Microbiological control of library collections – a tool for preservation and disaster response

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Abstract:

The paper presents the subject of microbiological control applied for preservation and protection of the library collections. The microbiological control is presented as a complex of activities including: air quality and surface (of objects, equipment and rooms) control as well as supporting tool for conservators. It is considered as integrated and basic part of any conservation proceeding. Basic terms and definitions as well as their correct understanding are discussed: contamination, contamination level, background level, disinfection.

The microbiological control is a key for conservation treatments of objects (with special stress on interpretation of sampling results – classes of contamination are discussed) or surveys and actions providing appropriate storage conditions. The theory is supported with description of activities in the field of microbiological control in the National Library of Poland (procedures, regulations, workflow, organization).

On the other hand – services and orders executed by the National Library for clients has brought a vast experience in microbiological control of objects and whole collections particularly after floods or disasters as well as introducing recovery procedures that are also presented.

1. Introduction

Library and archival collections are objects of altering and destruction that can be caused by physical and chemical factors. The biological factors fit well in this division, since we can face either mechanical destruction (consumption by animals) or chemical one (enzymatic decomposition or corrosive influence of fungal/bacterial metabolic products).

The greatest potential danger for collections of paper objects is created by organisms commonly known as molds that are microscopic fungi. These ubiquitous organisms spread easily, their spores are very resistant to external factors (that is why they are so common) and they have highly advanced enzymatic system that makes them able to decompose cellulose.

On the other hand, it is extremely difficult to eliminate the infecting factor - spores of molds out of large collections of prints and manuscripts. With all substrata provided (cellulose as source of carbon and simple mineral salts that are very common in environment) the growth of molds depends on two factors only: relative air humidity and temperature [1]. (Assuming the objects are dry – water activity in them depends on air humidity and can reach the level allowing fungi to grow).

The microbiological control at the National Library of Poland has two basic directions:
– monitoring of the levels of microorganisms in the indoor air and on the surfaces of collections and equipment
– actions taken to reduce those levels to values considered as safe

In general the microbiological control is concentrated between two levels that are mentioned above. If the stated levels are lower than desired, no further actions are needed.

Few terms are basic for correct understanding of microbiological control:

microorganisms – microscopic fungi (molds), yeasts, bacteria. It is assumed in the National Library, that molds are most dangerous for the objects (because of the lower environmental requirements)[2]; therefore in any evaluation (also because of the work costs) the colonies of yeasts-like microorganisms and bacteria are only noted. Molds are usually identified as far as genus.

cfu – abbreviation for *colony forming unit* that is any microbiological particle (one cell or more) that will grow into a colony upon a microbiological medium after inoculation (bringing to that medium). *cfu* is used for creating units describing the levels of microbiological presence in the air - *cfu/m³* (*colony forming units per cubic meter of air*) and on the surface *cfu/dm²* (*colony forming units per square decimeter of surface*) It is assumed that one colony grows from one cfu.

contamination – (mostly misused and misunderstood) in general it describes the situation with microbiological presence above safe and desired levels, but the point is, that those levels may often be relative and evade the strict definition, especially with air quality. Since sterile (absolutely clean) spaces and surfaces are not natural in biosphere, there are levels of microbial presence that cannot be described as *contaminated*.

background or *background level* – in air quality control – levels of microbiological presence in the outdoor (atmospheric) air that depends on climate and season (hence the difficulties in defining when the microbial presence becomes the contamination).

sampling – the action of taking samples that bring desired information on examined objects or rooms. It also includes time required for growth as well as qualitative and quantitative analysis of microbiological material.

examination tactics – the procedure of evaluation of the microbiological presence that is built on scheme: characteristics of examined object or room – choice of the sampling method – sampling - analysis of the results – conclusions: condition statement (evaluation) – suggestions for further actions

2. Microbiological control of the indoor air

However the highly filtrated or sterilized air or modified atmosphere is possible to achieve, the costs of maintenance of sterile conditions will be enormous if the objects are accessed in a normal way. Only few, most precious objects can be preserved that way and the question of access is still open: either there is no direct contact with the objects or complicated actions are needed for sustaining sterility. Accepting of microbial presence in the air of storage, reading and conservation rooms leads to two directions of keeping the objects safe: monitoring and keeping this presence as low as possible and maintaining the constant and proper air temperature and relative humidity values[3]. The water activity of objects building medium/support is also important, but it is a consequence of storage conditions that are precisely defined for almost every kind of object.

