*, *C. puteana* and *F. vaillantii*. The fourth most common in buildings was the white-rot fungus *P. gigantea*.
2. Analyzing the occurrence of individual species, the occurrence of *S. lacrymans* and *C. puteana* has decreased twice, while the share of the "polypore group" in infested buildings has increased twofold.
3. From an economic point of view, the most important wood-decaying fungi in buildings in Poland are still the brown rot fungi of coniferous wood, although there is a noticeable increase in the diversity of white-rot fungi in buildings. The increase in the diversity of wood-decaying fungi in buildings is mainly due to the increase in white rot fungal species. Despite the increase in the number of white rot species in buildings, the frequency of their occurrence is not high. Consequently, they cause little economic loss in buildings in temperate climate zones.

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Data Availability Statement

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Research Procedures

All methods were carried out in accordance with relevant guidelines of the Code of Ethics for Research Employees - Polish Academy of Sciences.

Statement

Informed consent was obtained from all the study participants.

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