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Bioaerosols in the workplace: Evaluation, control and prevention guide

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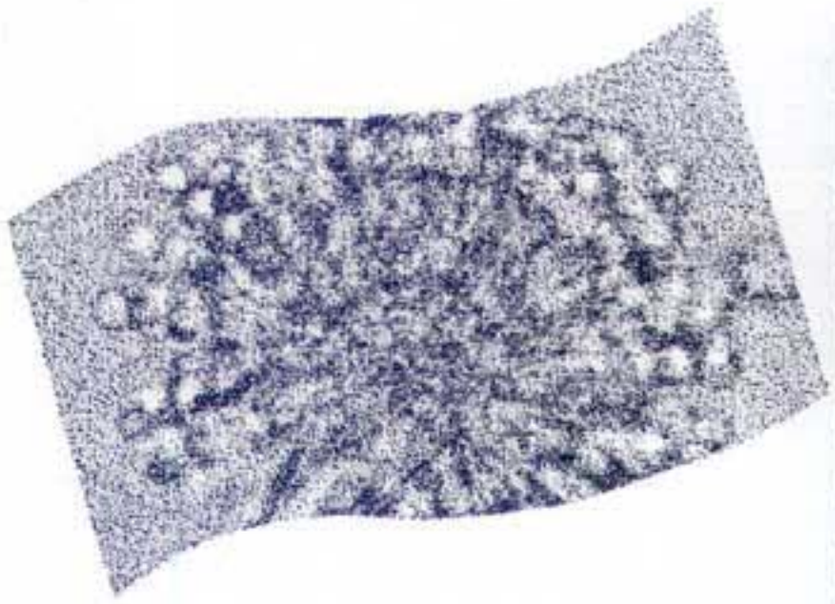

ÉTUDES ET RECHERCHES

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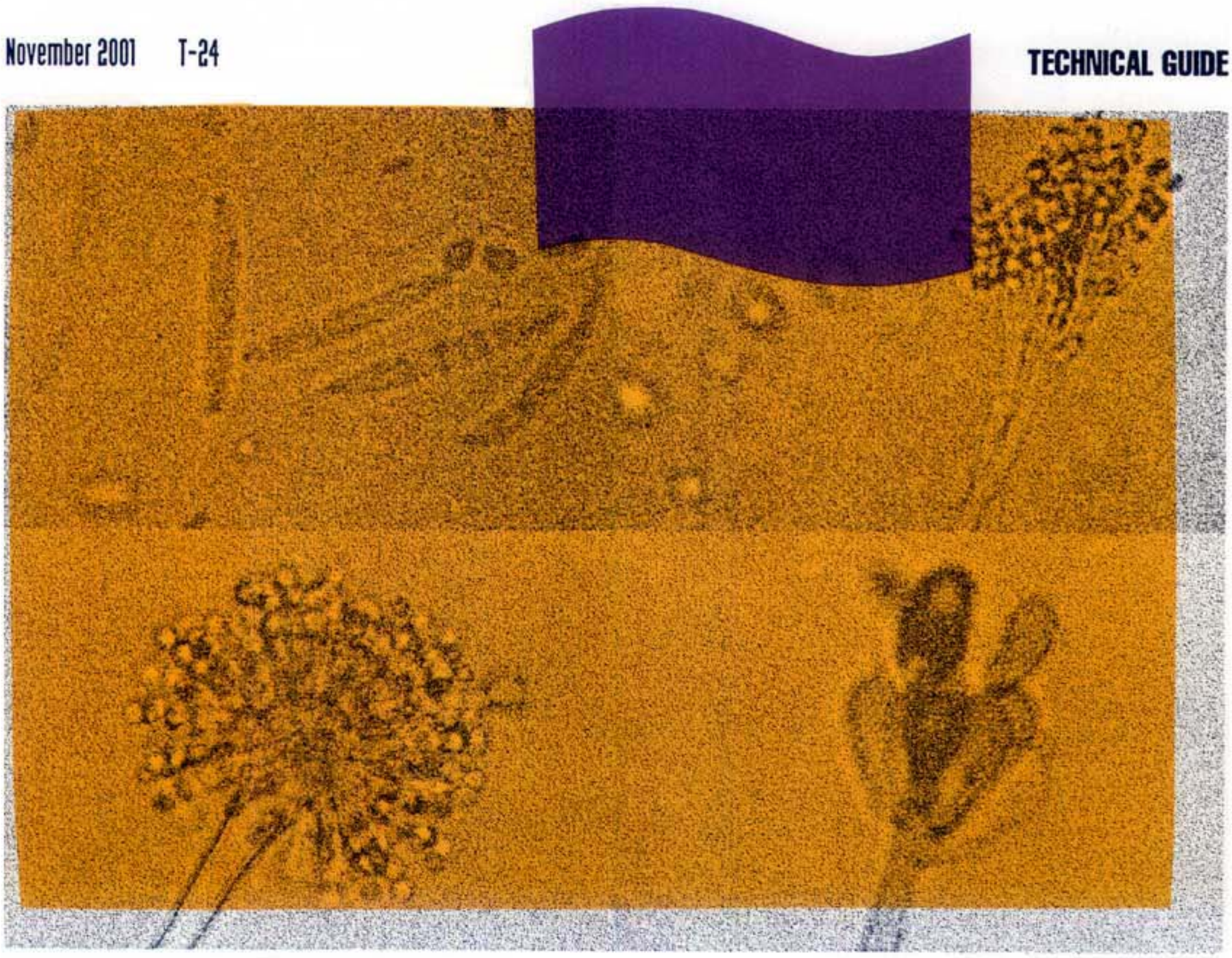
TECHNICAL GUIDE



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ÉTUDES ET RECHERCHES

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TECHNICAL GUIDE

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CONTEXT

Microorganisms are ubiquitous in our environment: they are present in water, soil, air, plants, animals and people. In the workplace, the interest in microorganisms mainly relates to their presence in the air; they are then called bioaerosols. Bioaerosols are defined as airborne particles consisting of living organisms such as microorganisms or originating from living organisms, such as metabolites, toxins or fragments of microorganisms. For the majority of them, the dose/effect relationships by inhalation have not been established, but the scientific community nevertheless agrees that some bioaerosols may cause health problems. The international interest in bioaerosols as an agent that can affect workplace air quality and workers' health has rapidly increased the pool of knowledge on their identification, quantification, their presence in different workplaces, and the effects that they can produce in the people exposed to them.

Different approaches for risk evaluation are used by occupational health researchers and professionals, which raises questions mainly about the types of microorganisms or derivatives to be investigated; the purpose, techniques and locations of sampling; result interpretation, taking into account the lack of exposure standards and dose/effect relationships, and the most effective means for correcting an abnormal situation or for maintaining healthy conditions.

This practical guide describes the approach recommended by the IRSST for the evaluation, control and prevention of bioaerosol exposure; it corresponds to the typical industrial hygiene procedure, namely the anticipation, identification and evaluation of the risks, with the ultimate purpose of controlling exposures in order to prevent disease.

The guide is divided into three sections. The first section synthesizes the most current information on the types of bioaerosols present in workplaces, their natural environment, and the conditions conducive to their growth and proliferation. The effects on health of the different bioaerosols are presented in a brief and general way, since this aspect of the procedure must always be entrusted to a physician. It also includes information on the concentrations measured in different workplaces and the proposed exposure values. The second section covers the strategies for evaluating a workplace based on the objective pursued. The methods, techniques and tools available for this evaluation, the sampling plan, and result interpretation are addressed. The third section presents means of control and prevention. The specific case of the demolition and repair of water-damaged materials is considered. For each of the chapters, the consulted references are listed, as well as those that may serve as complementary tools.

The aim of this guide is to harmonize the evaluation and prevention approach for bioaerosol exposure through a better understanding of the possibilities and limits of the procedure applied. This procedure applies to all activity sectors where bioaerosols can be present in abnormal concentrations.

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NOTICE TO THE READER

Since microorganisms are ubiquitous in the environment, bioaerosol exposure in unavoidable. In this document, the expressions “potential exposure to bioaerosols” or “exposure to bioaerosols” refer to a situation in which the bioaerosol concentrations are abnormally high.

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SECTION 1: GENERAL INFORMATION

1.1 Knowledge about microorganisms

Microorganisms are ubiquitous in our environment: they are present in water, soil, air, plants, animal and humans. The interest of an industrial hygiene viewpoint mainly relates to the bioaerosols or microorganisms in the air, and more specifically the bacteria, molds and yeasts and their metabolites, toxins or fragments. Other microorganisms are occasionally associated with air quality and are considered briefly in this document; these are dust mites or acarids and viruses. The majority of bioaerosols are of respirable size, namely in the order of 0.003 µm for viruses, from 0.5 to 20 µm for bacteria, from 10 to 100 µm for plant pollens, and from 2 to 200 µm for molds. The health effects reported here are of a comprehensive and general nature since this aspect of the process must always be entrusted to a physician. A scientific advisory from the ministère de la Santé et des Services sociaux du Québec (Québec ministry of health and social services) dealing with exposure to molds in the indoor environment is being prepared and will be a reference document for health effects and medical investigation tools. Additional information can be found in the references mentioned at the end of this section.

1.1.1 Bacteria

Bacteria are abundant in the environment and in humans. There are more than 150,000 known species of bacteria. They are single-celled organisms that reproduce by simple cell division. The majority of bacteria contain the necessary genetic information and energy capacity to ensure their growth and reproduction. They are capable of using various inorganic and organic nutrient sources. The majority of the species encountered in air quality are saprophytes, meaning that they get their energy from organic sources.

Bacteria are classified on the basis of cellular, morphological or biochemical characteristics. They are divided into two major groups based on their reaction to Gram stain: Gram positive bacteria and Gram negative bacteria. Bacteria require a lot of moisture to multiply. Gram negative bacteria have a fragile cell wall that does not tolerate well the dehydration that they undergo when exposed to air for prolonged periods or during sampling. Gram positive bacteria have a more resistant wall, and some produce spores that give them an increased resistance to variations in environmental conditions. This group contains thermophilic bacteria, bacteria whose growth is promoted at higher temperatures and that are of particular interest in air quality.

In the outdoor environment, bacteria mainly come from water, soil and plants and are associated with the presence of humans and animals. Bodies of water can dissipate bacteria into the air by aerosolization, just like the emissions from certain industrial processes and cooling units. Inside non-industrial buildings, bacteria come mainly from the occupants because bacteria make up the natural flora of the skin and mucous membranes. Indoors, the species are more numerous and the concentrations are above those of the outdoor environment. Some workplaces such as barns, breeding farms, waste and wastewater treatment plants, and food and beverage plants are themselves conducive to the presence and growth of bacteria. This type of environment is where Gram negative bacteria are more likely to be measured.

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The majority of bacteria naturally present do not cause adverse health effects. Some bacteria are even essential to both the human body and the environment. Health risks appear when the concentrations of some species become abnormally high. High concentrations of thermoactinomycetes bacteria may cause hypersensitivity pneumonitis such as farmer's lung.

Some bacteria are recognized as the agents responsible for infectious diseases. The health risk related to the presence of *Legionella pneumophila* bacteria, namely legionnaire's disease, is well documented. There are two distinct types of legionellosis, namely legionnaire's disease, a progressive pneumonia that can be fatal, and Pontiac fever causing symptoms similar to those of influenza. This bacterium is known for its ability to develop in water tanks. It is prone to drying and does not survive outside water. However, it can be transmitted through the air by the projection of the droplets of water that contain it.

The genus *Mycobacterium* is also of health interest, and particularly the species *Mycobacterium tuberculosis*, the etiologic agent responsible for tuberculosis. The majority of species of mycobacteria live in soil and water but their main niche is the unhealthy tissues of warm-blooded animals, including humans. The *Mycobacterium tuberculosis* bacterium is airborne by droplets generated by carriers of the disease and by ventilation systems.

People who have persistent health problems that seem to be related to exposure to bacteria or other bioaerosols must consult a physician.

Table 1 reports the main types of bacteria that are potentially present in workplace air according to the literature. Figure 1 shows the prevalence of the different types identified by the IRSST's microbiology laboratory in 63 work environments, including 36 office buildings, 12 schools and 15 hospitals, originating from requests for analyses that it has received in the last 8 years.

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1.1.2 Molds and yeasts

There are currently several tens of thousands of known species of molds and yeasts, with the two groups being in the fungus family. Fungi are ubiquitous in the environment and are primary saprophytes, meaning that they use dead organic material as a source of nutrients for their growth and reproduction. Several live in the soil and take an active part in the decomposition of organic material. They are generally aerobic. Humans may be commonly exposed to more than 200 species of them, several of which proliferate well in a humid indoor environment.

Yeasts are single-cell organisms that divide by fission and budding. Molds are multicelled and they propagate by spores. These components develop into filaments called hyphae, which, by clumping, form the mycelium. This produces a more specialized structure, the spore apparatus, responsible for the formation of spores. Spores differ in form, size and color. They can survive from a few days to several years. Each spore that germinates may produce a new mold, which in turn, under the appropriate growing conditions, may produce millions of spores.

Molds release their spores under the effect of major air currents or as a reaction to unfavorable conditions such as a rapid increase or decrease in humidity or to reach a new source of food. The presence of these spores in the air also depends on their mode of dispersion. In fact, the mode of dispersion and transfer for spores differs with the species. Some spores, called gloeiospores, have a thick wall of moist consistency and remain stuck together by mucus. They form heavy bodies that are not easily transported by the air. They are carried by substrates by contact, insects or water. This is the case for molds of the genera *Acremonium* and *Exophiala*. Other genera such as *Penicillium* and *Cladosporium* have spores with dry walls, easily dissociable and light. They are more easily dispersed in the air. Spore concentrations in the air depend on the surrounding conditions and therefore vary during any given day.

In nature, the concentration of molds has its peak from July to the end of the fall. Contrary to pollens, molds persist after the first frost. A few may develop at temperatures below the freezing point but most become dormant. Snow cover drastically reduces the concentrations in the air but does not kill molds. When the snow melts, molds develop on the dead vegetation. Temperature affects the rate of growth of molds. They have a minimum, maximum and optimal growth temperature. The ambient temperature in the order of 20 to 25^0C maintained in the majority of indoor environments corresponds to an ideal growth zone for the majority of them.

