Microbial Contamination in Archives and Museums: Health Hazards and Preventive Strategies Using Air Ventilation Systems

By Nieves Valentín

Introduction

Many fungi and bacteria produce serious damage in historic materials, which are decomposed from the impact of specific enzymes, cellulases, proteases, ligninases, and organic acids. Pigmentation and physical damage in materials are other deleterious effects in addition to biodeterioration. Fungi are particularly dangerous because they show a substantial tolerance to environmental conditions. In addition, they require lower relative humidity (RH) than bacteria for their development and produce spores that are easily dispersed by moving air. Dispersion of spores is the main cause of contamination in the environment; the spores produce allergies and other illnesses in people and biodeterioration in historic objects. Florian showed biological alterations to historic objects caused by the most common species of microorganisms and insects in museums and archives. She emphasized the priority of controlling environmental conditions by improving air quality (Florian 1997).

Spores in a dormant state are commonly present in the air and on the surfaces of objects. However, it is the moisture content of materials that allows microbial growth, because it determines the water available for the germination of spores. In this context, air ventilation is an easy and safe method to control and stabilize RH, temperature (T), moisture content, and, consequently, microbial activity rate.

Over the pass twenty years, various air-conditioning systems have been installed in buildings to control environmental conditions and to prevent the development of biological agents. Nevertheless, it has been found that very often these systems present a high risk of proliferation of fungi and bacteria and spread contaminated aerosol that damages objects as well as human health. In particular, the humidifier components of these systems are favorable to microbial growth.

In fact, it has been observed that some historic buildings that are used as museums and archives, as well as modern "intelligent buildings" built for other purposes, present serious conservation problems because of the excessive insulation that is characteristic of the new architectural design—insulation that is actually required for the installation of air-conditioning. It has also been found that sophisticated climate control systems do not avoid condensation phenomena in some areas of the building, a factor that produces an increase of water content in inappropriate materials such as carpets, wallpapers, paints, and new products, including plasters and silicone joints. These materials provide ecosystems adequate for the development of microorganisms. In such buildings, the air-conditioning systems work using common standards of 50% $\pm$ 5% RH and 20°C $\pm$ 2°C T, and air changes/hour (ACH) in a range of 6–8. However, Michalski has reported that very often it is not required to maintain these strict standards (Michalski 1993). To determine correct or incorrect values, it is crucial to take into consideration many factors, such as the specific characteristics of the building and collections types and the use of historic objects (paintings for exhibitions, books and documents handled by people for reading or research), and then evaluate environmental parameters indoors and outdoors, including ventilation.

To avoid biodeterioration in museum and archive collections exposed to warm and humid climates, a research project was carried out in a storage room, measuring approximately 66 m^3, belonging to an archive, the Town Hall Archive, located in La Laguna, Tenerife Island, Spain (Maekawa and Toledo 2001). In addition, a comparative study was developed in a storage area of 437 m^3, in the Anthropological Museum located in Valle Guerra, Tenerife Island. The storage facility holds a large collection of ethnographic objects. This work was included in the Getty Conservation Institute's (GCI) project Alternative Climate Controls for Historic Buildings (http://www.getty.edu/conservation/science/climate/index.html). Therefore, we have evaluated the efficacy of an alternative system of ventilation designed by the GCI to control environmental conditions and reduce microbial activity by improving air quality.

Objectives

This work was carried out to quantify requirements for ventilation to control and decrease fungal and bacteria growth in buildings exposed to high humidity.

The aims were as follows:

- Determine the efficacy of ventilation rates in arresting microbial growth in the environment and in historic objects.
- Identify fungi and bacteria isolated from air samples and the surfaces of objects made of organic materials.
- Show isolated microorganisms that could represent health hazards.

Among the microorganisms isolated, we have found fungi and bacteria that are considered to be human pathogens and are therefore included in hazard groups.

Materials and Methods

According to the method described by Valentín and colleagues, aerobiological samplings were performed in the archive and museum storage with a microbial air sampler (Microbio MB1 Bioser) passing 300 L of air per sample (Valentín et al. 1998). The air sample impacted the culture media—nutrient agar to assess bacterial activities and Czapek agar to evaluate the development of fungal population. The airflow rate of the Microbio equipment was assumed to be 90 L/min. A set of three air samples captured in each area was used to obtain average contamination values and representative results.

La Laguna Historic Archive

Environmental sampling was carried out in different areas: the central area (C), close to the window (W), and close to the door (D).

Cotton swabs humidified with a solution of sodium chloride (0.9%) were used to take microbial samples from books and documents. According to the classic methods in

microbiology, culture media were employed to assess quantitative results and identify microorganisms. For these analyses, Czapek, Sabouraud, and Malta agar were utilized for the development of fungi. Nutrient agar was employed for bacterial growth.

In the archive room, filters were installed in the ventilation system to decrease the impact of external contaminants indoors. In this case, three samples corresponding to both the external and the internal face of the filter were analyzed for assessment of microbial growth. Surface contamination on books located on the shelves was also analyzed. In addition, the contamination on documents kept in boxes was assessed to detect the impact of microclimates and possible condensation phenomena.

Microbial contamination in both environment and surface samples was analyzed monthly for over one year in the archive without ventilation. Thus, the results were considered as the control. In a second phase, a mechanical ventilation system was installed in the room, and biological analyses were performed monthly for a ten-month period, to determine the effect of ventilation in decreasing microbial growth on materials (Maekawa and Toledo 2001).

Valle Guerra Anthropological Museum

In the museum storage of Valle Guerra, environmental contamination was measured in five different areas—A, B1 and B2, C, D, and E. The first set of samples was taken in the storage area without the climate control system. The results obtained were considered as the control. In the second phase, the climate control system was installed (Maekawa and Morales 2006), and air samples were taken and analyzed every four months after the installation of ventilation equipment. Filters were also analyzed for the development of microbial contaminants.

Results

The biological samples from the La Laguna Historic Archive and the Valle Guerra storage were incubated at 28°C for 2 weeks. The fungi and bacteria were identified and quantitatively evaluated. Measurements of environmental parameters, including T, RH, and ventilation rate were recorded over the complete research project in the archive and museum (Maekawa and Toledo 2001; Maekawa and Morales 2006).