Depending on the method of ventilation or air exchange, there could be different levels of co-relation between the indoor air and the background (atmospheric) air. A good example is the main storage building of the National Library in Poland. The microbial presence in the storage rooms does not depend directly on the background air – because of the air filtration system and (after last modifications) lack of the windows in the main storage rooms. The dependence is not direct – the users and readers bring the microbial material – during the control in 2008 the cfu/m^3 values in readers' area were decreasing from the level close to the background air as the distance from the readers' entrance was rising). Because of the sedimentation of microbial material from the air the objects return from reading rooms in worse microbiological condition than they were before accessing.

The general microbiological conditions of air and objects (surfaces) are correlated and tend to a balance. Along with the sedimentation of fungi particles on surfaces the microbiological presence in the air will change while normal handling of the objects causes emission from their surfaces and on the other hand surfaces – especially porous ones may work as a reservoir ("surface memory"effect) of *colony forming units* of species that are currently not present in the air (one of the observations from research conducted in 2010 during the project of moving the whole iconographic collection to the new storage rooms). See table 1. for details.

After many years of applying of the sedimentation method the National Library turned 2008 to the impact method of air control . The sedimentation method (simple, but time and work consuming, now obsolete) is based on free fall of particles suspended in the air into open Petri dishes with medium in a known period of time. After incubation the number of colonies is counted into the cfu/m^3 values. The impact method is based on mechanical aspiring of the pre-set volume of air, so the particles impact the microbiological medium on a Petri dish placed in a sampler. The sampler (about 3000 EUR) pays for itself (method is far more credible and therefore requires less Petri dishes than sedimentation) within 2 years by 1000 samples a year (about 40 rooms evaluated). Usually 2 to 30 samples on different height are taken per room (depending on the size of the room) – 30 samples in diagonal covers main storage building's floor of about $1000m^2$. The sedimentation method sampling in the same room requires over 100 dishes.)

Regular control (see pattern – table 2.) allows to foresee an expected level of microbial presence depending on the nature of storage room, objects preserved and access. For example: in Res Publica Palace expected average level in storage rooms (no mechanical air exchange, only windows) for old prints collections is between 60 and $150cfu/m^3$ and not exceeding the 80% of background level , while in main storage building (with mechanical ventilation, filtration and possibility of air temperature and relative humidity modification) the average levels are usually below 20 cfu/m^3 and rarely exceeding 60 cfu/m^3 in a single sample disregarding the background levels (see graph

1).

There is also o correlation between the type of activity in the evaluated area – see graphs 2. and 3. The Neschen C-900 deacidification process creates high values without sources of microbiological growth upon objects.
The actions of bringing too high levels to usual values are based on:
1. Searching for the potential source of infection and removing it. Clean objects should be moved into clean storage rooms.
2. Cleaning the air with portable filters and air-flow UV lamps, decreasing air relative humidity (portable dryers).
3. In rooms with mechanical ventilation (problems here are very rare) – increasing air exchange ratio, decreasing humidity

3. Microbiological control of the objects.

In the National Library of Poland microbiological evaluation of the objects is an integral part of the conservation proceeding. The main assumption of the conservation is always to preserve the object from further destruction and that includes the termination or elimination of destructive factors. The colony forming units of molds mean a potential danger for material if proper for fungal growth conditions of air temperature and relative humidity appear.
Furthermore, even without growing colonies spores and other fungal elements could be very dangerous for users and conservators. [4,5,6]

The main goal of microbiological evaluation is to define the character and intensity of the contamination (on condition that there are levels of microbial presence that cannot be described as *contamination*).
The final conclusion of the microbiological evaluation should define the condition of the object and point directly the further conservation treatment. The main difficulty in microbiological sampling is the vulnerability of the archival and library objects to moisture and mechanical factors. The correct *examination tactics* (as defined in *Introduction*) is essential.