The main genera of molds and yeasts potentially present in workplace air according to the literature are listed in table 1. Figure 2 shows the prevalence of the different genera identified by the IRSST microbiology laboratory in 126 work environments including 47 office buildings, 41 schools, 23 hospitals and 15 plants. These data originate from requests for analyses sent to the laboratory in the last 8 years. This distribution agrees with those reported in the literature (Thorne and Heederick, 1999; Nolar, 1999). Photographs of molds are given for information purposes in Appendix 1.

Yeasts and molds can therefore be found everywhere there is an appropriate temperature, humidity, oxygen, sources of carbon and nitrogen and the minerals that they need. Their

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biological activities of biodegradation or biodeterioration depend on their own enzymatic activities, the environmental conditions, the phenomenon of competition, and the nature of the substrate. For example, some molds easily use cellulose, and their proliferation is favored when the materials containing it are soaked with water. Table 2 lists the main genera of molds that can develop on different substrates.

To date, epidemiological studies have not established a causal relationship between the extent of the fungal presence, exposure to the molds in the air and specific health effects, or the frequency and severity of the symptoms reported. Studies tend to demonstrate the existence of relationship between mold exposure and the development of some symptoms, particularly respiratory symptoms. Several of these studies have also noted the presence of high humidity. It can therefore be difficult to separate the effects of high humidity from those of the molds.

For the majority of people, ambient concentrations of molds do not cause health effects. However, in situations where the concentrations are abnormally high or for certain people suffering from respiratory problems or whose immune systems are deficient, exposure to molds may promote the appearance of symptoms and illness. The effects felt depend on the species present, their metabolic products produced, the concentration, and duration of exposure, and individual susceptibility.

The nature of the dose-response relationship between exposure to molds and the impact on health is not known, no more than a safe exposure threshold below which there is no risk.

The main health effects associated with exposure to molds are hypersensitivity reactions (allergy), infections and irritation.

Hypersensitivity reactions

Allergy is the most common manifestation associated with exposure to molds. Most produce antigenic proteins that may cause an allergic reaction in sensitized people, including asthma, rhinitis and conjunctivitis. Hypersensitivity pneumonitis may also occur. However, several authors associate exposure to low levels of molds with an exacerbation of asthma and other respiratory problems.

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Infections

Some one hundred species are known to cause infection in people. There are three classes of infections caused by molds: systemic, opportunistic and superficial. Systemic infections such as histoplasmosis (due to the mold *Histoplasma capsulatum* found mainly in bird droppings) are caused by the inhalation of spores. Opportunistic infections are generally limited to people whose immune systems are deficient. The main molds responsible for these opportunistic infections are *Aspergillus, Acremonium, Beauvaria, Cladosporium, Fusarium, Mucor, Paecilomyces, Penicillium, Rhizopus, Scedosporium, Scopulariosis* and *Trichoderma.* Dermatophytes are a group of molds that affect the scalp, skin and nails. These infections occur by skin contact. Transmission to humans through the air is very unlikely.

Irritation

Metabolism of molds produces volatile organic compounds that cause the "musty" smell associated with fungal growth. The following compounds have been identified as indicators of microbial growth: 1-octene-3-ol, 2-octene-1-ol, 3-methyl furan, 3-methyl-2-butanol, 3-methyl-1-butanol, 2-pentanol, 2-hexanone, 2-heptanone, 3-octanone, 3-octanol, 2-methyl-isoborneol, 2-methyl-2-butanol, 2-isopropyl-3-methoxypyrazine, geosmine. These compounds can be irritating to the mucous membranes.

Individuals who have persistent health problems that seem related to exposure to molds or other bioaerosols must consult a physician.

The physical examination and patient's history may lead to the clinical diagnosis. Few complementary clinical tests are available, except in cases of allergy. Immunological tests such as skin tests are used to detect specific antibodies. Measurement of the antibodies developed by a person following exposure only means that there was exposure without determining its extent or duration. Considering the pervasiveness of molds and therefore exposure, this measurement is of limited usefulness. Respiratory function and respiratory provocative challenge tests are also used to help in the diagnosis.

1.1.3 Metabolites, toxins or fragments of microorganisms

Mycotoxins

During the nutrient degradation process, molds release secondary metabolites called mycotoxins that they use as a defense against other microorganisms including other molds. A given fungal species may produce different toxins depending on the substrate and the local environmental factors. Mycotoxins are nonvolatile compounds and will be found in the air only if the environment in which they are produced is disturbed.

The health effects from respiratory exposure to mycotoxins are not well known. They could be the causal agents of the effects reported following exposure to molds. The reported symptoms vary with the type, nature and extent of contact. They include: skin and mucous membrane

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irritation, immunosuppression, and systemic effects such as dizziness, nausea, headache, and cognitive and neuropsychological effects. It should be noted that the latter effects are not extensively documented and that the potential causal mechanism has not been elucidated. Some mycotoxins such as aflatoxin are considered carcinogenic; the ingestion of aflatoxin is a known cause of liver cancer. The only relationship between cancer and the inhalation of mycotoxins has been demonstrated in very contaminated environments in agriculture or industry.

There are more than 400 known mycotoxins. Table 1 lists the main mycotoxins and the organisms that produce them.

Endotoxins

Endotoxins are components of the exterior cell membrane of Gram negative bacteria and are composed of lipopolysaccharides associated with proteins and lipids. The term “endotoxin” refers to the toxin present either in the bacterial cell or in the fragments of the cell walls released during bacterial lysis. Their presence in a work environment is linked to that of Gram negative bacteria.

Health effects vary greatly with the species, individual, dose and route of entry. The symptoms reported following respiratory exposure to endotoxins are cough, shortness of breath, fever, lung obstruction and inflammation, and gastrointestinal problems.

Glucan / Ergosterol

β-(1-3)-D-glucan is a polymer of glucose of high molecular weight found in the cell walls of molds, bacteria and plants. Recent evidence suggests that β-(1-3)-D-glucan may be a respiratory irritant. Ergosterol is a component of the cell membrane of molds whose mass proportion would be practically constant.

Glucans and ergosterol could act as potential environmental markers of exposure to molds but their quantitative significance is still unknown.

Others

Peptidoglycans are components of the cell wall of bacteria. They are suspected of being a potential causal agent of lung inflammation associated with the inhalation of Gram positive bacteria.

Exotoxins are bioactive molecules, normally proteins secreted during the growth of bacteria. They are also released during the lysis of bacteria. Although generally associated with infectious diseases such as botulism, cholera and tetanus, they can be found on substrates that support bacterial growth and can subsequently take aerosol form. The risks associated with their presence in the air are not documented.

1.1.4 Other microorganisms

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Viruses

Viruses require a living host cell to live, reproduce and propagate. They can be aerosolized by the projection of droplets from infected people, but they are rapidly rendered inactive in the ambient environment. The presence of symptoms or illness in the host is sufficient evidence of their presence.

Dust mites (acarids)

Mites are natural hosts in the environment. They belong to the arachnid family, which includes spiders and ticks. They feed on pollen, bacteria, molds, and skin scales. Mites live optimally at 25^0C and between 70 to 80% relative humidity. Due to their very small size and their low weight, acarid droppings, known allergens particularly for asthma, are easily airborne. Skin tests are available to detect immunological sensitivity to acarids.

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Table 1: Main bioaerosols potentially present in the air

GRAM NEGATIVE BACTERIA	
Acinetobacter	*Klebsiella*
Citrobacter	*Legionella (eau)*
Enterobacter	*Moraxella*
Escherichia	*Pseudomonas*
Flavobacterium	*Xanthomonas*

GRAM POSITIVE BACTERIA	
Arthrobacter	*Micrococcus*
Bacillus	*Staphylococcus*
Kocuria	*Streptococcus*

IRREGULAR GRAM NEGATIVE RODS AND ACTINOMYCETES	
Corynebacterium	*Norcardiopsis*
Mycobacterium	*Streptomyces*
Saccharopolyspora	Thermoactinomycetes

MOLDS AND MYCOTOXINS

GENUS (Number of species)	MYCOTOXINS[A]	REMARKS
Acremonium sp. (70)	---	
Alternaria sp. (40-50)	*A. alternata*: alternariol, tenuazoic acid	Large dimension septate spores *A.alternata*: the most common
Aspergillus sp. (200)	*A flavus, A. parasiticus*: aflatoxins, citrinin *A. clavatus*: cytochalasins *A. fumigatus*: fumitremorgins, gliotoxin *A. niger*: oxalic acid *A. ochraceus*: ochratoxins *A. versicolor*: sterigmatocystin	Very common group. Small dry spores easily airborne.
Aureobasidium sp. (15)	---	Colonizes leaves in fall, facilitating the decomposition activity
Botrytis sp.	---	
Chaetomium sp. (80)	Chaetomin *C. globosum*: chaetoglobosins	

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Cladosporium sp. (50)	Epicladosporic acid, cladosporin	The most prevalent group in the outdoor air
Epicoccum sp. (2)	Flavipin, epicorazins, indole-3-acetonitrile	Develops on substrates where *Cladosporium* and *Aureobasidium* are present
Fusarium sp. (50-70)	Fumonisins, trichothecenes: T-2, vomitoxin, zearalenone	Plant pathogen
Geotrichum sp.	---	
Memnoniella sp.	Griseofulvins	Resembles *Stachybotrys*.
Mucor sp. (50)	---	
Paecilomyces sp. (31)	Paecilotoxins *P. variatti*: patulin	Small dry spores that are easily airborne
Penicillium sp. (200)	*P. expansum*: citrinin, patulin *P. griseo-fulvum*: griseofulvins *P.viridiatum*: griseofulvins, ochratoxins *P*. polonicum: verrucosidin	Very common group Small spores that are easily aerosolized
Phoma sp.	*P*. soghina: tenuazoic acid	
Stachybotrys sp. (15)	*S. chartarum*: trichothecenes: satratoxin, stachybotrylactams, lacones	*S. chartarum*: spores not easily aerosolized; not very competitive in the presence of other molds in culture: rather unreliable measurements in the air
Trichoderma sp. (20)	*T viridi*: trichothecenes: satratoxin	Ability to kill other molds
Ulocladium sp. (9)	---	Septate spores. Resembles *Alternaria*

[A] Incomplete list.

YEASTS

Candida
Cryptococcus
Rhodotorula
Trichosporon
Torulopsis

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Table 2: Dominant bioaerosols in relation to substrates

SUBSTRATE	DOMINANT MOLDS AND BACTERIA
A – FOOD PRODUCTS	
Peanuts	*Aspergillus, Penicillium, Eurotium, Emericella, Trichothecium, Paecilomyces, Fusarium*
Cereals: during cultivation	*Alternaria, Chaetomium, Cladosporium, Epicoccum, Fusarium, Helminthosporium, Trichoderma*
Cereals: in silo	*Aspergillus, Eurotium. Penicillium, Absidia, Mucor, Rhizopus*
Cereals: flours and derivatives	*Aspergillus, Absidia, Alternaria, Cladosporium, Fusarium, Trichothecium, Mucor, Scopulariopsis, Wallemia*
Fruits and vegetables	*Penicillium, Phomopsis, Diplodia, Botrytis, Geotrichum, Monilia, Trichotecium, Fusarium Alternaria, Aspergillus, Paecilomyces*
Eggs	*Penicillium, Aspergillus, Cladosporium, Mucor*
Milk products: cheese	*Mucor, Penicillium, Cladosporium, Scopulariopsis, Epicoccum, Trichoderma, Alternaria, Botrytis, Trichothecium*
Milk products: butter and margarine	*Alternaria, Aspergillus, Eurotium, Moniliella, Phialophora, Phoma, Penicillium*
Meats and deli meats	*Aspergillus, Chrysonilia, Geotrichum, Cladosporium, Geomyces, Penicillium*
B – MISCELLANEOUS PRODUCTS	
Wood and plants	*Alternaria, Aureobasidium, Chaetomium, Cladosporium, Bipolaris, Fusarium, Trichoderma, Ulocladium*
Cosmetics	*Aspergillus, Paecilomyces*
Leather	*Aspergillus, Eurotium, Aureobasidium, Catenularia, Neosartorya, Paecilomyces, Penicillium*
Cork	*Penicillium, Aspergillus, Trichoderma*
Damp cellulose-containing materials	*Chaetomium, Cladosporium, Aspergillus, Penicillium, Stachybotrys, Ulocladium*
Plastic materials	*Aspergillus, Aureobasidium, Penicillium*
Metals: aluminium, steel	*Aspergillus, Trichoderma*
Paper	*Aspergillus, Penicillium, Chaetomium, Acremonium, Beauveria, Cladosporium, Epicoccum, Papulospora, Phoma, Scopulariopsis, Ulocladium*
Paints and adhesives	*Aureobasidium, Phoma, Cladosporium, Alternaria, Fusarium, Trichoderma, Gliomastix, Penicillium*
House dust	*Alternaria, Aspergillus, Mucor, Trichoderma, Penicillium*
Petroleum products	*Cladosporium, Aspergillus, Penicillium,*

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	Aureobasidium, Acremonium, Fusarium
Tobacco	*Aspergillus, Scopulariopsis*
Textiles: cotton	*Alternaria, Aspergillus, Eurotium, Emericella, Epicoccum, Aureobasidium, Cladosporium, Dendrodochium, Fusarium, Stachybotrys, Trichoderma, Ulocladium*
Textiles: jute	*Aspergillus, Curvularia, Memnoniella, Myrothecium, Paecilomyces, Penicillium, Stachybotrys, Talaromyces*
Textiles: wool	*Alternaria, Aspergillus, Fusarium, Microsporum, Phoma, Scopulariopsis, Trichoderma*
Glass	*Eurotium, Penicillium*
	C – WORKPLACES
Bakeries	*Penicillium, Aspergillus, Cladosporium*
Offices (ventilation systems / humidifiers	*Aspergillus, Alternaria, Cladosporium, Acremonium,Aureobasidium, Rhodotorula, Mucor, Penicillium,* Bactérie *Legionella, Pseudomonas* bacterium
Household waste (composting)	*Aspergillus, Alternaria, Paecilomyces, Penicillium, Trichoderma, Actynomyces* bacteria
Household waste (sorting)	*Aspergillus, Penicillium, Actynomyces* bacteria
Wastewater (treatment)	*Aspergillus, Penicillium, Cladosporium,*
Farms	*Aspergillus, Penicillium, Absidia, Rhizomucor, Fusarium, Wallemia, Curvularia*
Cutting fluids (machining)	*Fusarium, Pseudomonas* bacteria
Sawmills	*Alternaria, Cryptostoma, Paecilomyces, Penicillium, Rhizopus, Serpula, Monilia*