The results from the aerobiological analyses carried out in the archive and museum storage are represented in figures 1a, 1b, and 2; the data, which correspond to average values obtained from each set of samples, are given in colony-forming units (CFU), in the form of CFU/m^3. The results reflecting the microbial contamination on surface samples are expressed in CFU/sample (colony-forming units/sample). Each surface sample corresponds to 1 cm^2.

La Laguna Historic Archive

Air Samples

Figure 1a shows measurements of environmental contamination, over a period exceeding one year, in the room without the climate control system. After the system was installed, a drastic decrease was observed in microbial growth, as a result of stabilization and decrease of RH (fig. 1b). However, even after the system was installed, the first set of samples tested showed high contamination. This effect could be caused by the air movement initiated when the ventilators were installed and activated. It is surmised that the increased air movement removed spores from the surfaces of objects and from the walls and floor of the room. In addition, the specific sampling method used by the Microbio air sampler apparatus traps more spores from the environment if air turbulence in the room is produced by a higher ventilation rate. During the air treatment, a slight increase in microbial activity was also detected in the seventh sampling, corresponding to February (fig. 1b). This finding could be due to various factors, such as the presence of more people in the storage room, some environmental changes, or sample manipulation. However, this effect was not significant in the analyses of the surface samples (figs. 3a and 3b).

After the climate control system was used for one year, a low amount of accumulated dust on objects was observed. It is thought that after long exposure to the airflow from the system, the decreased dust level contributed to a reduction in microbial growth.

Surface Samples

The contamination on books and documents is presented in figures 3a and 3b. These data reveal a decrease in and a stabilization of microbial development in most of the books and documents exposed to the improved climate, including documents kept in boxes. A high variability of CFU/sample was found on surfaces. Contamination level depended on the nature and type of materials, including hygroscopicity, location, and other factors. In general, microbial development was more variable on the surfaces of books than in the internal pages, and it depended on the moisture content of the paper and condensation phenomena.

In this study, fungal contamination of air and paper samples was higher than the measured bacterial growth in all the samples tested (figs. 4a, 4b, and 5). Fungi can grow in a range of 60% to 90% RH. Bacteria contamination could increase at levels over 85%, because they need more water to grow.

With regard to a comparison between air and surface analyses, it was observed that cellulose objects required longer exposure time in the improved climate to achieve a significant decrease in microbial growth. According to the results obtained in the La Laguna storage room, one month was required to substantially decrease microbial growth in the environment. In contrast, three months were required to achieve a significant arrest of microbial growth on books.

Isolation of Bacterial and Fungal Organisms

Figures 4a, 4b, 5, and 6 show that identical genera of fungal and bacterial organisms were isolated from air samples from different environments. Among identified fungi, many species in the genera *Aspergillus, Penicillium, Cladosporium, Chaetomium,* and *Trichoderma* were found; they are known to be very dangerous fungi for historic materials (organic and inorganic supports). In fact, *Aspergillus, Penicillium,* and *Cladosporium* have spores that can regenerate significant development, in conditions in which RH is above 65% and T is 22°C–24°C, in a short time period (24 h.). In addition, *Chaetomium* and *Trichoderma* have high cellulolytic activity. The genera *Penicillium, Aspergillus, Cladosporium, Paecilomyces, Stachybotrys,* and *Curvularia* were isolated from books and air samples.

Our results show that isolated species such as *Alternaria alternata*, *Aspergillus niger*, *Cladosporium herbarum*, *Penicillium commune*, *Penicillium notatum*, *Trichoderma viride*, *Gliocladium sp*. and *Mucor sp*. were common airborne biological particles identified (fig. 6). The genera *Aspergillus*, *Penicillium*, and *Cladosporium* had the highest number of viable colonies in indoor environments. *Mucor* and *Rhizopus* are Zygomycetes that have been found mainly on surface samples. *Rhizopus*, a soil fungus, has been detected in surface samples from objects with dust accumulation.

The bacteria isolated from air and paper samples included the genera *Bacillus*, *Bacteroides*, *Pseudomonas*, *Micrococcus*, *Streptococcus*, *Streptomyces*, and *Staphylococcus* (fig. 5). *Actinomyces* strains have commonly been detected in both air and surface samples. *Bacillus subtilis* had a wide distribution in the storage room. Its resistance to environmental changes may account for the abundance of its spores in the atmosphere. *Pseudomonas* is a common outdoor airborne biological pollutant that is also found in museums, archives, and libraries. *Pseudomonas* and *Streptomyces* attack paper and textiles with cellulolytic enzymes.

In general, the data concerning surface sample analyses indicated higher fungal contamination rates in documents kept in boxes than in books directly exposed to air. The potential risk of biodeterioration was also higher in objects placed on lower shelves. These results are due to the impact of specific microclimates.

Filter Samples

Figure 7 shows microbial contamination on the external and internal faces of filters; data were derived from three analyses each of the two sides of the filters. A lower microbial development was found overall on the internal face. It would be desirable to perform additional tests to quantify autotrophic microorganisms on the external and internal faces.

Valle Guerra Museum Storage

Air Samples

The results obtained in the museum storage prior to installation of the climate control system showed a high level of environmental contamination in most of the tested areas. Air circulation produced a drastic decrease in microbial growth after one month. However,

although the contamination was maintained at low levels over the months when the climate control system was used, some fluctuations in microbial growth (CFU/m^3) were detected in the areas C, D, and E, as seen in figure 2. These fluctuations could be explained as follows:

- Microenvironments were created in zones where many objects were placed in a small area. Therefore, in some places in the storage, the airflow rate could be low, and higher RH could be produced.
- Objects were moved into and out of the room, for exhibitions, restoration, and other reasons.
- Dust was introduced by the entry of objects that had not been cleaned.
- There were changes in the environmental parameters resulting from modifications in the climate control system, the ventilation rate, T, or the repair or improvement of the system.
- The room was wet cleaned before sampling.

Inside of furniture such as bookcases, cupboards, trunks, and drawers, the contamination was not decreased, even though an acceptable ventilation rate was established in the room.

The most common genera of microorganisms identified are indicated in figures 8 and 9. *Penicillium* was highly isolated in all the samples tested. *Cladosporium, Aspergillus, Rhizopus, Mucor, Phoma,* and *Fusarium* were isolated in both the La Laguna Historic Archive and the Valle Guerra Anthropological Museum. Among bacteria and Actinomycetes, *Bacillus, Micrococcus,* and *Actinomyces* showed the highest levels of colony-forming units per cubic meter (fig. 9). *Bacillus subtilis* is considered a dangerous species because it exhibits the highest activity in hydrolyzing collagen, but it occurs at very high RH, above 95%.