In the Section of Microbiological Control and Conservation of the Untypical Collections of the Division – Laboratory for Conservation of Library Collections at The National Library of Poland three methods for microbiological control of the surface are used: filtration paper impress, dry swab with dilutions and commercial tests with ready medium (eg. Hygicult Y+F or Rodac); for details see table 3. The results from all three methods can be counted into *cfu/dm^2* (*colony forming units per square decimeter of surface*) units, although they have different credibility and sensitivity.

The perfectly clean objects (without any colony forming units on surface) are usual the effect of sterilizing procedures. The microbiological condition of non-sterilized objects is defined either by microbiological sampling or evaluation by microbiologists.
Following facts (beginning with most important ones) are reason for decision to proceed to microbiological sampling or disinfection of the objects:
– (naked eye) visible colonies of microorganisms
– evidence of microbiological activity (characteristic spots and staining)
– evidence of water activity on objects (stains, flooding signs)
– spots, discolorations, damp patches

Samples are taken form places of possible mold development; when there is too many spaces (e.g.

in a book or on a large size map) – the sampling should cover as many different suspected spots as possible.

In practice – with complex and technologically diversified objects (e.g. old prints with bindings) – there could be above 50 samples taken in first session. On the other hand – with a wide range of potential infecting factors – even 20 samples can be taken from large map on paper with linen back.

Almost all objects at the National Library are sampled with filtration paper impressing method.

The decision determining the further actions on object is taken on the basis of following facts:

- intensity of microbiological growth on samples (see also: *Fluffy Stuff...* [7] for assessment based on direct interpretation of quantitative results: 0-45 cfu/dm^2 – *good*, 45-150cfu/dm^2 - *moderate*, over 150 cfu/dm^2 – *bad*).
- the number of samples with growth in the total number of samples taken,
- technology of the objects.

These activities may be:

- next session of sampling (if previous one was not unambiguous); only the places with growth observed on samples are examined again,
- disinfection and control sampling session,
- further conservation treatment (without the disinfection) or return to normal use.

The most important part of final description of evaluated objects is differentiation between (microbiologically) CLEAN and STABLE ones:

(microbiologically) STABLE means:

1. *not sampled* (no reason observed for sampling or disinfection)
2. *sampled, with some level of microbiological presence, but not dangerous upon stable and appropriate storage conditions*

There are following objects in this class in point 2:

- objects with technology that does not allow the disinfection (parchment, photography, unknown technology)
- objects with microbiological presence even after numerous disinfections

Objects considered microbiologically STABLE (especially valuable ones) should be controlled for microbiological changes periodically and after every change of storage conditions – within 42 – 72 hours from the change and after 2 weeks (when object adapts to the new conditions).

(microbiologically) CLEAN means:

always after sampling evaluation that has not detected any colonies forming units

For clear and comparable classification of evaluated objects the following system of 5 final conclusions (categories of objects) was created (see also tab. 4) as final conclusions in documentation (operation chart):

class 1 – *object microbiologically CLEAN, no disinfection needed, return the object*

class 2 - *object microbiologically CLEAN, no further disinfection needed, return the object*

class 3 - *object microbiologically STABLE, no disinfection needed, return the object*

class 4 - *object microbiologically STABLE, no further disinfection needed, return the object*

class 5 - *object microbiologically STABLE, no disinfection or sampling needed, return the object*

Every object evaluated with samples or visually by microbiologists of Section of Microbiological Control receives a *Microbiological evaluation or disinfection chart*, that is considered a part of conservation documentation and contains the following informations: staff delivering/receiving/working on/returning the object, signature of the object, library unit of the object, case number, dates of receiving/returning of the objects, sampling data (number of samples with and without growth), conclusions, disinfection (if performed) data (date, cycle number, ethylene oxide concentration, exposition time, relative humidity and temperature in the chamber), notes and recommendations, signatures of staff. The copy of the chart should be stored with objects

or become a part of documentation (after conservation in Conservation Division), the original chart stays at the laboratory. The Conservation Division should not accept for conservation any object without *Microbiological evaluation or disinfection chart* with final conclusion ending with *return the object*.