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Figure 1: Bacteria found in 63 work environments

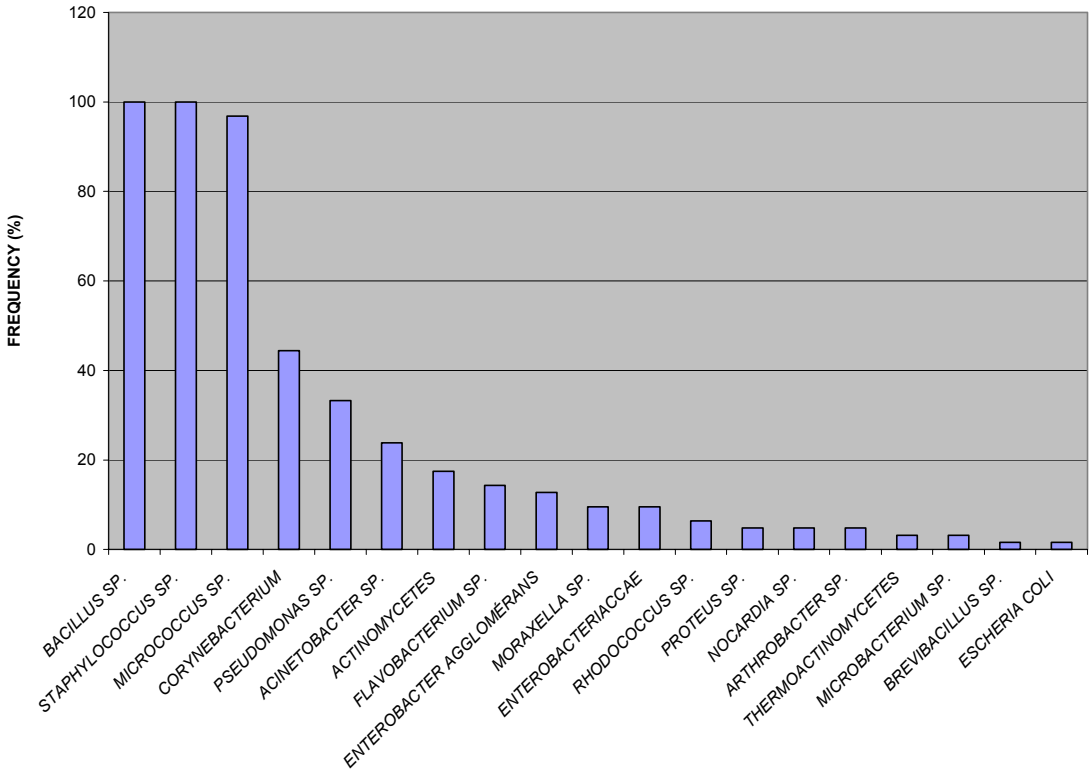
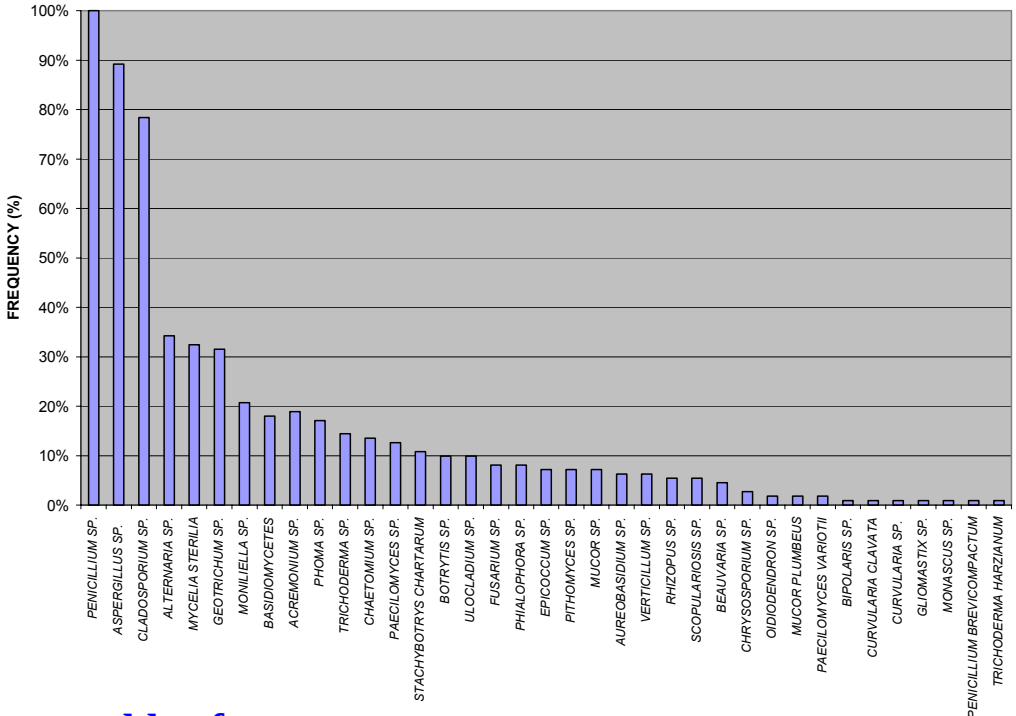


Figure 2: Molds found in 126 work environments



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1.2 Bioaerosol concentrations measured in the workplace

Microorganisms are ubiquitous in the environment but their concentrations vary in relation to several parameters including the type of substrate and the environmental conditions. Therefore, some workplaces such as breeding farms, barns, waste and wastewater treatment plants, and food and beverage plants and warehouses promote the presence of bacteria and their growth, particularly Gram negative bacteria with which endotoxins are associated. These environments are also conducive to the development of molds.

Tables 3 and 4 give examples of concentrations of viable bioaerosols and of endotoxins measured in different workplaces. The results must be interpreted with care and considered as indications since the methods differ with the study.

These results show that:

- The concentrations of total bacteria are very high, in the order of 10^6 CFU (colony forming units) /m^3, in agriculture, in the production of compost for mushroom cultivation, when cutting fluids are used, and in paper mills and pig-housing facilities.
- The maximum concentrations of Gram negative bacteria, in the order of 10^4 CFU/m^3, are found in wastewater treatment plants, when cutting fluids are used, and in pig-housing facilities and sawmills.
- The concentrations of actinomycetes may present problems in agriculture and in the production of compost for mushroom cultivation, with concentrations in the order of 10^7 to 10^9 CFU/m^3.
- Molds are found in high concentrations, in the order of 10^6 to 10^9 CFU/m^3, in agriculture, in sawmills and in peat bogs.
- The maximum concentrations of endotoxins were measured in agriculture, in fiberglass plants, and in potato preparation plants. It was in this last location that the maximum concentration of 1.9 x 10^6 ng/m³ of air was measured.

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Table 3: Bioaerosol concentrations measured in workplaces

Workplace	Total bacteria (CFU/m³)[a]	Gram negative bacteria (CFU/m³)	Thermophilic Actinomycetes (CFU/m³)	Molds (CFU/m³)
Outdoors	10^2	10^1	10^1	10^3
Agriculture (normal)	10^7	10^3	10^3	10^{3-4}
Agriculture (moldy hay)	10^9	10^3	10^9	10^9
Bakery				10^{2-3}
Composting center	10^5	10^2	10^4	10^4
Wastewater treatment plant	10^4	10^4	10^0	10^3
Mushrooms (compost)	10^6	-[b]	10^7	10^4
Mushrooms (cultivation)	10^3	-	10^2	10^2
Household waste (collection)	10^4	10^3	10^3	10^4
Office building	10^2	10^1	10^1	10^{2-3}
Paper mill effluents	10^4	10^3	10^1	10^4
Cutting fluid	10^6	10^4	-	10^5
Humidifier	10^3	10^3	-	10^{2-3}
Cotton mill	10^5	10^4	10^5	10^3
Papermill	10^6	10^{2-3}	-	10^3
Pig-housing facility	10^6	10^{3-4}	-	10^4
Sawmill	10^4	10^{3-4}	10^3	10^6
Peat bog	-	-	-	10^8
Sugar processing	10^5	10^3	10^2	10^3
Household waste sorting	10^4	10^3	10^0	10^4
Tobacco plant	10^3	10^2	-	10^4

[a] CFU/m^3 = colony forming units per cubic meter of air
[b] - = not documented

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Table 4: Endotoxin concentrations measured in workplaces

Workplace	Concentration ng/m^3 [a]
Biotechnology	<1-1810
Bakery	<1-7
Grain cultivation	6-16,000
Silo emptying	159-8,850
Office building	<1-254
Bird breeding	30-720
Oat warehouse	1290
Wood furniture manufacture	1.2-350
Fiberglass manufacture	<1-27,800
Fur-bearing animal farm	1 –1,950
Dairy farm	10 –50,000
Lumber mill	<1-80
Grain mill	3-530
Paper mill	1-760
Pig-housing facility	1-75,000
Poultry house	1-2,680
Food preparation for animals	<1-1,850
Litter preparation	44-1,430
Potato preparation	45,000-1,893,000
Rice production	48-1,340
Sawmill	20-17,000
Brewery silo	60-927
Corn silo	19-5,450
Textile (cotton)	<1-2,200
Water treatment	<1-410
Waste treatment	0-990
Emptying of compost	6-30

[a] ng/m^3 = nanograms per cubic meter of air; 10 ng/m^3 = 1 EU/m^3 (EU = endotoxin unit)

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1.3 Exposure values

There are no Québec, Canadian or American standards for bioaerosol exposure limits. There are several explanations for this lack of exposure limit values:

- The dose/effect relationships have not been sufficiently documented. The information currently available is based on relationships between health effects and environmental measurements on a case-by-case basis. Individual susceptibility seems to be very important.
- In the majority of cases, the reported effects involve a specific species, while in any environment, the diversity of viable and non-viable species is high. The synergistic effects of multiple exposure to bioaerosols, for example molds and mycotoxins, have not been studied.
- It is difficult to conduct rigorous epidemiological studies with objective exposure measurements and objective health evaluation criteria on a sufficient number of groups of workers.
- The composition and concentrations of species that make up an environment's microbial flora are affected by many factors, including variations in ambient conditions and the life cycle of the different species. The background levels therefore fluctuate greatly.
- The documentation of exposures is based on very short-term ambient samples. No measurement of the cumulative exposure dose is possible.
- No method allows all of the bioaerosols present to be measured, and sometimes major differences are noted in the methods used.

A lot of information is missing in establishing exposure limit values. If such limit values are established for a group of agents or for a specific agent, they will not only have to give a concentration value but also specify the evaluation strategy and the sampling and analytical methods.

Despite the mentioned shortcomings, some values and some criteria are proposed to help assess the significance of the bioaerosol exposure.

- The scientific community agrees that the comparison of species and concentrations of bioaerosols found inside premises in relation to those outdoors (or from another reference site) is a useful indication in determining whether there is a proliferation site indoors. If the indoor concentrations are significantly higher or the species are different, a bioaerosol generation or proliferation site is possible. This approach is recommended for molds in general, and for bacteria originating from the outdoors. Besides the outdoor concentrations, the concentrations measured in a control area or during a process shutdown or work stoppage may also be used as reference concentrations. For example, the control area can be a process control centre if it is independently ventilated or an area where there are no complaints, in the case of an office building.
- A similar approach is proposed for evaluating endotoxin exposure, namely the comparison of endotoxin activity levels in a given environment with the simultaneously measured background levels. The ACGIH proposes relative comparison values for endotoxins. If respiratory symptoms are present in relation to the presence of endotoxins for exposed workers, the measured concentrations must be 10 times lower than the background. If there are no symptoms, the exposure levels can be up to 30 times higher than the background.

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- Guidelines of 10,000 CFU/m³ of air for total bacteria and 1,000 CFU/m³ of air for Gram negative bacteria are proposed by the Scandinavian countries for eight-hour exposures in environment-related activities (Malmros,1990; Poulsen et al,1995).
- Different organizations and researchers propose guidelines based on certain molds
  - AIHA:
    - Molds such as *Cladosporium, Alternaria,* and *Epicoccum* and Basidiomycetes, normally present in the outdoor air (depending on the climate), must be at lower concentrations inside mechanically ventilated buildings.
    - The confirmed presence of *Stachybotrys chartarum, Aspergillus versicolor, Aspergillus flavus, Aspergillus fumigatus* or *Fusarium moniliforme* requires immediate measurement. The confirmed presence of a species is defined as its presence in several samples, several colonies on a sample or, if there is only one colony on a sample, confirmation of its growth on a surface.
    - Bird or bat droppings must be immediately eliminated.
  - Health Canada:
    - Bird or bat droppings must be immediately eliminated.
    - The persistent presence of toxigenic molds (*Stachybotrys chartarum,* some species of *Aspergillus*, *Penicillium* and *Fusarium*) requires a more detailed analysis.
  - Workshop (Holland 1992, reported in Samson et al., 1994):
    - The following species are considered as indicating a humidity problem or a health risk (based on the dampness of the materials): *Aspergillus fumigatus, Aspergillus versicolor*, *Exophiala*, species of *Trichoderma*, *Eurotium*, *Wallemia* and *Penicillium (chrysogenum, aurantiogriseum), Stachybotrys, Phialophora, Fusarium*, *Ulocladium* and yeasts (*Rhodotorula*).
  - ACGIH:
    - Of the previously mentioned species, the ACGIH assigns particular importance to: *Aspergillus versicolor, Stachybotrys* and *Fusarium.*
    - The presence of low concentrations of indicator species must be interpreted with care. Furthermore, it should be noted that species identified as indicators are not the only molds to be considered.

Table 5 presents the action criteria proposed by the IRSST. They correspond to concentrations and observations justifying further investigation of the situation as well as the required action being taken.