The analyses of the filters used at the museum storage for a one-year period indicated no significant changes in contamination levels on both external and internal faces (fig. 10).

The impact of T should be also considered in ventilation treatments. The activation T for the microbial growth of many microorganisms is in the range of 20°C–37°C. In the case of common fungi, the activation T is in a range of 22°C–30°C. For common bacteria, it is in the range of 23°C–37°C. For this reason, higher ventilation rates should be established in warm regions to avoid spore germination and cell reproduction (or lower the temperature to 20°C).

In a comparison of our findings from the studies at both buildings, it can be seen that the analyses carried out in the La Laguna Historic Archive were more conclusive, because of the archive's small size, which allowed greater control of environmental conditions by the climate control system. In addition, the nature of the materials in the archive—for the most part paper—contributed to the more homogeneous results regarding surface contamination.

Optimal Conditions for Conservation

The literature indicates favorable conditions, including ACH, RH, T, and exposure time, to arrest microbial activity in different volumes of space (Valentin et al. 2002). It was found that the optimal values for the conservation of historic materials should be fixed in ranges of parameters rather than in specific values. Table 1 summarizes the ranges of parameters adequate to achieve significant decreases in microbial growth. We have observed that microorganisms, because they respond quite sensitively to environmental changes, are a useful tool in the detection and assessment of environmental conditions.

Type of samples and space analyzed	Ventilation rate (ACH)	Relative humidity (%)	Temperature (°C)	Exposure time	Volume of space (m^3)
Air samples in experimental case	0.48–1.2	55–85	20–24	25 h.	0.5
Paper samples in experimental case	0.48–1.2	55–85	20–24	25 h.	0.5
Air samples in experimental room	0.2–1.5	55–65	24–26	24 h.	3
Air samples in experimental room	0.2–1.5	65–75	24–26	48 h.	3
Air samples in experimental room	0.2	65–75	18–20	96 h.	3
Paper samples in experimental room	0.4	55–60	20–22	48 h.	3
Air samples in archive storage	6*	70*	19 ± 1*	1 month	66
Surface samples in archive storage	6*	70*	19 ± 1*	3 months	66
Air samples in museum storage	8*	65*	21*	2 months	437
Air samples in a room (common standards)	6–8	50	20	—	50

Table 1

Conditions required to decrease environmental and surface microbial contamination. Sampling was carried out in different locations. Asterisks (*) indicate measurement at biological sampling time.

Health Hazards

Some fungi identified in this study are considered potential pathogens for humans. Species in the genera *Aspergillus*, *Penicillium*, *Chaetomium*, *Alternaria*, *Cladosporium*, *Geotrichum*, *Mucor*, *Trichoderma*, *Rhizopus*, and *Fusarium* are capable of producing various illnesses among people involved in the conservation of cultural heritage. *Actinomyces* are bacterial mycelium producers that are included in hazard groups.

Among bacteria, species in the genera *Bacillus, Bacteroides, Clostridium* (a common contaminant of proteinaceous materials), *Pseudomonas*, *Streptococcus*, *Staphylococcus*, and some strains of *Micrococcus* could produce allergic problems and other illnesses.

According to Hödl, most fungi spores manage to penetrate into the bronchial area because of their small size, 2–10 µm (Hödl 2004); particles large than 10 µm are caught in the mucous membranes of the nose and throat. There is little investigation into allergies causing illness; development of such diseases basically depends on the presence of specific protein compounds. In a comparison of conidiophores with other parts of the fungus body, mycelium has lower potency. It has been reported that the minimum amount of spores that can cause serious allergic reactions are in ranges between 100/m^3 (for *Alternaria alternate*) and 3000/m^3 (*Cladosporium herbarum*). In this study we found lower levels of these contaminants.

Nolard has published that the most common illness detected in personnel involved in archives and museum conservation were rhinitis, dermatitis, allergic bronchitis, asthma, allergic bronchopulmonary aspergillosis, and hypersensitivity pneumonitis (Nolard [2001]). In this context, Nolard shows that β1-3 glucans are components of the walls of molds that act as potent inflammatory agents.

Salkinoja-Salonen and colleagues described the deleterious effect of fungi and bacteria involved in the biodeterioration of cellulose objects—species such as *Stachybotrys chartarum, Trichoderma harzianum,* and *Aspergillus versicolor,* which are considered producers of dangerous mycotoxins that affect eyes and ears as well as leaves. These mycotoxins are lipophilic and affect grass tissue. Among mycotoxins, sterigmatocystin is an aflatoxin produced by different fungi isolated under indoor environments. *Stachybotrys chartarum,* often isolated on wood and paper, produces trichothecene mycotoxins known as satratoxins. In moisture-damaged buildings Salkinoja-Salonen and colleagues found bacteria, *Streptomyces griseus* and *Bacillus cereus*, developing in indoor environments (Salkinoja-Salonen, Peltola, and Andersson 2003). The toxin produced by *Streptomyces griseus* is called valinomycin. Cereulide has been identified as the toxin produced by *Bacillus cereus.* These substances are likely to penetrate the skin or become absorbed into the mucosal cells of the airways. They are nonimmunogenic; consequently, they do not induce or inhibit the production of antibodies. Very little research is being done in this field. In fact, solutions coordinated with health and safety regulations are

needed. Also, efforts to implement strategies to prevent biological risk in museums, archives, libraries, and other cultural assets are required.

Conclusion

In this study, similar fungi and bacteria were identified in air, paper, and filter samples, although the quantities were different. *Penicillium* was the most common fungus genus found. It was isolated in all the samples taken in the archive and museum. High levels of contamination of *Cladosporium, Aspergillus, Alternaria, Trichoderma, Rhizopus,* and *Actinomyces* were found in environmental and in surface samples.

It was found that qualitative and quantitative analyses carried out according to classic methods of microbiology have some limitations. It should be considered that microorganisms that do not grow in culture in laboratory conditions could, even so, be present in the environment and on objects. In biodeterioration research, molecular biological analyses are now recommended for detecting specific species and obtaining accurate results, even though they are expensive.

A significant decrease in the levels of environmental contamination was detected in the storage of La Laguna Archive after the installation of a climate control system. The decrease was noted a month after implementation of ventilation. A longer period of exposure to ventilation (three months) was required to detect a decrease in fungal and bacterial activities in surface samples from books and documents.