4. Microbiological control of the library collections at the National Library of Poland

In the National Library of Poland five people are responsible directly for microbiological control. They are four specialists in different fields of nature sciences lead by environmental biologist and conservator of works of art (specialized in paper objects). These posts are conservators' ones. Two people perform most of the contact sampling (over 6000 samples and 900 objects in 2009) and over 70% of air samples (about 1200 samples in 2009). Two other provides technical support (medium preparation and disposing of microbiological material after sampling), run the whole ethylene oxide disinfection and freeze-drying processes and works also with air samples and sampling for non-library objects. The chief of the Section co-ordinates these actions (performs also manual and microscopic work with sampling to keep in touch with daily practice) and leads all emergency actions (e.g. sampling, planning, recommendations by emergency response). The other direction of Section's activity is conservation of untypical collections (mostly based on photographic techniques). In this field head of the section works with one of the disinfection chamber operators and two renovators of microfilms. There are also research programs and conservation methods evaluation run in the section.

The present trend of microbiological control in the Section is to reduce the disinfection of the objects by increasing the number of samples and rather repeating the sampling session than disinfecting the objects. In effect in the last two years the ratio of repeated disinfection on one object has fallen from 10% of all evaluated objects per year to 0,5%.
There is a lot of pressure put on developing the awareness, that disinfection is a conservation process and decision to execute it must come from conservator. Therefore if there are any doubts about disinfection (e.g. parchment, photographic, gilded objects), the conservator supported by microbiologists and chemists (sometimes also other specialists) has to make the ultimate decision. This strategy helps to avoid unnecessary and dangerous for objects disinfections and makes the whole microbiological control an integrated part of conservation proceeding with conservator responsible for all the processes.
On the other hand – microbiologists work with Technical Exploitation Department in the field of air quality control.

5. Microbiological contamination as a consequence of a disaster.

The mechanism of the most common disasters in libraries and archives is based on flooding (rain, pipe or fire-extinguishing water). The final effect is the same – large amount of objects become humid/wet enough for molds to grow. Situation may be even more difficult with river floods with contaminated water. As soon as wet objects emerge from water, the growth of molds on them is expected within 24 hours and without actions taken it is guaranteed within 48 hours. Even in moderate climate after 72 hours from initial appearance of growing fungi on objects they may be damaged to the point of total loss of contents and decomposition of medium / support to the level of loss of any mechanical properties.
The massive growth of fungi causes a large scale contamination of air and in consequence of dry objects in the same room.
In order to preserve the objects and to restore their utility properties drying, disinfection and microbiological control/ evaluation is needed. In tab. 5 there is a short calculation of costs of

restoring flooded archival material after flood (sewage water) that happened in a medical archive in Poland after heavy rain in July 2009.

This simple calculation shows that a very common habit of keeping files or books in cellars can easily lead to a financial disaster or irreversible lost of collections. In the emergency response costs calculation of collection recovery the cleaning and repairing (some damage cannot be avoided while handling wet material) are 16 times higher than packing, freeze-drying, disinfection and microbiological sampling together.

6. Conclusions:

Although the guidelines for correct preservation are known and very easy to find (like PL-ISO 11799:2006, many publications and also internet sources) along with the disaster reports there is still little awareness of the scale of damage that molds can cause. Some curators and conservators still consider not only preventive control but even pre-conservation sampling not necessary.

The last microbiological evaluation in the Division of Iconographic Collections in the National Library of Poland shows the importance of microbiological control even of properly stored collections in good condition with regular conservation care ("surface memory" effect). In this point I have to recommend a very valuable publication of Netherlands Institute for Cultural Heritage: *Fluffy Stuff. Integrated Control of Mould in Archives* by Agnes W. Brokerhof, Bert van Zanen and Arnold den Teuling and thank the authors for useful information that was helpful in organizing the work at National Library in the field of microbiological control.