Table 5: Action criteria proposed by the IRSST

Parameter	Action criterion
Total bacteria	Agricultural and industrial environment: 10,000 CFU/m^3 of air (8 hours) Mechanically ventilated non-industrial environment: 1,000 CFU/ m^3
Gram negative bacteria	Agricultural and industrial environment: 1,000 CFU/m^3 of air (8 hours) Non-industrial environment: presence
Endotoxins	Concentration > 30 times the background

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	Concentration > 10 times the background (if there are respiratory symptoms)
Molds	Visible growth on a surface Characteristic odor perception
Molds	- Concentration > background concentration in the air at the reference site - Different species at the reference site (in the air)
Bioaerosols	Excessive humidity Presence of water (infiltration, flooding, accumulation, etc.)

For the *Legionella* bacterium, concentration values in cooling-tower water have been associated with a risk of contracting Legionnaire's disease:

Legionella (CFU/mL)	Risk level
> 1,000	High
100-999	Moderate
< 100	Low

Considering the constant increase in new knowledge in this field, it is important to verify whether the recommendations provided by reference organizations are still endorsed by these organizations. As an example, in 1999 the ACGIH no longer endorsed any of the numerical guideline values that it had already published.

Bioaerosol measurement and result interpretation mainly with limit values must be one aspect of the evaluation strategy and not the only documentation of a bioaerosol exposure.

The following section specifically covers the strategies to be used in relation to the objectives pursued.

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SECTION 2: EVALUATION STRATEGY

The first part of this section presents the general procedure for evaluating a situation in which there is potential workplace exposure to bioaerosols. The second part covers specific steps in this process, namely the methods, techniques and tools available for this evaluation, the sampling plan, and result interpretation. Brief examples of the application of this process to work situations are then presented.

2.1 General evaluation procedure

As in the evaluation of any workplace parameter, the strategy developed must be based on the objective while taking into account the available methods and tools. A representative result is obtained with a realistic strategy, adapted to the objectives and supported by appropriate statistical treatment and a quality assurance program.

First, it is important to formulate the objective of the intervention. For example, this may involve documenting the air quality in order to develop a health program, an environmental monitoring program, or a personal protection program, responding to a complaint, establishing a relationship between a health problem and a specific bioaerosol, or evaluating the impact of a technological change or the efficiency of corrective measures.

When an environmental assessment is necessary, the second step then consists of documenting the three elements that interact during exposure to bioaerosols, namely the sources of proliferation or emission, the mechanisms of dispersion into the work environment, and the people exposed. The study of the process and detailed visual inspection are the main tools for obtaining information on the first two aspects. They are covered in detail in section 2.2. The third aspect is documented by work organization, the studying the tasks, and the record of complaints and reported or diagnosed symptoms. The symptom aspect must be addressed with a health professional.

The information obtained in this step must conclude that a) no hazardous situation exists, in which case, a healthy environment must be maintained and a follow-up mechanism implemented, b) immediate corrective measures including temporary personal protection must be applied to eliminate or reduce emissions; the effectiveness of these corrective measures must be verified, and a follow-up mechanism to maintain a healthy environment must be implemented, and c) a detailed risk evaluation is necessary; a sampling plan must be developed in relation to the hypotheses resulting from this initial data collection. This sampling plan must specify which bioaerosols are being studied, where and when the sampling must be done, and what techniques are most appropriate. The number of samples must be sufficient to ensure that the observed situation is representative and that the results are correctly interpreted. The results must provide a clear conclusion about the formulated hypothesis.

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Without exposure limit values and conclusive toxicological data, the interpretation of the results of an environmental assessment of bioaerosols is complex and depends on the evaluator's competency and experience and the collaboration of several professionals, including physicians. In such a context, it is essential that the results, the criteria retained for their interpretation, as well as the ensuing conclusions and recommendations be communicated. In the context of a disease prevention approach, the aim of the results of any intervention and the ensuing recommendations must always be to ensure and maintain healthy working conditions.

It is important to remember that in the majority of cases, bioaerosols are not an integral part of the process; they are ubiquitous environmental contaminants. The "sampling to see what is in the air" approach is therefore totally inappropriate since the presence of microorganisms in the air is normal. This approach can even be risky because it produces information that is difficult to interpret, which might create unnecessary concern that leads almost inevitably to the sampling being redone professionally, and therefore with a specific objective and using a solid methodology by which this objective can be met.

Figure 3 describes the general procedure for evaluating a situation where there is potential exposure to bioaerosols.

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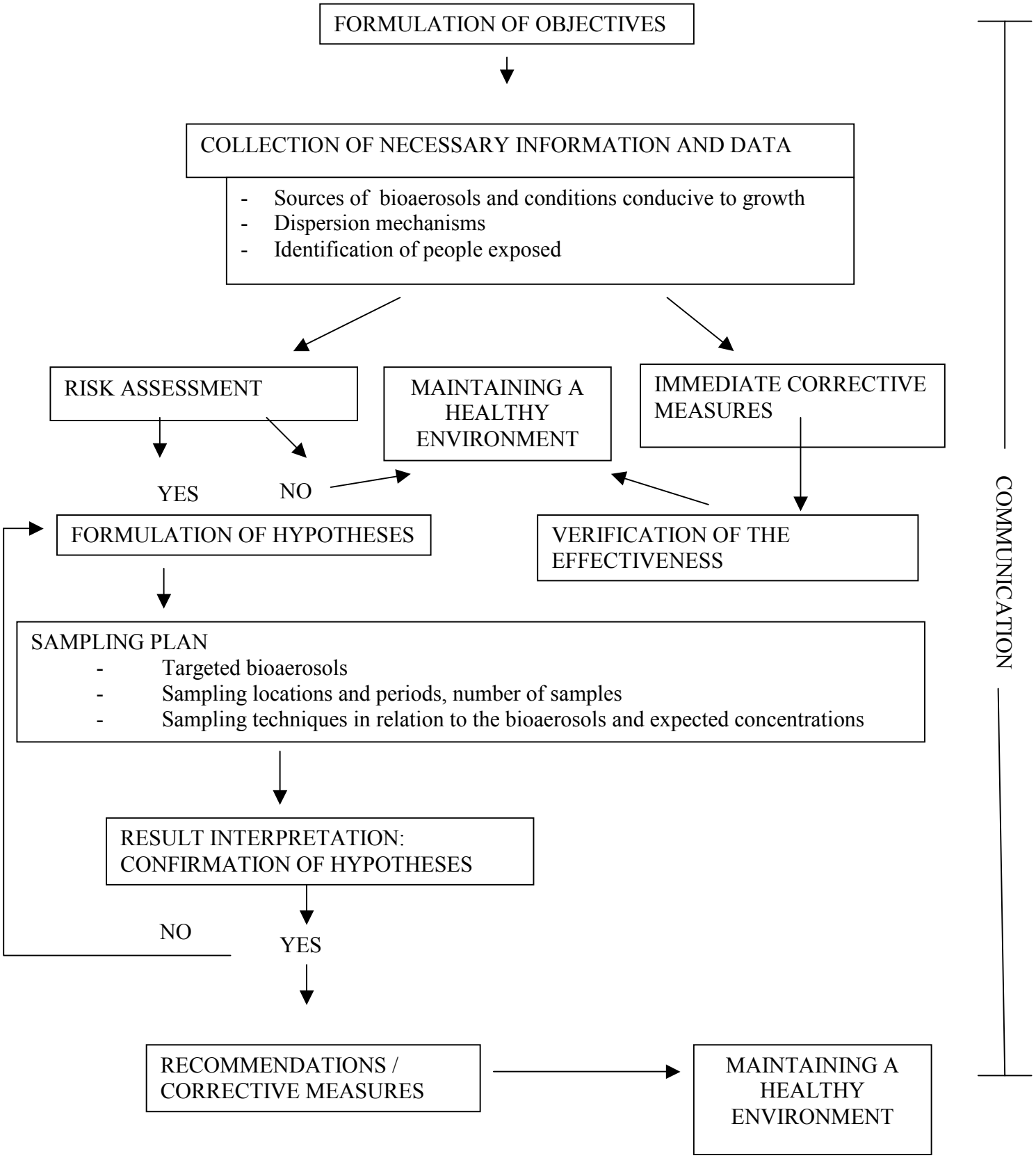
Figure 3: General procedure for evaluating workplace exposure to bioaerosols



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2.2 Evaluation methods

The strategy for evaluating a work situation must be developed in relation to the objective, while taking into account the available methods and tools. To evaluate a situation where there is potential exposure to bioaerosols, the tools and methods can be divided into two different types, namely those that more directly involve the work environment, and those that are related to the measurement of the bioaerosols or their components.

2.2.1 Evaluation of the work environment

An exhaustive visual inspection or the observation of the steps in a process is the most effective means of identifying situations where there may be problem exposure to bioaerosols.

Visual inspection or study of the process must:

- identify and locate all the potential sources or reservoirs of bioaerosols.

Sources can be people themselves, animals, water-damaged materials, a poorly maintained or insufficient ventilation system, waste accumulation, piles of compost, wastewater tanks, etc. The conditions promoting bioaerosol proliferation must also be identified, such as high humidity; waste; water infiltration, accumulation or reservoirs; condensation; and high levels of dust. The presence and extent of visible fungal growth on surfaces must be verified. The following section describes in detail the aspects to be considered in a building's outdoor and indoor inspection.

In some industrial environments, the presence of microorganisms is not only due to the fact that the conditions are conducive to the growth of the microflora normally present in any environment, but also directly associated with the manufacturing or conversion process. The basic materials, products, by-products and activities that are carried out in some plants promote not only the proliferation of microorganisms but also their dispersion and propagation.

- identify the mechanisms of bioaerosol propagation in the air.

Bioaerosol dispersion is promoted by any stirring action of the air or substrates, aerosolization, or projection of liquids and dusts.

- identify the corrective measures to be carried out and the measures to apply.

Measures include : cleaning or removal of sources, installing mechanisms or equipment that limit propagation, establishing safe working procedures, establishing a personal protection program, establishing strict personal hygiene rules, etc. Section 3 in this document deals specifically with corrective measures and control.

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2.2.2 Detailed inspection of a building

Three elements promote microbial growth in an indoor environment: a) a microbial source, b) nutrients, and c) water. When these elements are present, it is recommended that a prevention procedure be developed to minimize the risks of excessive growth. Controlling water accumulation is generally the most effective means of limiting colonization. The pervasiveness of microbes in our environment and the presence of many materials and other nutrient substrates limit the possibilities of rapid and effective intervention at these levels.

In general, the humidity in a building comes from: 1) the normal activities of the occupants or from the processes, 2) water infiltration in liquid or vapor form through cracks in the building envelope, 3) moisture that has collected in the construction materials, 4) the gradual release, during winter, of the humidity that was absorbed in the furniture and materials during the summer period, and 5) the migration of the moisture from the ground through the walls and the basement floor slab.

The initial step in the intervention process is a preliminary inspection of the workplace. It provides different information on the activities that take place inside the building, the nature of the processes, the general operation of the ventilation systems, the plumbing system, and exterior development. These data will be completed, as needed, by specific information relating to the components of the heating, ventilation and air conditioning (HVAC) system, including its control sequence; the building envelope; and the hydraulic parameters of the subsoil. The building occupants as well as the technical personnel assigned to equipment operation and maintenance must be involved in this evaluation.

In many cases, these initial interventions will identify the source of the water by observing either infiltration, leaks, sweating or signs such as blackened wood and water stains.

The building's history must be documented, namely past water infiltrations, sewer backups, floods, fires, dust, as well as the cleaning techniques used for such events.

Water and water vapor can also result in a reduction of the thermal resistance of the insulating materials and a deterioration in their structural resistance. In general, the resulting degradation can be seen by 1) the presence of molds and mildew on surfaces, 2) degradation of wood materials, 3) spalling of masonry and concrete by freeze-thaw cycles, 4) hydrolysis of plastic materials, 5) corrosion of metal components, 6) damage caused by the expansion of materials (e.g., warping of wood floors), 7) a change in surface finishes (flaking of paint on wood siding and efflorescence on masonry), and 8) bulging and cracking of stucco due to condensation of humid air escaping from the envelope or originating from inadequate removal of rain and snow.

A- Exterior inspection of a building

This inspection must identify the locations where water may infiltrate from outdoors. The inspection involves the exterior sheathing, foundations and roof. For an easier understanding of these concepts, examples of building envelopes are presented in Appendix 3.

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Exterior cladding

It may be difficult to find the location of water infiltration on the exterior sheathing. Since water can travel long distances before appearing on an interior surface, the inspection of the exterior envelope should not be limited to the zone near where the water is appearing. As a result, all the exterior wall components must be inspected, preferably while it is raining, because several infiltrations occur at this time. It must also be kept in mind that the cavities in the envelope can act as reservoirs, which can result in a delay between contact of the water with the sheathing and its appearance on the interior.

From the exterior, water can migrate through the envelope under the effect of forces due to 1) gravity, 2) capillarity, 3) a difference in air pressure, 4) the kinetic energy of raindrops, and 5) surface tension. The effect of gravity is to carry the water towards the bottom of the cladding, allowing it to enter through the orifices. This type of infiltration occurs mainly when the materials are not superimposed at the horizontal joints or if the overlapping is reversed. Capillary suction allows water to move in porous and permeable materials as well as through small orifices such as cracks, joints and connections. When the air pressure on the sides of the sheathing is unequal, air moves towards the lower air pressure. The negative pressure produced inside the building by draft or by mechanical ventilation as well as the excess pressure caused by wind on the exterior cladding promote air and water infiltration. Surface tension allows the water to adhere to the lower face of horizontal surfaces.