A high variability in levels of contamination after implementation of the ventilation treatment was found in the museum storage room of Valle Guerra. This variability was probably due to the large size of the room, to its complex geometry, and to an excess of objects per square meter—objects made of heterogeneous materials and located on the floor and on shelves. These factors prevented the desired air exchange and created adverse microclimates and ecosystems. Consequently, longer exposure to ventilation was required to achieve stable environmental conditions and low microbial contamination. It is essential to maintain air movement, even in a difficult area where ventilating air may not normally reach.

Air circulation could produce significant spreading of spores in the environment—a fact that was detected during the initial phase of the ventilation treatment. Therefore, continued ventilation with low airflow is recommended.

The efficacy of air ventilation systems depends on the combination of RH, T, ventilation rate, and exposure time. The number of objects located per square meter, as well as the nature and state of conservation of the historic pieces, should be also considered. In a warm climate, with T in the range of 22°C–28°C, higher airflow rates should be employed.

Books should be placed on open shelves rather than on compact shelves. The use of boxes and compact shelves will prevent the deposition of dust on objects, but it can create microclimates that produce an increase in microbial activity.

The creation of an acceptable air quality and environment without significant fluctuations would reduce the cost of the maintenance and preservation of buildings and collections. Ventilation and housekeeping are the most important preventive measures for archives, libraries, and museums, as well as for personnel.

Fungi and bacteria that are considered potential pathogens for humans have been identified. The environmental conditions and the number of spores per cubic meter will determine the risk of infection. This issue should be taken into consideration when preventive conservation plans are made. Very little research is currently being carried out on the subject of health hazards in the field of cultural heritage. It is proposed that clear regulations appropriate for the protection of workers and visitors in museums, archives, and libraries is required.

Acknowledgments

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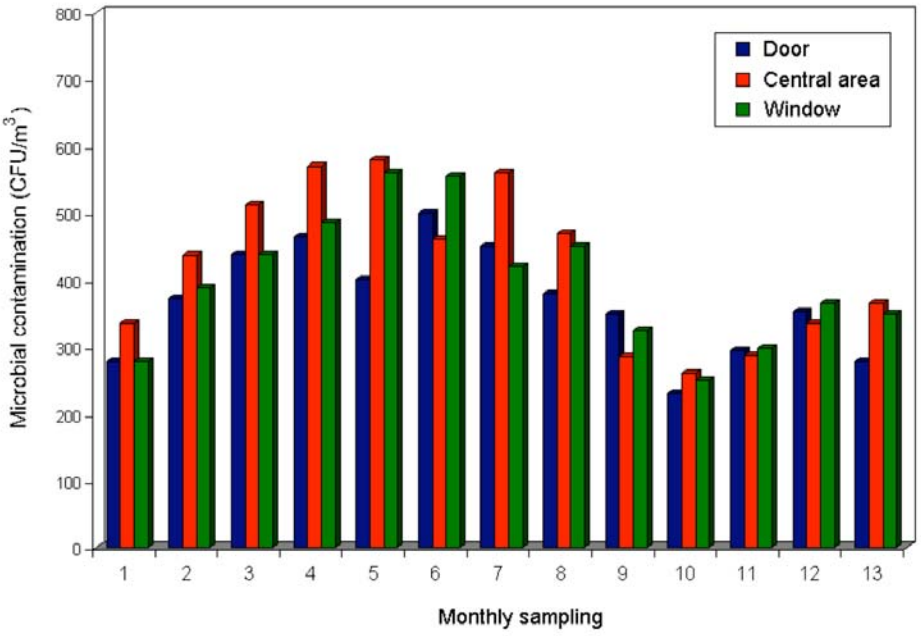
Author Biography

Nieves Valentín has a PhD in biology from Complutense University of Madrid, Spain. In 1973 she joined the Ministry of Culture as a microbiologist, and since 1985 she has worked as a research scientist in biodeterioration control and the preservation of cultural heritage at the Instituto del Patrimonio Histórico Español, Ministry of Culture of Spain. She is an advisor on conservation matters, has developed deinfestation systems using nontoxic treatments for historic collections, and is involved in reseach into the reduction of microbial infection by environmental control systems.

Figures



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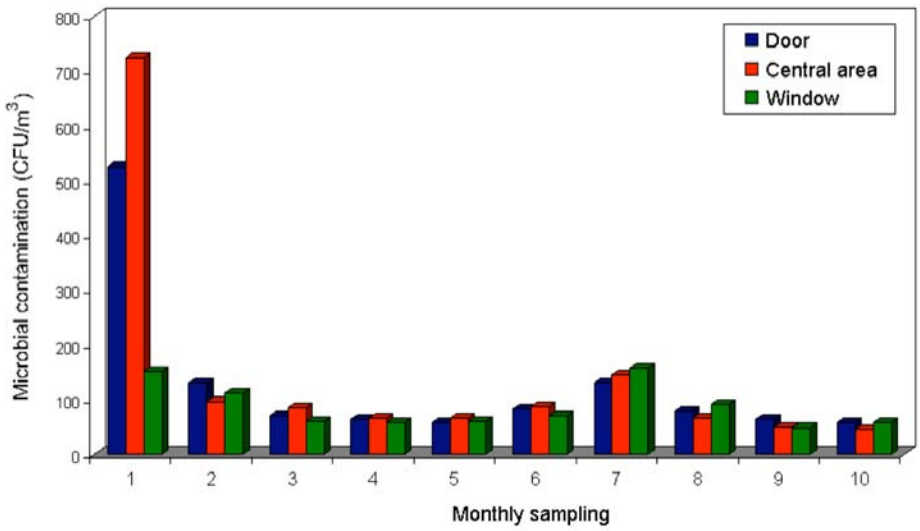


b

Figures 1a and 1b

Effect of ventilation on microbial contamination in the archive storage of La Laguna Historic Archive, Tenerife Island, Spain; data are shown for the storage area without ventilation system (a) and with ventilation (b).