The proper preservation policy should include the control of microbiological factor as an integral part of conservation processes, history of the objects and storage rooms as well.
The information about the most dangerous for the collections destructive factor is essential for keeping the heritage for the next generations.

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outer material	outer surfaces		inner surfaces	
	samples with growth	samples without growth	samples with growth	samples without growth
linen	9	5	4	10
	cfu/dm^2	average	cfu/dm^2	average	
	4-224	48	4-8	5	
no linen	samples with growth	samples without growth	samples with growth	samples without growth
	20	16	7	29
	cfu/dm^2	average	cfu/dm^2	average	
	4-104	29	4-24	9	
Species isolated on objects:	*Penicillium, Cladosporium, Hormodendrum, Alternaria, Aspergillus, Chaetomium, NN*			
average in air : 80 cfu/m^3	Species:	*Penicillium, Botrytis, NN*		
background : 460 cfu/m^3	Species:	*Cladosporium, Penicillium, Acremonium, NN*		

*NN - "lack of morphological features allowing identification"*

Tab. 1.
Room 215 (Iconographic Collections) – dependence of number (colonies growing on medium) of isolated fungi from the covering material of the boxes and folders and objects inside as well. "cfu/dm^2" fields show the range of the values. Note the variety of species on the surfaces comparing to only 2 identified species in the storage room air and 2 more species in the background air that are not present in the storage room. The data show that the co-relation of surface particles, storage room air particles and background air particles are complicated.
The results are also empirical proof that protective boxes and folders are essential for objects preservation.

month	week 1	week 2	week 3	week 4
I	same floor in C building	Old Prints Div.	changing floor in C build.	Old Prints Div.
II	same floor in C building	Iconographic Div.	changing floor in C build.	Carthographic Div.
III	same floor in C building	Manuscripts Div.	changing floor in C build.	Microfilms Div.
IV	same floor in C building	Library Archives	changing floor in C build.	Mass Conservation Div.
V	same floor in C building	Conservation	changing floor in C build.	Scientical Information
VI	same floor in C building	Social Life Documents	changing floor in C build.	Collections Access Div.
VII	same floor in C building	Sound and Audiovisual	changing floor in C build.	Iconographic Div.
VIII	same floor in C building	Old Prints Div.	changing floor in C build.	Old Prints Div.
IX	same floor in C building	Manuscripts Div.	changing floor in C build.	Microfilms Div.
X	same floor in C building	Carthographic Div.	changing floor in C build.	Mass Conservation Div.
XI	same floor in C building	Conservation	changing floor in C build.	Bibliology Documentation
XII	same floor in C building	Musical Collections	changing floor in C build.	Reading Rooms Div.

Additional surveys: the Vault: 3 samples once a month, Laboratory rooms – as needed