To limit the risks of water infiltration, it is important that the following waterproofing principles be applied during building design and construction:

- the building is equipped with a water collection system (gutters, flashing)
- the roof can drain easily (sufficient slope, presence of a roof drain)
- the two levels of protection to control rainwater infiltration through the exterior walls are applied:

  - the first level of protection consists of ensuring that the amount of water that can come in contact with the exterior sheathing is minimized mainly by 1) the presence of protective components such as eaves, cornices and drip edges under the window sills, 2) choosing the cladding based on its permeability, the attention paid to the details of the joints and connections, the limited number and size of openings in the cladding, and 3) controlling the effect of forces exerted on the wall.
  - the second level of protection consists of intercepting the water that has come through the first protection and of discharging it outdoors. In a wall built using the rain screen principle, protection is achieved by the presence of an air space with or without a waterproof membrane on the internal wall of the cavity. Any water that enters the cavity is subsequently carried towards the bottom of the wall, to then be drained by the flashing or the weepholes. The installation of protective flashing around the windows for recovering and draining any water that could appear due to inadequate sealant between the cladding and the window, as well as the use of waterproof cladding as covering on the sill serving as support for a window are also examples of secondary protection.

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It should be noted that the means of protection implemented for waterproofing the building may, under certain climatic conditions, be insufficient to prevent water penetration. Abundant rain, snow accumulation, ice and wind are elements likely to hinder water flow and drainage.

Other factors may promote infiltration through the exterior cladding:

- improper installation of seals during window manufacture
- deterioration (cracks, scaling, surface bubbles) of the seals and sealant around the windows
- the use of sealant products that are not weather resistant or are incompatible with the support on which they are applied
- the lack of a proper support when sealant is installed between the metal sections and the cladding
- the presence of cracks in the exterior cladding (masonry veneer, stucco, woods)
- crumbling of the mortar in masonry structures
- water accumulation at the window weepholes due to a reversed slope in the sill
- no drip edge at the window ledges and door sills
- nonexistent or improperly installed sealant around the doors, sill and trim
- nonexistent or improperly installed sealant along the vertical joints between the different exterior sheathing materials not protected by flashing.

Furthermore, doors, windows and skylights not installed according to the manufacturers' recommendations also present risks of infiltration. Certain buildings require the use of expansion joints to allow the materials to expand. The force applied when materials move may result in the loss of adhesion or separation of the sealant and allow water to enter.

Foundations

Foundation inspection may detect the presence of cracks. These cracks can have various causes, mainly deficient design, an incorrectly proportioned concrete, the lack of framing, inadequate backfilling, excessive hydrostatic pressure, frost, aging and differential settlement produced by the drying of the soil. Better surface-water drainage conditions may in some situations eliminate infiltration. This may be achieved by increasing the ground slope near the foundations and by moving the downspouts farther away. A blocked or overloaded foundation drain located on the building's perimeter may also result in water at floor level. Connection of the downspouts to the building drain is not indicated due to the significant hydraulic load that it imposes on the drainage system. In some cases, infiltration may result from the deterioration of the impermeable coating covering the exterior face of the foundations.

Roof

Infiltration from the roof can in some cases be detected from the roof space. The presence of damp surfaces, traces of water and corrosion on the structural components and the accumulation of frost or molds are signs of infiltration or condensation. Noted among the possible causes are the lack of a ceiling vapor barrier or damage to it, insufficient ventilation of the roof space, insufficient insulation, perforations in the roof sheathing, leaks of humid air from an exhaust fan, and the lack of insulation on the roof drain and vent piping.

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Visual inspection done from the roof may reveal damage to the flashing whose purpose is to ensure waterproofness at the juncture of two roof planes, between a wall and a roof, or around openings for chimneys, vents, ventilation outlets, mechanical system piping and skylights. Water accumulation on the roof, due to inadequate drainage (insufficient slope; settlement of the structure; damage; blockage or lack of a drain), must be avoided because it promotes the premature aging of some types of roofing. The condition of the flashing used for covering parapets and other walls extending beyond the roof must be checked.

Signs of roof deterioration vary with the type of roofing. In the case of a multilayer roofing (consisting of felt paper and asphalt in alternating layers, all covered with a layer of asphalt and gravel), the most common problems are:

- perforations resulting from wear or impact
- blisters between the layers caused by trapped water vapor or air
- bubbles in the asphalt caused by expansion of the asphalt due to solar radiation
- bare membranes due to too thin a layer of crushed stone or poor adherence to the asphalt
- surface folds due to the sliding of the felts, or adherence problems caused by the softening of the asphalt under the effect of sun
- cracks caused by the hardening of the asphalt (oxidation of the asphalt by the sun results in hardening that creates contraction forces), crushing of the blisters, structural movement or the contraction of materials under frost action.

For roofs made of asphalt shingles, the risk of infiltration is generally associated with the following problems:

- improper installation of shingles
- premature deterioration caused by water vapor infiltration, solar radiation, wind
- deformation and movement of shingles by bending, or displacement (deficient attachments) of the roofing support or improper attachment of shingles
- formation of an ice jam due to inadequate ventilation of the roof space, significant heat loss, or the presence of a thermal bridge.

B- Interior inspection of a building

This inspection must identify the areas that promote bioaerosol proliferation, and verify the presence and evaluate the extent of visible fungal growth. The inspection involves the ventilation/air conditioning system and all surfaces (rugs, ceilings, walls, beams, window contours, work surfaces, etc.). In general, sources of stagnant water are sites for bacterial growth, while poorly maintained and dusty surfaces are sites for mold growth. The IRSST document “Guide for the Prevention of Microbial Growth in Ventilation Systems” as well as the document published jointly by the EPA and NIOSH entitled “Building Air Quality, a Guide for Building Owners and Facility Managers” describe all the components to be inspected in a ventilation system and in the indoor environment.

Surfaces can be damaged not only by obvious phenomena such as floods, water damage or infiltration, but also in more subtle ways by the condensation and migration of water vapor.

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Water vapor can travel across the building envelope by two mechanisms, namely 1) air movement, and 2) diffusion caused by a difference in vapor pressure. It is accepted that air movement is the main mode of vapor transfer. When vapor crosses the envelope from a warm area to a cold area, it may condense. This situation occurs when the surface temperature is equal to or less than the dew point of the air-water mixture. If the water is not eliminated, it may cause deterioration of the materials and promote the development of molds and bacteria.

Air movement across the envelope is caused by wind forces, the stack effect, and by ventilation. In the majority of buildings, air infiltration is observed on the lower part of the building and exfiltration on the upper part. When there is no vapor barrier or it is improperly installed, the humid air from the interior moves towards the outside and is likely to condense. On wood siding, scaling of the paint is often associated with the diffusion of vapor from the interior towards the exterior. The efflorescence observed on a masonry surface can be related to the same phenomenon. Water accumulation in porous materials may, under frost action, cause them to significantly degrade. In general, the vapor barrier is placed on the warm surface of the insulation in order to 1) limit the exfiltration of the moisture towards the exterior, and 2) prevent condensation of the air on contact with the cold surfaces. Air leaks can be detected using a smoke tube. Dust deposition in the vicinity of joints or cracks is also indicative of air movement. Leaks occur at the following locations, among others:

- around windows, doors, access doors
- around piping and air ducts
- through electric outlets (exterior walls), light fixtures, around wires crossing a partition
- through cracks in wall sheathing or ceilings
- along moldings, at the juncture of the structure and masonry walls or the chimney.

When water vapor concentrations at two points differ and there is no air movement, water vapor flows from the point of high concentration towards the point of low concentration. Diffusion across a material depends on the difference between the vapor pressures, the permeability and the length of the material. In winter, since the vapor pressure is generally higher inside a building than outside, the result is a flow of water vapor towards the outdoors. Condensation occurs when the vapor pressure is greater than the maximum allowable vapor pressure (saturation vapor pressure) at this temperature.

During a visual inspection, particular attention must be paid to rugs, ceiling tiles, gypsum panels, paper, cardboard as well as any other cellulosic surface.

C- Specialized techniques and instrumentation

When visual inspection does not locate sources of leaks, a spray test can be performed on the exterior cladding. Two in situ methods are proposed by the American Society for Testing and Materials (ASTM E-1105) and the Architectural Aluminum Manufacturers Association (AAMA 501.2). Although their respective methodologies are different, these methods essentially consist of spraying the exterior surface with water and of observing whether there are leaks.

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Infrared thermography is also used in some situations. It is a non-destructive technique that can be used both inside and outside a building. Using a camera that captures the infrared radiation emitted by a body, thermal images are obtained that show the variations in temperature of a surface. The thermal irregularities that are revealed originate from variations in thermal conduction, air flow and from temperature inversion in the exterior cladding, the roof, as well as the interior walls. Anomalies in the building envelope such as the lack or movement of insulation, damp insulation, the presence of a thermal bridge and air leaks can thus be located. Because of the expertise needed to apply these methods and the costs involved, it is recommended that building envelope specialists be called on to carry out and interpret this type of evaluation.

The use of a moisture meter can be very practical during an inspection to detect non-visible accumulations of water. This instrument is used to determine the water content of wood, which is expressed as a percentage and corresponds to the weight of water contained in the wood in relation to the weight of oven-dry wood. The water content is determined by measuring the resistivity between two electrodes embedded in the material. By consulting tables that come with the instrument, it can be used for different species of wood. It can also be used qualitatively for other types of porous materials such as concrete, gypsum and insulating materials. However, the user must establish the water content beforehand, using a dry sample of the material to be tested. The percentage displayed by the moisture meter is therefore the reference value for this material and not the material's actual water content. When the instrument is being used, contact of the electrodes with a metal surface (metal stud, aluminized vapor barrier) may result in a significant error.

A rigid endoscope can be used to confirm the presence of water mainly in cavities and ventilation ducts as well as to detect signs of microbial growth or the accumulation of nutrient substrates in these areas. The instrument consists of an optical sensor 24.5 cm long powered by a halogen light source.

2.2.3 Methods for measuring bioaerosols

The main pathway for workplace exposure to microorganisms is inhalation. Different techniques for evaluating their presence in air can be used to measure viable organisms (cultivable or not), dead cells, and some components such as endotoxins, mycotoxins, glucan, ergosterol or volatile organic compounds. In addition to evaluating their presence quantitatively (by a count or a determination) and qualitatively (by identifying the genus and species or the product), air sampling may be used to evaluate the propagation of a source in space or the effectiveness of the implemented control measures. In the specific case of water-damaged buildings, measurement of molds in the air has proven to be an effective tool for assessing the situation.

Surface sampling is also possible for microorganisms. It is appropriate for confirming the presence of molds when visual inspection is ambiguous (e.g., discoloration, stains) and, although it is not quantitative, it may be used to assess the effectiveness of cleaning. It can be useful for measuring the relative degree and extent of microbial growth or as a complementary technique in identifying the species present. Because of the very great variability in the results obtained for these surface samplings and the poor correlations obtained with the measurements in the air or

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the health effects, this type of sampling alone cannot be used to assess the exposure risk; it is a complementary tool in environmental assessment and medical diagnosis.

The counting of microorganisms in accumulated deposited dusts is not recommended because it may not be representative of the situation due to variations in environmental conditions and the presence of nutrients in the dusts, which affect the development of microorganisms.

Table 6 presents the air and surface sampling techniques regularly used at the IRSST. Several types of samplers are available on the market for sampling bioaerosols in the air. The IRSST has not recently done a comparative study or a performance study on these instruments, but recommends the following criteria in their selection:

A bioaerosol sampler must be able to be disinfected, its sampling efficiency must be known, and its sampling flow must be able to be properly measured.

The analytical techniques are described in the following sections.

A- Bacteria and molds in the air

Currently, methods based on the culture of microorganisms are the ones most commonly used; they measure only the viable and cultivable fraction of the bioaerosols, meaning the living microorganisms able to develop and compete with the other organisms present. The culture medium and growing conditions chosen are the first determinants in bioaerosol sampling and depend on the objective. A large number of nutrient media are available, some for general use, for growing a large variety of microorganisms; others are selective or differential. A selective medium offers a nutrient advantage to the targeted microorganisms, while a differential medium contains ingredients that produce differences in the appearance of the microorganisms and that make their identification easier. Broad-spectrum media are those generally supplied by the IRSST. Upon request, the laboratory can supply specific nutrient media.

The sampler used by the IRSST is the Andersen impactor or its single-stage modified version. For work environments where high microorganism concentrations are expected (above 10,000 CFU/m³), sampling on filter is recommended. Refer to the "Sampling Guide for Air Contaminants in the Workplace (2000)" for the procedures for using these techniques.

Two methods are available for analyzing bacteria and molds. The basic method consists of counting the colonies formed following an incubation period specific to the microorganisms investigated. The count indicates the quantities of bioaerosols present in a given location at a given time. This count is done by stereomicroscopy. The species can then be identified. To do this, each of the different colonies found on the initial agar must be transferred to a specific agar, incubated again, and identified by different techniques. Bacteria are identified by a series of biochemical tests or by chromatographic analysis of their fatty acid profile, while molds are identified by morphological observation.

Bioaerosol identification is complex, requires specialized professional expertise, is time-consuming, and must be limited to situations that justify it.

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Measurement of species based on their growth on a nutrient medium has limitations and biases mainly due to competition between species, differences in growth rates and size of colonies, or the invasion of the nutrient medium by certain species. It should also be noted that in culture, relatively few microorganisms will grow.

Despite these limitations, this method is appropriate, insofar as it is used in a constant and rigorous way.

The results from different studies can be compared only if the same sampling and analytical parameters were used.

B- Endotoxins in the air

Endotoxins are sampled on filters, extracted and analyzed. Different types of filters and different extraction and analytical techniques exist, and consequently, the results sometimes vary considerably between laboratories. When results are being reported, all the parameters of the method used must therefore be indicated. IRSST method 332-1 uses a glass fiber filter and a flow rate of 2 L/min for 4 hours. Endotoxins are extracted in an aqueous solution and analyzed using the limulus amebocyte lysate (LAL) method. The determination is done by a kinetic chromogenic analysis using a spectrometer at a wavelength of 405 nm.

C- Other components in the air

The methods for analyzing mycotoxins in the air have not been validated; the evaluation of mycotoxin exposure is therefore based on circumstantial evidence such as the presence of molds in the air and mycotoxin-related health effects. However, recent studies tend to demonstrate that there is no correlation between the presence and concentrations of mycotoxins and molds in the air and vice versa.

Analyses using the LAL method and immunoassays have been tried for measuring glucan. Due to the lack of data on toxicological effects as well as on background concentrations, the specific analysis of glucan is not recommended.

Volatile organic compounds are measured using conventional sampling methods on adsorbent tubes and chromatographic analysis. However, the limits of detection for the majority of them are higher than the concentrations given off by bioaerosols. The results are difficult to interpret in relation to bioaerosol exposure.