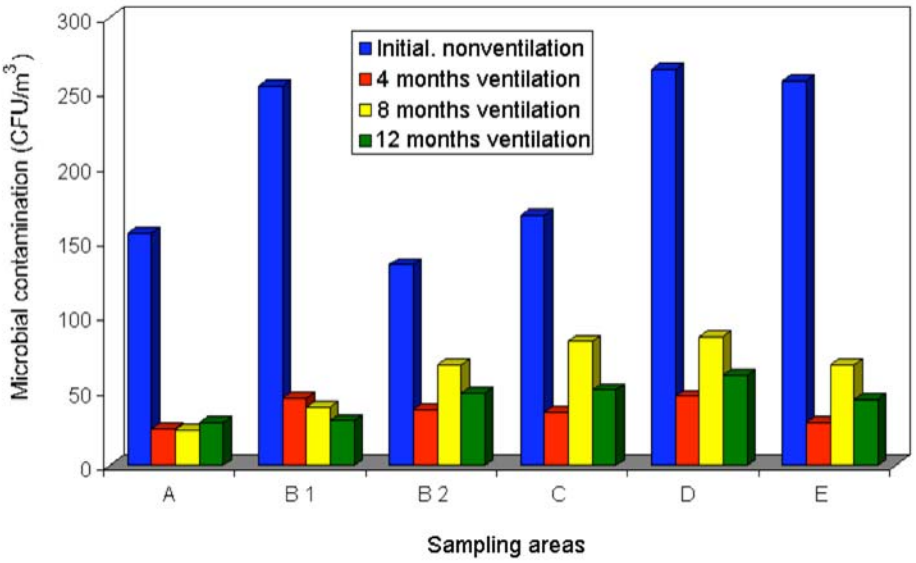
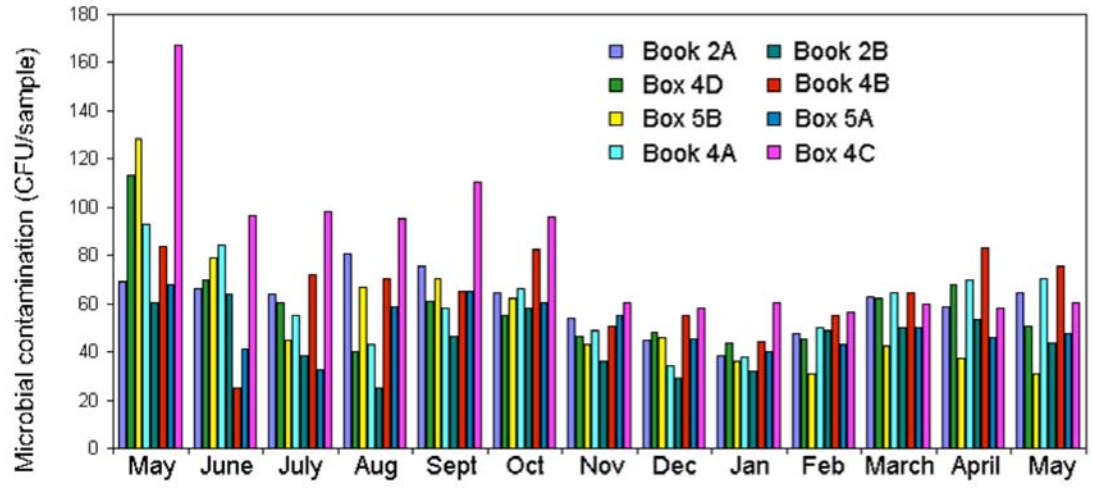


Figure 2

Effect of ventilation on environmental contamination in the museum storage of the Valle Guerra Anthropological Museum, Tenerife Island, Spain; data show the reduction in microbial contamination from the use of a climate control system over a period of one year.



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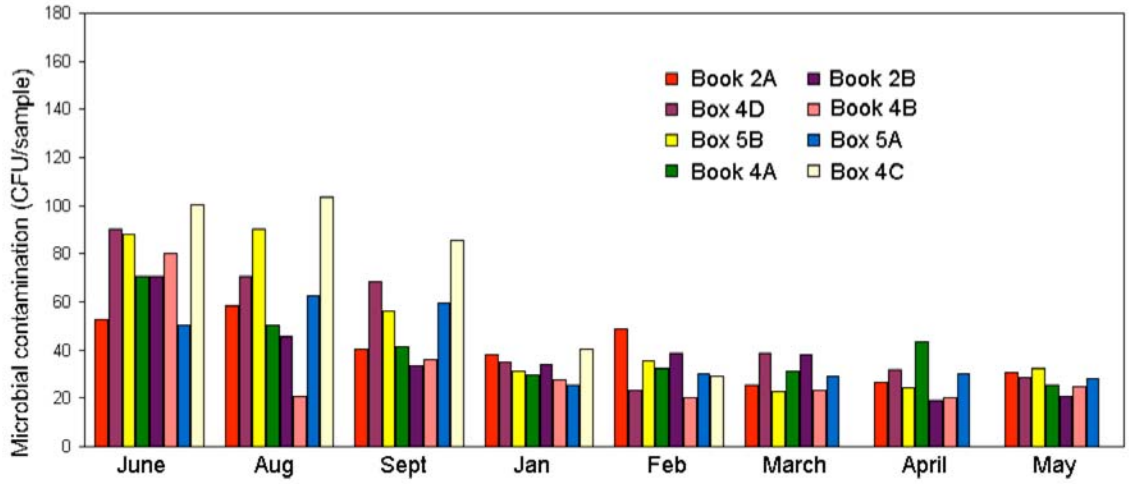
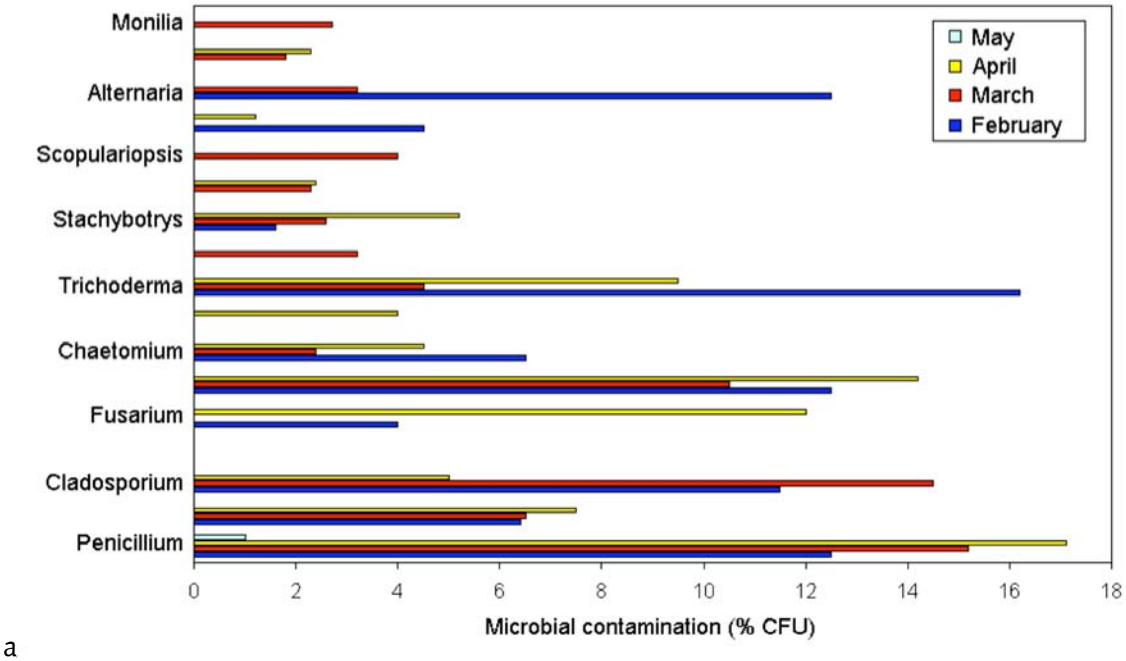