Tab. 2.
The annual pattern of microbiological air control, divided by library units and floors in main storage building (C building). One floor is checked every month, second monthly survey in main storage (C) building is executed on another floor. Within a year one floor is checked 12 times and all others once. The cycle starts every April. Surveys in Special Collections, Conservation and Microfilms Divisions are executed twice a year. A single survey generally does not exceed 40 samples + 6 for background air.
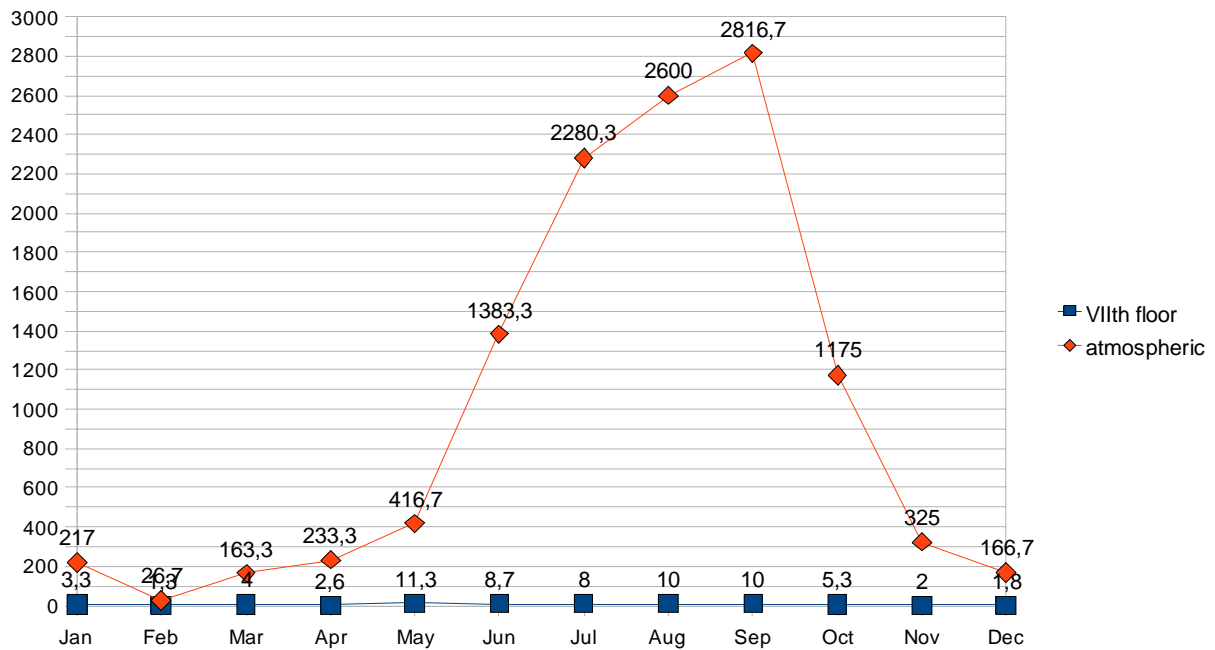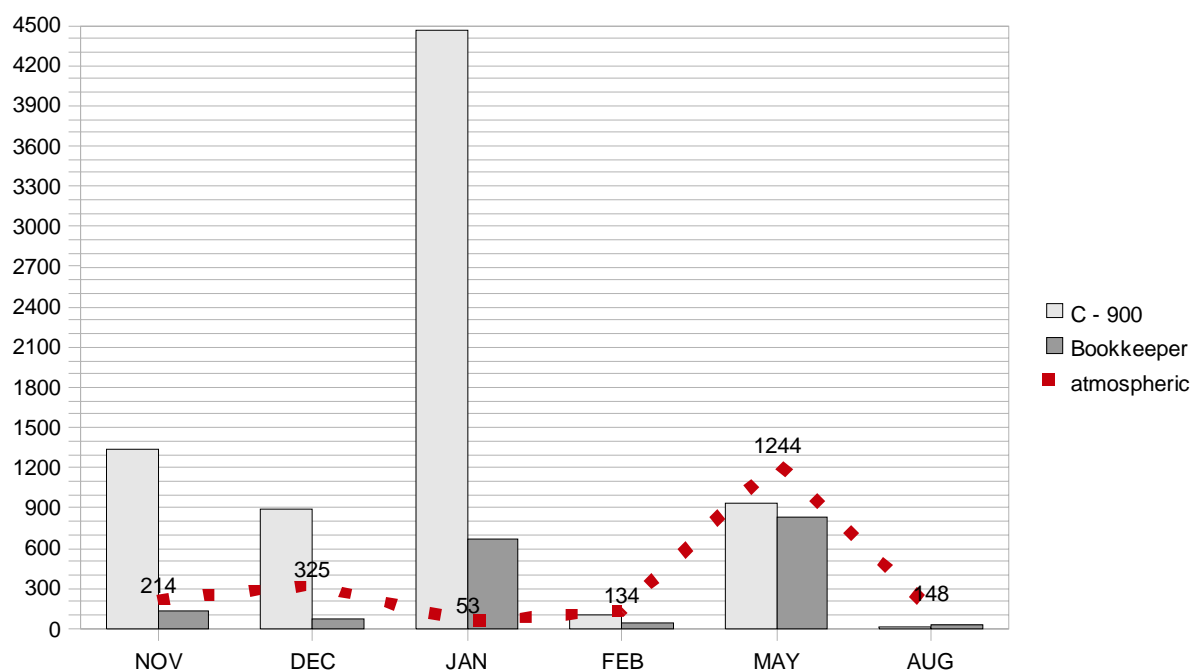
Graph. 1.