Mycotoxins, glucan, ergosterol or volatile organic compounds should be measured solely within the context of methodological or epidemiological studies.

D- Surface sampling

Surface sampling is generally done in situ. Microorganisms are collected from smooth surfaces, by smears using a moist sterile swab that is rotated on the surface to be sampled. A surface of

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approximately 100 cm² is recommended. The entire surface of the culture medium is then inoculated using the same rotation principle. A sponge can be used for sampling a larger surface. The sponge is placed in a clean bag supplied by the laboratory. Sampling by direct contact of the culture medium on the surface is also possible.

In specific cases such as the presence of visible mold on a porous surface, samples of material placed in clean plastic bags can be sent to the laboratory. These techniques are used to identify viable microorganisms, and the availability of a larger quantity of material facilitates the laboratory work.

The laboratory must be contacted before doing such sampling so that the samples are properly collected and handled and are processed within the stipulated time.

The results of surface samplings are only qualitative, meaning that they determine the presence of the identified species without giving a number or a concentration.

E- Outdoor sampling / reference sites

Comparison of species and concentrations of bioaerosols found indoors to those outdoors or at a reference location is a key aspect of an environmental assessment, particularly for molds and endotoxins.

Different parameters affect outdoor sampling, namely wind conditions, temperature, humidity, the period of the day, and the sampling site. With windy conditions, higher concentrations of particles will be suspended in the air. Sampling during or after rain could change the results; concentrations tend to be lower and the distribution of species different. Temperature and lighting are also factors that affect the distribution of species. The proximity of sites with a high concentration of microorganisms (farms, landfill sites, etc.) must be considered when choosing the sampling site. The following guidelines will ensure that the outdoor samples are valid:

- outdoor sampling must be done as much as possible at the same time as indoor sampling;
- if there are mechanical ventilation systems, the samples must be collected as close as possible to the air intakes of these systems and as far as possible from the vitiated air outlets;
- in establishments where the operations generate bioaerosols (composting centers, waste treatment, etc.), it is recommended that control samples be collected 300 meters upwind and not near a site where the microorganism concentration is high.

It may be appropriate under some circumstances to use a reference site other than the outdoor environment. Sampling at a location where there are no complaints or in an area ventilated by another system may help in diagnosing the problem at a location where there are complaints. Measurements in an independently-ventilated process control room or when a process is stopped can be used to locate sources. Outdoor air sampling in winter is recommended, insofar as one sample is also collected at a control location.

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F- Specific cases

- Dust mites

Mite exposure is evaluated by analyzing dust. The total number of mites or the concentration of allergens can be determined. Counting is done following separation of the mites from the collected dust, while the allergens in the dust are measured using the ELISA (Enzyme-Linked ImmunoSorbent Assay) immunological technique. This evaluation should be done in exceptional cases where a confirmation of high levels of acarids is essential in connection with a confirmed diagnosis of allergy. Specialized laboratories offer this analysis.

- *Legionella pneumophila* bacterium

Water sample analysis is the most effective method for identifying sources of the *Legionella pneumophila* bacterium, responsible for legionnaire's disease. Air sampling does not detect this bacterium.

Water is analyzed using the standard culture method on an enrichment medium (BCYE) or using molecular biology methods such as PCR (polymerase chain reaction). These methods are more rapid and more sensitive. Specialized laboratories offer this analysis.

- *Mycobacterium tuberculosis* bacterium

In a work environment, the species *Mycobacterium tuberculosis*, the agent causing tuberculosis, must be evaluated in the specific case where a transmission pathway for the disease is suspected. Sampling this bacterium is problematic. This bacterium grows very slowly, sometimes taking up to 6 weeks, favoring the predominance of mold growth. To reduce this interference, a specific medium (Middlebrook 7H10 agar) is recommended; this medium must be prepared not more than three days before sampling. This bacterium can also be detected using molecular biology methods. Specialized laboratories offer this analysis.

- Viruses

Viruses need living cells to proliferate and use their host to propagate. Viruses are not amplified in water and do not survive in the ambient air, and hence the difficulty in sampling and analyzing them. The presence of symptoms or of the disease in the host is sufficient evidence that the virus is present.

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Table 6: Bioaerosol sampling techniques regularly used at the IRSST

Technique	Application
AIR SAMPLING	
Impaction a) Andersen 1-stage (N-6)	- viable and cultivable bacteria and molds - low to medium concentrations (< 10^4 CFU/m³)
b) Andersen 6-stage	- viable and cultivable bacteria and molds - medium to high concentrations (< 10^7 CFU/m³) - useful for knowing the size of the particles
Filtration	- viable and cultivable bacteria and molds - high concentrations (>10^4 CFU/m³) - endotoxins - useful for sampling on workers
SURFACE SAMPLING	
Smears / swabs	- viable and cultivable bacteria and molds
Sterile sponges	- viable and cultivable bacteria and molds
Process (materials)	- viable and cultivable bacteria and molds - total microbial flora by microscopic observation

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2.2.4 Sampling plan

Once a situation of potential bioaerosol exposure has been documented by studying the process, by visual inspection or by studying diagnosed cases, sampling may be necessary. The sampling plan must be based on the hypotheses to be verified. It must specify which bioaerosols are being studied, where and when the samples must be collected, and which techniques are the most appropriate. A sufficient number of samples must be collected to ensure that the observed situation is representative and that the results are correctly interpreted. The results must provide a clear conclusion about the hypothesis formulated. Ideally, the criteria that will be used to evaluate a situation must be specified at the start. They can come from reference documents, the scientific literature, knowledge about the environment, and the evaluator's expertise.

The choice of bioaerosols to be studied follows directly from the situation documentation step and must take into account the available methods and their limitations. A count may be sufficient for certain situations, such as the exploratory study of a work environment, the comparison of two work situations or two locations, locating a source, the assessment of the propagation of a source, or the assessment of the effectiveness of corrective measures. The species must be identified when confirming the presence of species identified as causal agents of health effects, when documenting a work situation in detail for an epidemiological study, or when confirming the presence of normal concentrations of species following the application of corrective measures. The sampler must also be chosen in relation to the expected bioaerosol concentrations.

Personal sampling is the best way to estimate worker exposure by inhalation. However, there are few personal samplers. The IRSST has a method of sampling molds on cassette, but the workplace concentrations must be rather high. Endotoxins can also be personally sampled. Generally, stationary sampling in the workers' breathing zone is used to estimate average exposures to bioaerosols.

As with any industrial hygiene study, the sampling sites, periods and durations depend on the information to be collected to meet the objective and must correspond to the conditions being observed. It should be noted that sampling with the Andersen impactor is done in a very short time (less than 5 minutes). When calculating the concentrations expressed in CFU/m³, the number of colonies present on the culture medium must be multiplied by 18 (for the recommended flow rate of 28 L/min and a time of 2 minutes). Thus, a result of 108 CFU/m³ indicates that there were 6 colonies on the petri dish.

Samples of indoor air must always be compared to the background levels or controls, such as those collected in the outdoor air, at a reference location, or when the process or the source is stopped.

Analytical cost and time constraints must also be taken into account when developing the sampling plan. The measurement strategy must therefore be adapted in such a way as to limit the number of samples while obtaining an unequivocal conclusion. Observations and all other information about the situation are a valid alternative to the limited number of samples. The evaluator's knowledge, expertise and experience are therefore important advantages in planning the sampling.

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When the situation justifies it, such as an epidemiological study or a research project, the number of samples must be sufficient to arrive at an unequivocal conclusion about the formulated hypothesis. Different methods exist for calculating the minimum number of samples to obtain a representative sampling. The method of the British Occupational Hygiene Society (BOHS 1993) adapts well to air contaminant evaluation. It is based on knowledge about the arithmetic mean (μ) and the standard deviation of the sample (σ) obtained after preliminary sampling or from data taken in the same type of environment:

$$N = (t \bullet CV / E)^2$$

where N = number of samples

t = 1.96 (for a significance level $\alpha \leq 0.05$)

CV = Coefficient of variation (σ/μ)

E = Acceptable error (normally 10%)

Example: For a set of data on mold concentrations whose arithmetic mean is 100 CFU/m^3 of air, whose standard deviation is 30 CFU/m^3 of air, whose acceptable error is 10%, and whose confidence level is 95% (t = 1.96), the number will be:

$$n = (1.96 \times [(30/100)/0.1])^2 = 35$$

Researchers Mulhausen and Damiano (1998) estimated that 6 to 10 measurements are needed for estimating a mean and a standard deviation. Fewer than 6 samples result in great uncertainty in the determination of the exposure profile.

The ACGIH (1999) suggests numbers of samples in relation to the targeted objective. They are presented in table 7.

Table 7: Number of samples (ACGIH, 1999)

Purpose	Suggestion (for each site and each type of sampling)
To estimate worst-case inhalation exposures	Take ≥ 3 non-random periods of the worst cases. Collect duplicate samples.
To estimate average inhalation exposures	Take ≥ 3 times per day for 3 representative consecutive days. Collect duplicate samples.
To estimate the confidence interval around a mean exposure	Collect ≥ 6 samples
To estimate the variance of a data set	Collect ≥ 11 samples
The IRSST recommends always collecting duplicate samples.	

2.2.5 Interpretation and communication of results

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The interpretation of bioaerosol measurement results is particularly complex, considering the limitations in the methods, the lack of permissible exposure standards, and limited toxicological knowledge. It is even more difficult because living material is being evaluated, which changes with time.

It should also be remembered that the measurements are just numbers without significance if they are not accompanied by information on the circumstances that produced them or that is associated with them. This information is essential in understanding the results and their variability, and therefore their interpretation. The results must provide a clear conclusion. The data must be reliable, representative and reproducible. Incomplete results cause confusion and make the evaluation more difficult.

It is essential that workers be informed about the objective of the study, the results, their interpretation and the resulting conclusions and recommendations. The criteria on which sample collection and result interpretation are based must also be specified.

In general, bioaerosol evaluations carried out in the workplace demonstrate that:

- The presence of conditions favorable to microbial growth must be considered as a potential bioaerosol exposure requiring corrective measures; however, this does not mean that there will be microbial growth;
- Evidence of microbial growth must be considered as a potential bioaerosol exposure requiring corrective measures; however, this does not mean that there is exposure, or that there will be reported effects or that there is a causal link if effects are reported;
- Evidence of bioaerosol exposure must be considered as a hazardous situation requiring immediate corrective action; however, this does not mean that there will be reported effects or that there is a causal link if effects are reported;
- The measuring site / reference site comparison allows a conclusion about the prevalence of a species or about the existence of potential exposure.

When there is uncontrolled proliferation of microorganisms in an indoor environment, action on the causes is needed, whether health impacts are observed or not.

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2.2.6 Examples

The examples are presented very succinctly and take into account only the presence of bioaerosols in the work environment. The sampling plan is presented in a very limited way since it is based on a prior collection of data and its components are described in detail in the previous sections.

EXAMPLE 1: Industries where the presence of bioaerosols is probable (examples: water treatment plants, waste treatment plants, farms, pig-housing facilities)

1. Objective: To develop a respiratory protection program for bioaerosols

2. Necessary information and data:
- Identification of sources: observations of the process, identification of critical steps, water or waste accumulation, visual inspection, etc.
- Identification of dispersion mechanisms: stirring actions, aerosolization, projection of droplets of water or dusts, movement by conveyor, etc.
- Identification of exposed people: study of tasks and workstations, working methods and tools, etc.

   The information obtained must identify hazardous situations as well as the immediate corrective measures, if need be, to reduce the emissions.

3. Hypothesis: Despite the implementation of emission control mechanisms, bioaerosol concentrations remain high at certain workstations or when certain tasks are being carried out.

4. Sampling plan
   - Which bioaerosols: total bacteria, Gram negative bacteria, molds, endotoxins
   - Where: at workstations or during tasks promoting the proliferation, aerosolization or projection of liquids or dusts; outdoors or other control site to obtain background concentrations
   - Periods: in relation to the process: continuous, cyclic, intermittent; for the most hazardous situations
   - Methods: sampling and counting according to the IRSST's standard methods.

5. Interpretation of the results
   The concentration values and the comparison of concentrations at the measuring stations to background concentrations will determine the significance of the workers' exposure.

6. Recommendations
   - Based on the results and the duration of the tasks performed by the workers, issue a recommendation as to the necessity of wearing respiratory protection or not

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- Issue recommendations as to the necessity of wearing other types of personal protective equipment or not
- Apply stringent personal hygiene measures
- Develop prevention procedures for all work near sources.

EXAMPLE 2: Evaluation following a medical diagnosis

1. Objective: To establish a relationship between a health problem and a specific bioaerosol

2. Necessary information and data:
- Presence of a medical diagnosis consistent with exposure to this bioaerosol
- Evidence of bioaerosol exposure: knowledge about the process, knowledge about the workplace, identification of bioaerosol emission sources, existence of a mechanism for propagation of this bioaerosol, evaluation of bioaerosol concentration

3. Hypothesis: The suspected bioaerosol is present in abnormal concentrations in the work environment

4. Sampling plan
   - Which bioaerosol: bioaerosol associated with the diagnosis
   - Where: at the workstation or during the tasks done by the person or persons diagnosed; outdoors or other control location to obtain background concentrations
   - Periods: different periods during the work period and in relation to the emission sources
   - Methods: sampling on a specific medium, count and identification using IRSST standard methods.

5. Interpretation of the results
   The attending physician will use the concentration values and the comparison of concentrations of the specific bioaerosol at the measuring stations to background values to arrive at a decision.

6. Recommendations
   - Correct the problematic bioaerosol emission situations
   - Verify the effectiveness of the corrective measures by environmental measurements
   - Confirm the disappearance of the effects by medical follow-up

EXAMPLE 3: Evaluation of the air quality in a non-industrial building following water infiltration (examples: office buildings, schools)

1. Objectives: To document the presence of bioaerosols and to identify the emission sources

2. Necessary information and data
   - Presence of sources of proliferation and propagation: visual inspection of surfaces / ventilation system / structure; humidity; water accumulation, etc.
   - History: floods, water infiltration, water damage, corrective action, etc.