b

Figures 3a and 3b

Effect of ventilation on microbial contamination of surface samples (books and documents) in the La Laguna archive; data are shown for the storage area without climate control (a) and with climate control (b). Each surface sample corresponds to 1 cm^2.



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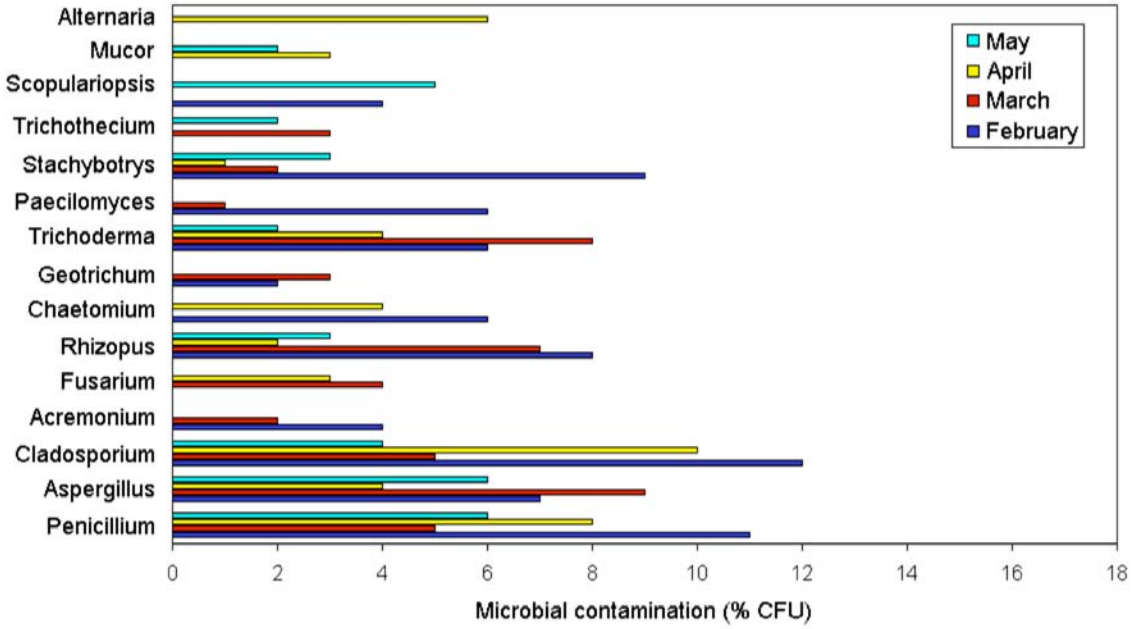

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Figures 4a and 4b

Fungal genera commonly found in air samples from the La Laguna archive; data are shown from archive storage without ventilation (a) and with climate control (b).

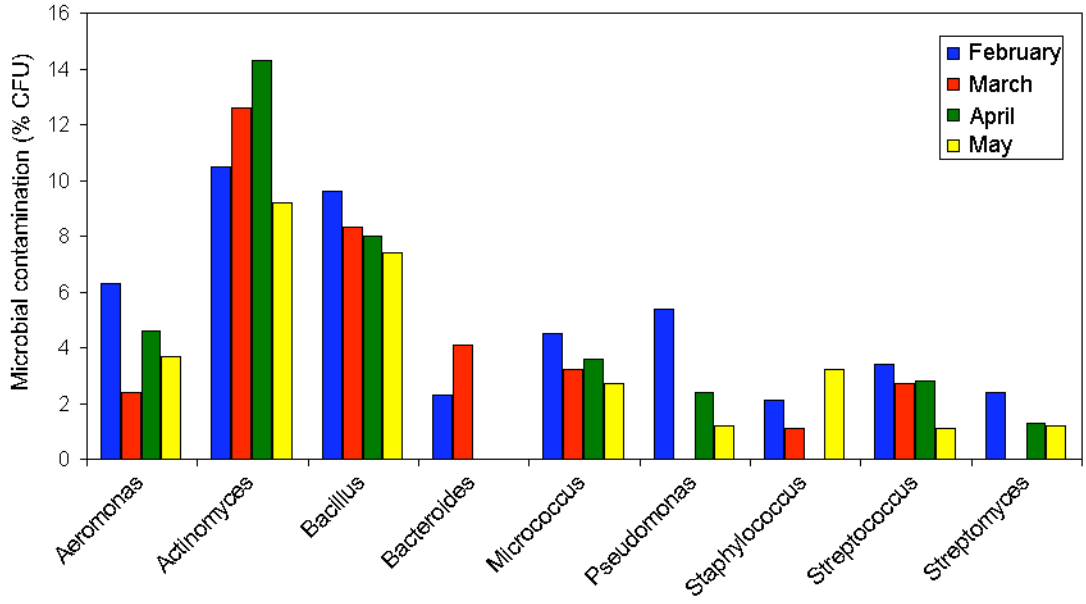

Figure 5

Frequency of bacteria identified in environmental air-sample analyses at the La Laguna archive.