Average (of 30 samples, one survey every a month in 2009) cfu/m^3 values of the air on the VIIth floor of main storage building compared with background samples taken at the same time. Because of the air filtration, constant relative humidity and temperature values the level of microbiological presence in the storage room does not depend on the microbiological presence in the atmospheric air.
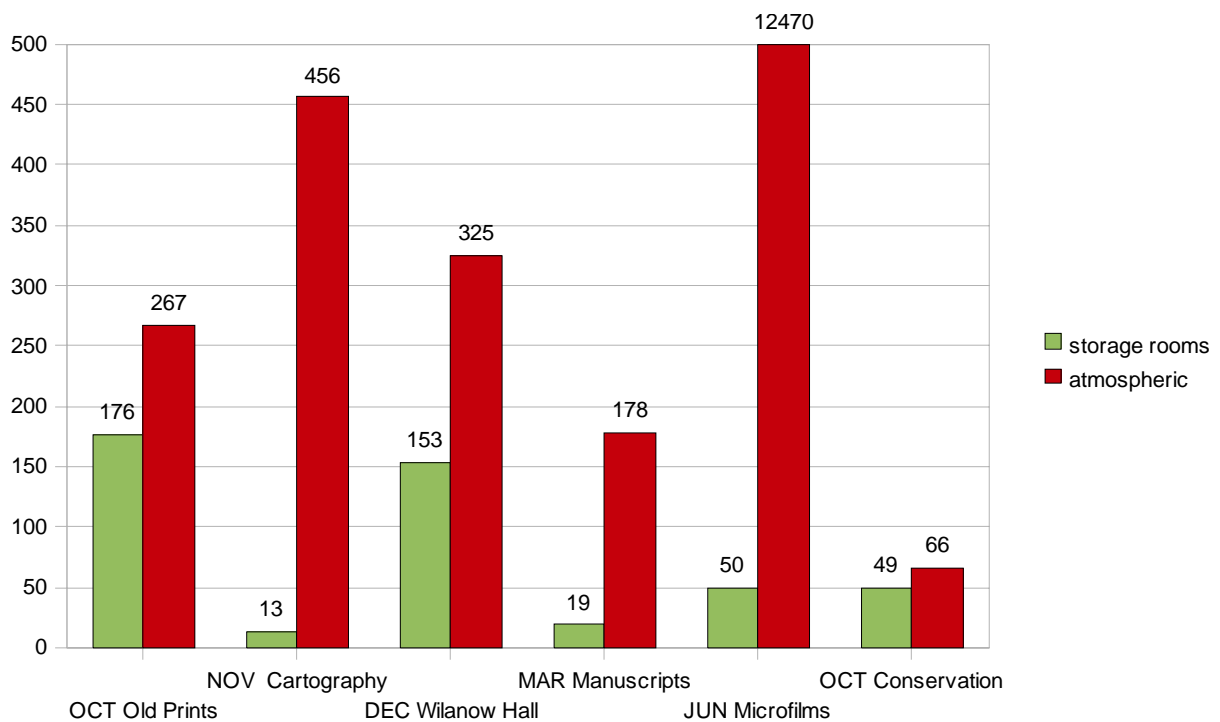
Graph. 2
Comparison of average microbiological presence in the different storage rooms and Conservation Division as well (values in cfu/m^3). Note low level in Manuscripts Divisions (Res Publica Palace, no climate control), close to the Carthography Division value (main building, temperature and relative humidity control).