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- Record of complaints and reported symptoms

3. Hypothesis: The presence of visible molds on a room's ceiling tiles is a situation with a risk of bioaerosol exposure

4. Sampling plan
   - Confirmation and delimitation of the extent of the microbial growth: surface sampling as needed
   - Location of water infiltration and path: endoscope, dampness detector, hygrometer

5. Interpretation of the results

Confirmation of the presence of molds and the location of infiltration require the immediate application of corrective measures.

6. Recommendations
   - Clean or eliminate damaged materials
   - Eliminate water infiltration
   - Establish a periodic follow-up mechanism: growth definitely eliminated

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SECTION 3: CONTROL OF BIOAEROSOL EXPOSURE

As with any exposure to chemicals or physical agents, the prevention and control of bioaerosol exposure is based on the three levels of intervention, namely elimination at source, controlling the source, and lastly, controlling exposure. High concentrations of bioaerosols in a work environment can be prevented only if the factors that promote their proliferation are identified and controlled. In many cases, based on a visual inspection (a key element in the identification and location of hazardous situations), corrective strategies can be immediately proposed.

3.1 Industrial work environments

The preceding sections have shown that bioaerosol concentrations in some workplaces can be very high. In some cases, their presence is not only due to the fact that the conditions are conducive to the proliferation of the microflora normally present in any environment, but also directly associated with the manufacturing or conversion process, such as the presence of thermophilic actinomycetes bacteria in compost and biotechnological processes. Elimination at source is therefore not always desirable.

Whatever the origin of the microorganisms, control must necessarily be achieved by controlling the operations that cause the projection and dispersion of water droplets or particles in the air.

The recognized methods of confinement, physical barriers, and general and local ventilation are applicable. Concrete application examples are reported here and are illustrated in the technical data sheets developed by the IRSST and presented in Appendix 2.

Confinement consists of isolating the source of contamination. For example, the confinement of conveyors in wastewater treatment plants and sludge presses limits the projection of wastewater and organic matter. The addition of confinement caissons on the flume also has the effect of eliminating aerosolization. The use of rubber anti-skid rugs on floor piping and drains is an effective, simple and rather inexpensive physical barrier. In pig-housing facilities, the use of a pit ventilation system, with air intakes installed directly above the temporary manure storage and with a sufficient flow rate, significantly reduces the bioaerosols.

If the corrective measures do not satisfactorily reduce the concentrations or if certain tasks require being near emission sources, prevention procedures must be developed.

In general, for all work or all situations where contact may occur with either manure, waste sludge, dung, manure effluent, household waste or any other potential source, the wearing of personal protective equipment is recommended. This equipment must include:

- Impermeable coveralls, with rubber gloves and boots. These coveralls must not be taken home.
- A helmet and visor for dirty work.
- A type N-95 disposable respirator. For damp locations, a respirator with a valve at the center is recommended.

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There may also be other types of exposure besides respiratory exposure, namely by ingestion and skin contact. In fact, the ingestion of a foreign microorganism as a result of bringing the hands in contact with the mouth produces gastrointestinal problems in the receptive host. Sources should therefore not be handled with bare hands. Workers should be able to wash their hands regularly during their work. Strict personal hygiene measures should be applied in order to limit the adverse effects of bioaerosols on the skin and lungs. Workers must:

- avoid putting their hands in their eyes, mouth and ears
- keep their nails short
- report and properly treat any cut or injury
- wash their hands before each break and when they use the toilet
- keep their work clothing and city clothing in separate lockers; work clothing and safety boots should not be taken home
- take a shower at the end of the workday.

3.2 Non-industrial workplaces

MOLDS

In non-industrial workplaces such as office buildings and schools, the presence of molds is due to excessive water or humidity and organic material. The first control therefore consists of eliminating sources of water and organic material. Organic material is reduced through appropriate and regular housekeeping. The section on building inspection describes in detail the aspects that could promote water infiltration, condensation, and dust accumulation as well as the technical means of controlling them.

Water-damaged material must be dried, repaired or disposed of, depending on the extent of the damage and nature of the material (porous vs. non-porous). If there is visible mold on the material, restoration requires that (a) the porous material showing excessive microbial growth be disposed of, (b) growth on non-porous or semi-porous material be removed, and (c) the relative humidity be reduced to 60% or lower. Growth can be eliminated by (a) vacuuming the surface with vacuums equipped with high efficiency (HEPA) filters or with exhaust into the outdoor air, (b) cleaning it with dilute solutions of biocides (ex. 250 mL of commercial bleach in 4 litres of water) or detergents, or (c) cleaning it and drying it well, particularly if it is wood. Porous material that has supported excessive growth must often be thrown out. Examples of porous materials are ceiling tiles, rugs, upholstered furniture and curtains. In the case of floods, gypsum walls and water-damaged insulation must be replaced up to 20 inches above the water line.

Contaminated material cannot be removed and cleaned without some precautions being taken, since moving the contaminated material results in the emission of bioaerosols. With extensive visible fungal growth (surface larger than approximately 3 m^2 (32 ft^2)), confinement procedures are required to remove the damaged material. The objective of confinement is to remove or clean the contaminated material in such a way as to avoid the emission of molds or dusts from the contaminated location into occupied adjacent locations, while protecting the workers who are doing this work. Process, surface or air sampling is not required prior to the restoration work. Decisions about the evacuation of occupants from a contaminated location must be based on case-by-case medical assessments. Except for cases of large-scale fungal contamination of an

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entire building and where this contamination is associated with disease, total evacuation of a building is not indicated.

Table 8, taken from the City of New York protocol (2000), gives the confinement measures to be applied for restoration work. Five levels of confinement are described in it.

With confinement level 2, the decontamination area must be covered with a plastic film and sealed with adhesive tape before the work is started in order to contain the emissions of dust and debris. Material that cannot be cleaned must be removed in sealed plastic bags. There is no specific precaution for disposing of moldy material.

At level 3, an occupational health and safety professional with experience in microbial investigations must be consulted before starting the decontamination activities. Personnel trained in handling hazardous substances are also recommended.

In the case of excessive contamination, or level 4, air samples must be collected in order to determine whether the location can be reoccupied. A decontamination room must be built for entering and leaving the contaminated zone. Depending on the size, this unit may consist of a work room, another for storing equipment, and a vestibule. To date, there is no evidence justifying the need for taking a shower in the decontamination room.

At level 5, the ventilation systems must be stopped during the work.

Rapid elimination of the moldy material and repair of the infrastructure must be the first response to fungal contamination of a building.

A response within 24 to 48 hours and in-depth cleaning of water-damaged material will prevent or eliminate microbial growth. If the source of water is high relative humidity, the level must be maintained below 60%. The simplest and fastest means of safely eliminating microbial growth must be used. In all cases without exception, the cause of water infiltration must be corrected or microbial growth will reappear. Emphasis should be on proper building maintenance and on the rapid restoration of water-damaged areas.

Table 8: Fungal abatement protocol (NYCDH, 2000)

Remediation parameter	Level 1	Level 2	Level 3	Level 4	Level 5A	Level 5B
Description	Small isolated areas (10 ft^2) (1 m^2)	Mid-sized isolated areas (10-30 ft^2) (1-3 m^2)	Large isolated areas (30-100 ft^2) (3-10 m^2)	Extensive contamination (>100 ft^2) (>10 m^2)	HVAC system (<10 ft^2) (<1 m^2)	HVAC system (>10 ft^2) (>1 m^2)
Examples	Ceiling tiles, wall surfaces	Wallboard panel	A few wallboard panels	Several wallboard panels		

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Remediation parameter	Level 1	Level 2	Level 3	Level 4	Level 5A	Level 5B
Qualifications of personnel	Trained building staff	Trained building staff	Qualified OHS professionals	Qualified OHS professionals	Trained building staff	Qualified OHS professionals
Respiratory protection	N-95 Disposable respirator	N-95 Disposable respirator	N-95 Disposable respirator	Full mask with HEPA cartridges	N-95 Disposable respirator	Full mask with HEPA cartridges
Gloves	Yes	Yes	Yes	Yes	Yes	Yes
Eye protection	Yes	Yes	Yes	Yes	Yes	Yes
Protective clothing[a]	No	No	No	Yes	No	Yes
Containment required[b]	No	Critical barriers	Critical barriers	Critical barriers, airlocks, negative pressure, Decontamination room with critical barriers.	Critical barriers	Critical barriers, airlocks, negative pressure, decontamination room with critical barriers.
Remediation while unoccupied	Yes	Yes	Yes	Yes	Yes	Yes
Vacation of adjacent spaces	For susceptible groups	For susceptible groups	For everyone	For susceptible groups	For susceptible groups	For susceptible groups
Dust suppression	Misting	Misting	Misting	Misting	Misting	Misting
Bagging of contaminated material	Yes	Yes	Yes	Yes	Yes	Yes
Subsequent cleaning of work areas	Cloth or mop with detergent	Cloth or mop with detergent + HEPA vacuum	Cloth or mop with detergent + HEPA vacuum	Cloth or mop with detergent + HEPA vacuum	Cloth or mop with detergent + HEPA vacuum	Cloth or mop with detergent + HEPA vacuum
Microbial conformity test	No	No	No	Yes	No	Yes

[a] Protective clothing refers to the wearing of full disposable coveralls and overshoes.
[b] Negative pressure must be created in the room to prevent the contaminants from leaving the decontamination zone. A fan equipped with HEPA filters must be used. A pressure difference of 5 Pa (0.02-0.03 in. water) is generally sufficient.

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TOTAL BACTERIA

In a non-industrial environment, the concentration of bacteria in the air depends on the number of occupants (who are the main emission sources), the activities carried out, and the fresh air flow rate. Bacteria can also come from water contamination. A high concentration of bacteria in an environment with little activity may indicate that there is overpopulation, that the ventilation is insufficient, that maintenance is insufficient or that water tanks or reservoirs have been contaminated. Recommendations can then include better housekeeping, a reduction in occupation density, an increase in or better distribution of fresh air, and the cleaning and maintenance of the water tanks and reservoirs.

LEGIONELLA BACTERIUM

The case of the *Legionella pneumophila* bacterium in public and industrial buildings must be specifically considered.

The *Legionella* bacterium is very resistant to city water chlorination; it can therefore be found in the water systems of public and industrial buildings. It can multiply rapidly in warm water varying from 40 to 60^{o}C. In addition to water towers and evaporative condensers, it can be present in household hot water systems, fountains, spas, air washers, humidifiers, cutting fluid systems, and eyewash fountains.

The transmission of legionnaire's disease can be described by a causal chain. The seven links in this chain are: 1) the bacterium must be present in a reservoir, 2) amplifying factors must allow the bacterium to multiply, 3) there must be means for the bacterium to propagate in air, 4) the bacterium must be virulent in humans, 5) the organisms must be inoculated in an appropriate site on the human host, 6) the host must be susceptible to infection, and 7) the disease must be diagnosed. Links 1, 2 and 3 can be controlled by housekeeping and engineering measures.

Systems must therefore be kept as clean as possible. Regular visual inspections must be done and water reservoirs cleaned when dirt, organic matter or other debris is visible. Records must be kept of the observed operating conditions, the modifications made to the facilities, the technical data sheets on the chemicals used, the water treatment program and the names of the people responsible for system start-up, shutdown and operation.

A water treatment program developed by specialists is also needed. The objective of this treatment program is to minimize corrosion, control microbial growth, and minimize the deposits of tartar and organic or inorganic solids. Oxidizing and non-oxidizing biocides must be alternately used. Halogenated compounds and ozone are included in the class of oxidants. Non-oxidants include several organic compounds including DBNPA (2,2-dibromo-3-nitrilopropionamide), bromonitrostyrene, carbamates, and glutaraldehyde. Quarternary ammonium compounds have proven to be ineffective against *Legionella.* It should be remembered that pH plays an important role in the efficiency of biocides.

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ASHRAE standard 12-2000 gives the method for disinfecting cooling towers according to different scenarios. Consult the ACGIH guide (1999) to obtain additional information on the quantity of biocides to be added and on the procedures.
In the design step, particular attention must be paid to maintenance requirements. Furthermore, the system must be easily accessible for periodic visual inspection and cleaning of the components. The cooling tower must be laid out in such a way that the water vapor or droplets that escape cannot enter through the windows or nearby outdoor air intakes. The installation of a droplet separator at the tower outlet is an excellent way of limiting droplet dispersion. The presence of filters at the fresh air intake, which are replaced at regular intervals and able to stop particles larger than 1 um, is additional protection.

Considering the exposure risks faced by personnel during cleaning operations, the wearing of protective equipment is indicated, namely an N-95 disposable respiratory mask, safety glasses, and coveralls.

Prevention and monitoring programs are recommended for hospitals, medical clinics, hotels, retirement homes, public utilities, schools and situations that promote the growth of the bacterium (water towers, sedimentation basins, etc).

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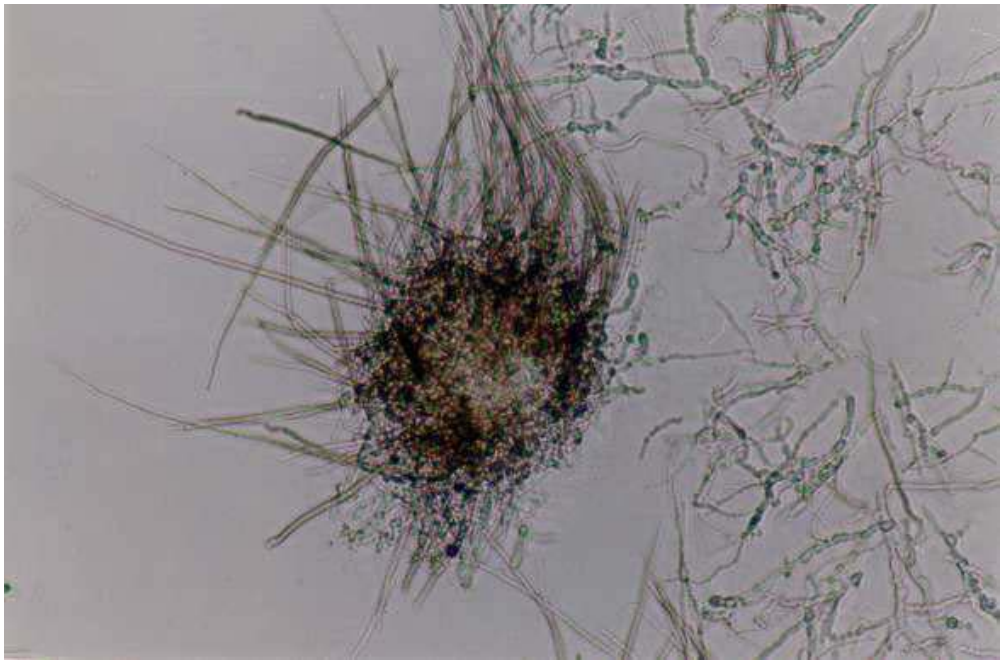
ANNEX 1 : PHOTOS OF MOULDS

Aspergillus sp.