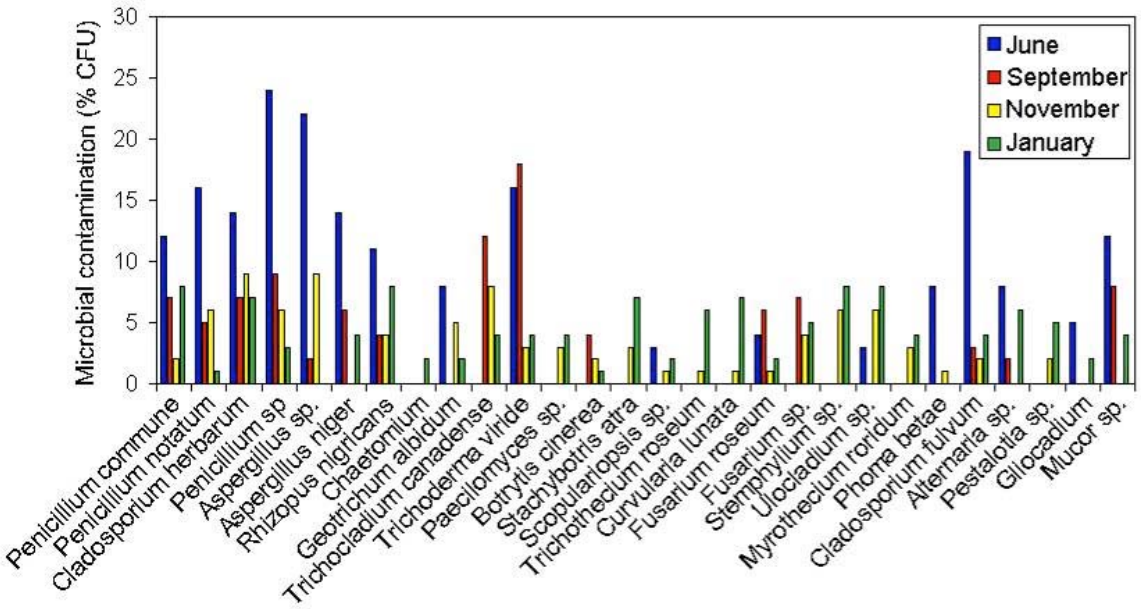

Figure 6

Frequency of fungal species identified in the environment, from air samples taken at the La Laguna archive after the installation of climate control.

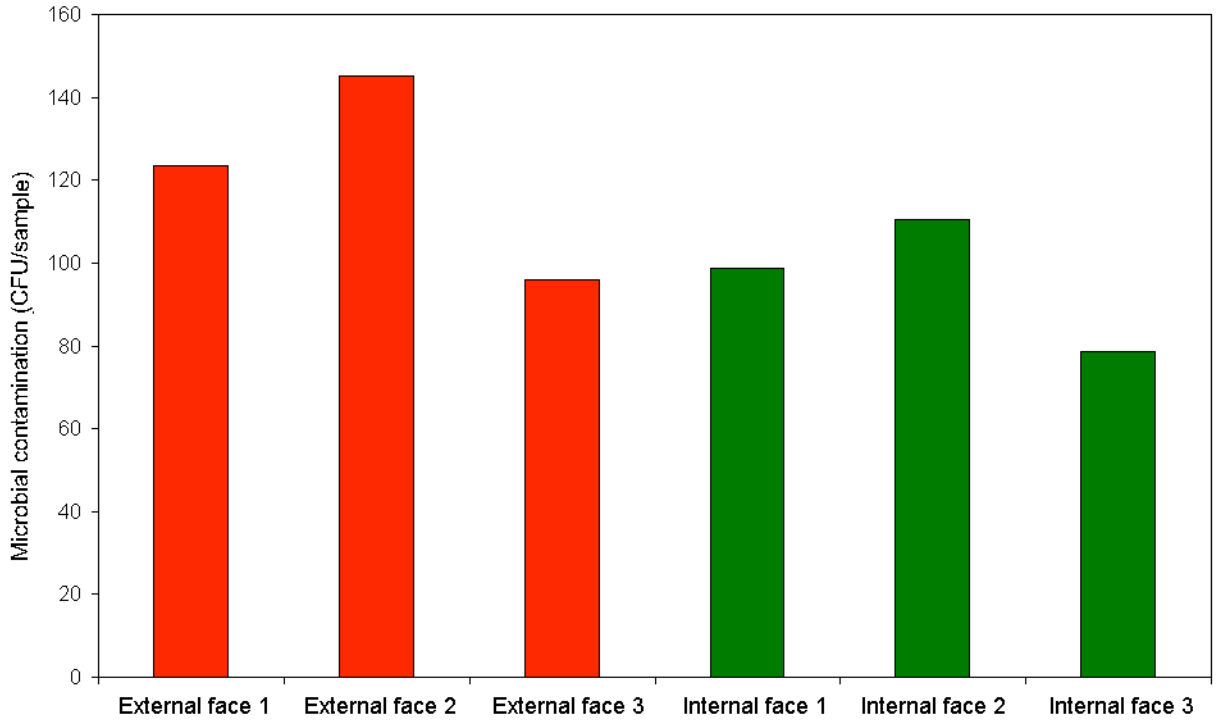

Figure 7

Microbial contamination on filters used for one year at the La Laguna archive. Each surface sample corresponds to 1 cm^2.