Graph. 3.
Two mass deacidification technologies: Neschen C-900 and Bookkeeper. Depending on work type and intensity levels of microbiological presence in the air may exceed the background levels without sources of infections or mold growth presence. The answer is the type of objects in conservation and technology: C-900 is a water based bathing process with mechanical transportation that brings water drops in the air. Bookkeeper does not use water for main process, but has higher work intensity with surface cleaning as an integral part.

	method	description	application	advantages	disadvantages
1.	filtration paper impress	traditional, 5x5cm filtration papers are pressed slightly against the object, placed upon medium in Petri dish and incubated up to 14 days; colonies are counted and identified	any objects with flat surfaces, disregarding the vulnerability	fast, low costs, safe for vulnerable, damaged and moisture susceptible objects	semi-quantitative, no credible data on fidelity (the ratio of material collected)
2.	dry swab and dilutions	adapted from food industry; collecting material with dry swab from approx. 5x5cm area; mixing the swab in a test tube with 4ml of water, inoculation of 100µl of basic solution and 1/10 and 1/100 dilutions onto medium in Petri dish and incubation up to 10 days; colonies are counted and identified	any objects resistant to rubbing; places and areas with difficult access; portable - swabs in plastic tubes are easy to handle	quantitative results with sensitivity of 80 cfu/dm^2 by two series of basic solution; option of collecting many samples outside the laboratory and delayed inoculation	invasive to objects; high time and work costs of inoculation and evaluation (up to 100 colonies per dish), advanced equipment required
3.	commercial contact tests with medium	ready medium on plastic dish or stripe is pressed to the surface, then closed and incubated (e.g. Hygicult Y+F – stripe or Rodac - dish).	mostly infrastructure and protective objects (boxes)	easy for use and incubation, no laboratory required, only for disposal	requires flat surface resistant to moisture, restricted option of identification

Tab. 3.
Methods of evaluations of microbiological presence on surfaces. Each of them is suitable for different type of survey and provides specific results. There is no universal method, so it is critical in exa*mination tactics* **to chose the method correct for object's nature, technology, condition and expected type of results. E.g. pastels can be sampled only with very delicate impress, while best results with reliefs on book covers will come with swabs.**

activities on object	final conclusions – object's evaluation	
	CLEAN	STABLE
visual evaluation - samples	class 1	class 3
visual evaluation – (disinfection)* - samples – (disinfection - samples)**	class 2	class 4
visual evaluation - no need for sampling	-***	class 5

Note:
* - with visible evidence of microbiological activity the proceeding may start with disinfection
** - the pair disinfection-samples (control) may be repeated up to 4 times
*** - description CLEAN is possible only for objects after samples, when there is no need for sampling - the objects (not checked microbiologically) are just STABLE.

Tab. 4.
In general the objects after evaluation returned to their home Divisions may be microbiologically CLEAN or STABLE; CLEAN term is reserved for sampled objects only. Objects classified as STABLE may be only visually evaluated with conclusion: *no disinfection or sampling needed***.**

	activity	time and comments	Cost in EUR
1.	Packaging in plastic sacks and boxes	8 hours of 2 person team	600
2.	Freeze drying of 50m of files = 7m^3	assuming 1m^3 of files is 200kg, 3 months	5600
3.	Ethylene oxide disinfection	at least 1 month	1250
4.	Random microbiological control	100 samples with Hygicult – 2 weeks	250
	Total	About 5 months	7700
	Not including: freezing and transportation costs and disinfection of the rest of the files		
5.	Restoration of about 150000 pages	Cleaning and repairing – 10000 pers/hour	125000

Tab. 5.
A case of flooding: archival storage room in a cellar of 50m^2 with 200 meters of A4 format files. After a flood about 50 meters of files was wet up to the half of their height (the lowest one out of the four shelves level, water reached 55 cm, the shelves started at 40cm above floor), the top half got humid by capillary migration. After handling the wet objects the rest of files has also to be disinfected.

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