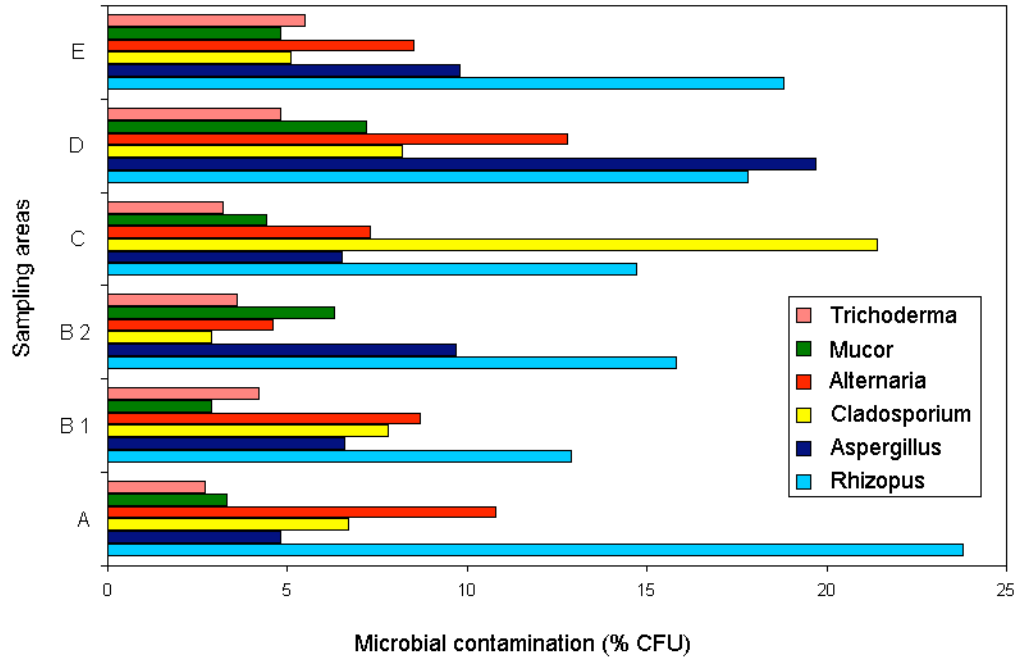

Figure 8

Fungal genera commonly isolated in air samples; data are from samples taken at the Valle Guerra Museum storage after the installation of climate control.

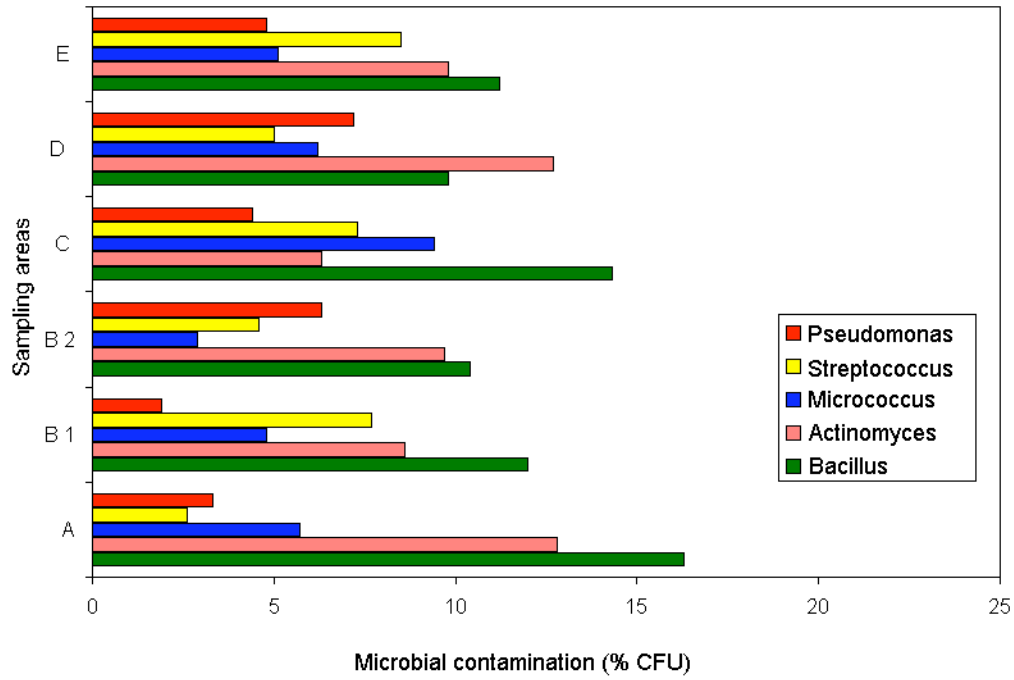

Figure 9

Bacteria genera commonly isolated in environmental air samples; data are from samples taken at the Valle Guerra Museum storage after the installation of climate control.

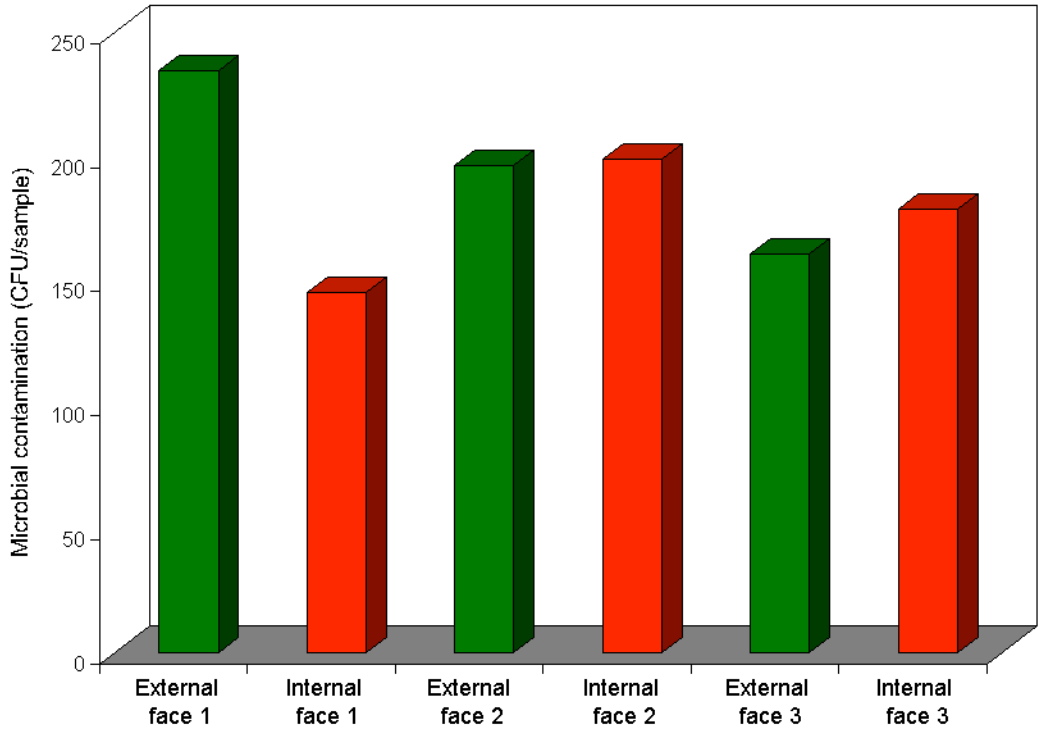

Figure 10

Microbial contamination on filters used for one year; data are from samples taken at the Valle Guerra Museum. Each surface sample corresponds to 1 cm^2.

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