Photo-IRSST (500 x)



Chaetomium sp

Photo-IRSST (12,5 x)

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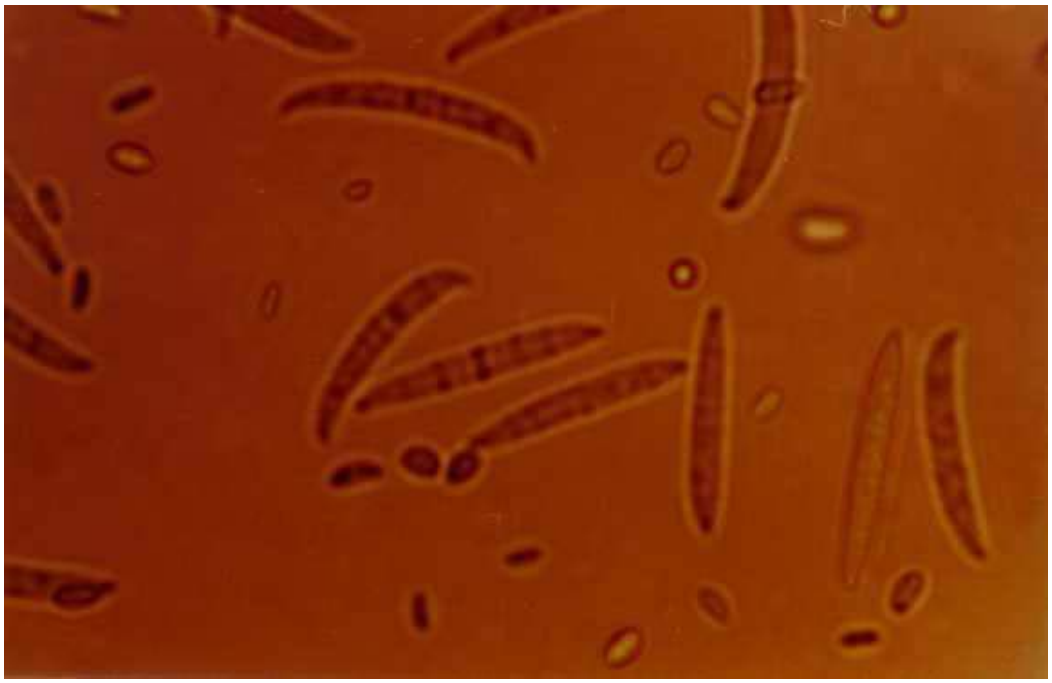

Fusarium sp

Photo-IRSST (500 x)

Mucor plumbeus

Photo-IRSST (1250 x)

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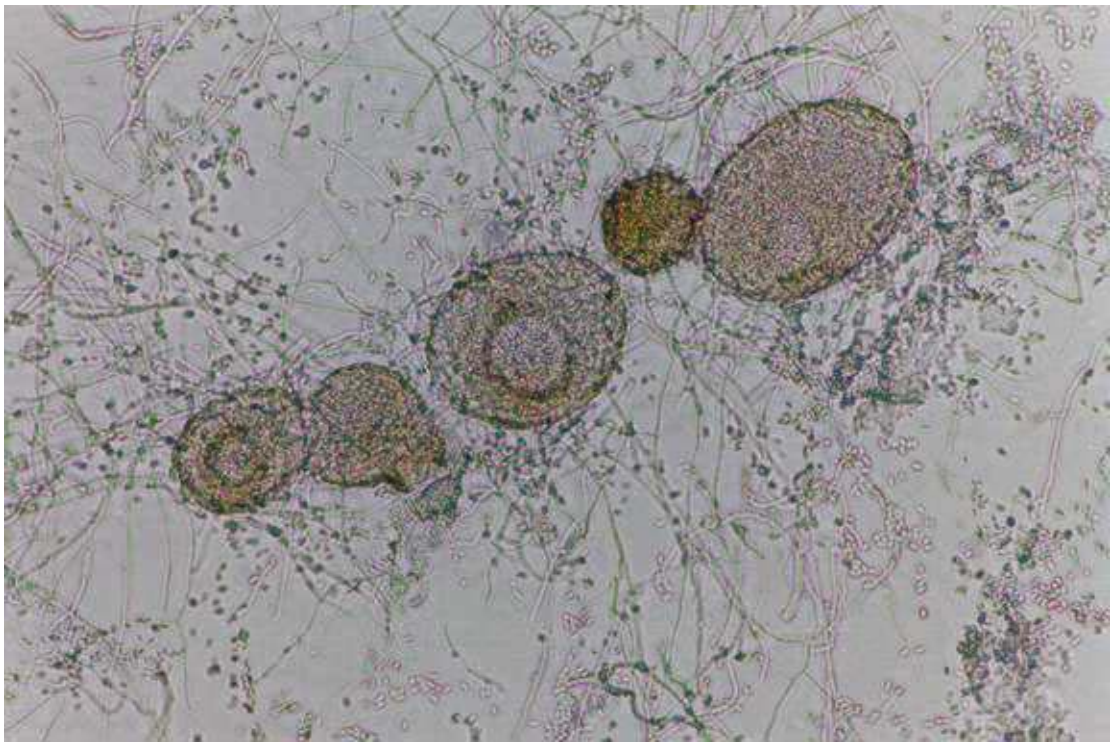
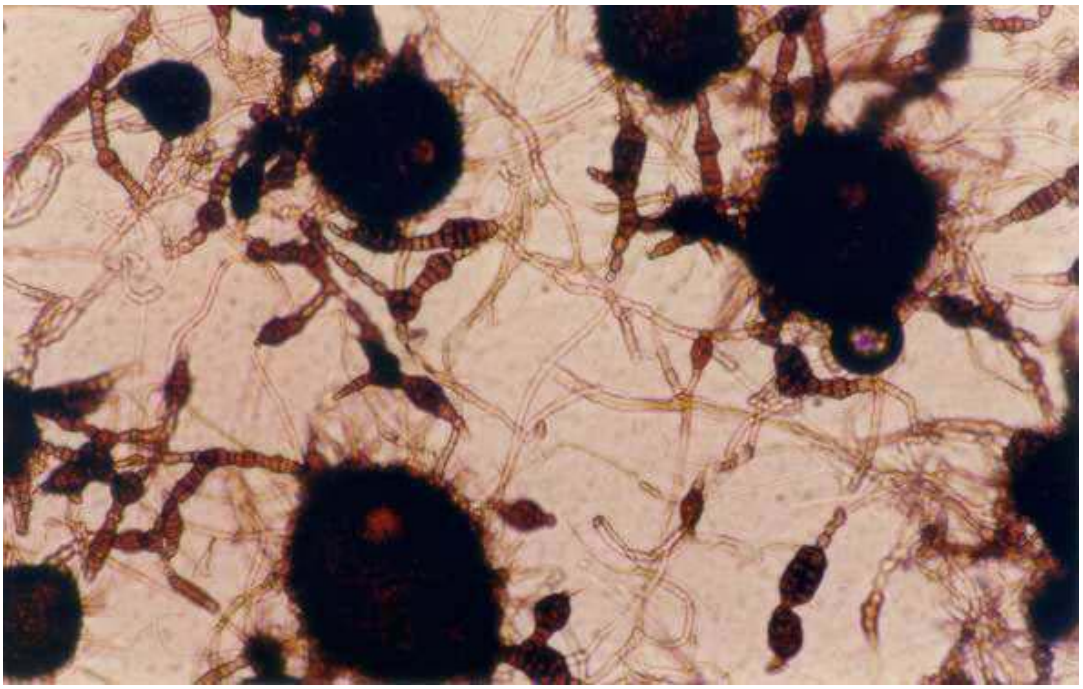


Phoma sp

Photo-IRSST (12,5 x)



Phoma glomerata

Photo-IRSST (12,5 x)

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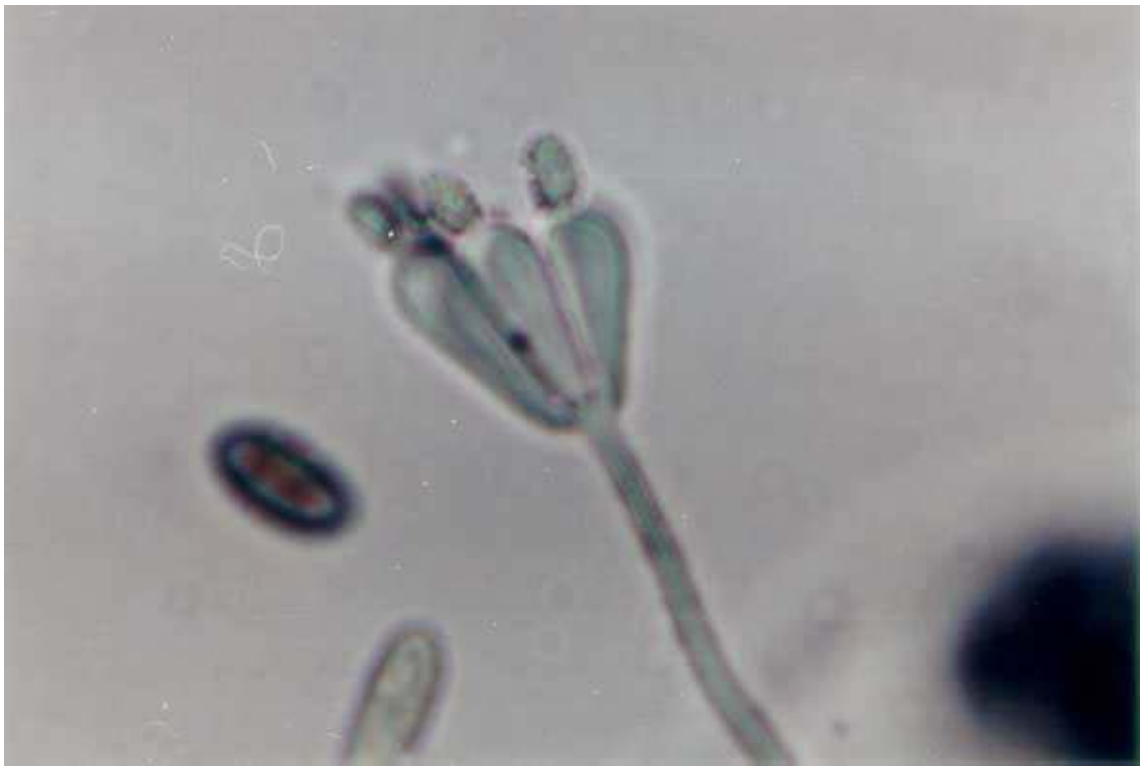
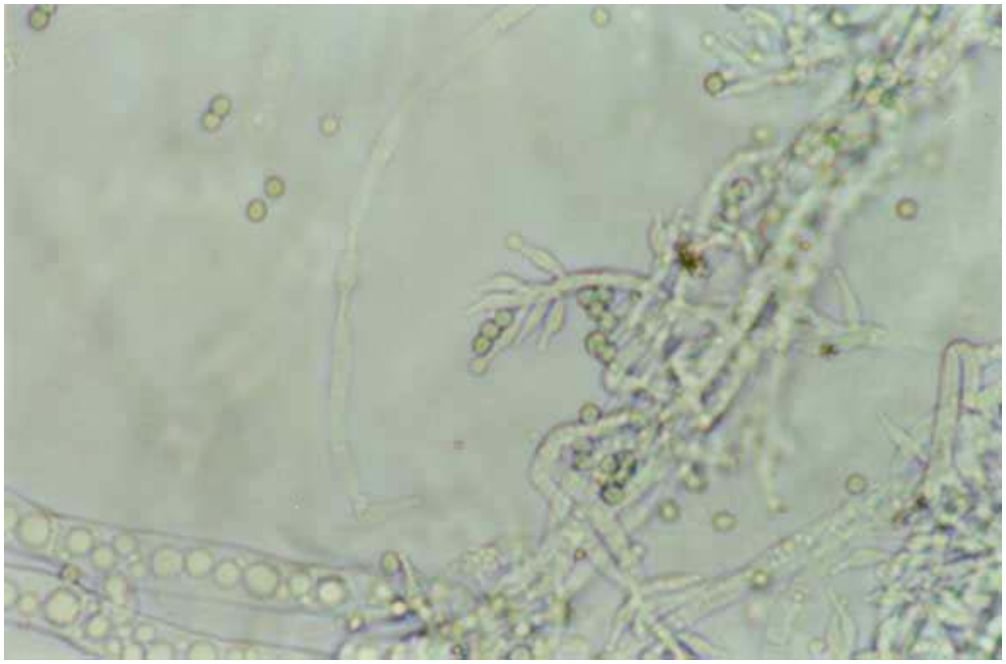


Stachybotrys sp

Photo-IRSST (1250 x)



Tricoderma sp

Photo-IRSST (500 x)

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Penicillium sp.

Photo-IRSST (500 x)

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ANNEX 2 : TECHNICAL SHEETS FOR THE CONTROL OF BIOAEROSOL EXPOSURE (available only in french)

- Le traitement secondaire des effluents des papetières
- Le compostage des déchets domestiques
- Les risques biologiques reliés aux eaux usées
- La prévention des risques à la santé et à la sécurité du travail dans les centres de tri de matières recyclables
- Programme d'intervention intégré sur les risques biologiques : l'exposition des éboueurs aux bioaérosols

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ANNEX 3 : MISCELLANEOUS ENVELOPE DETAILS

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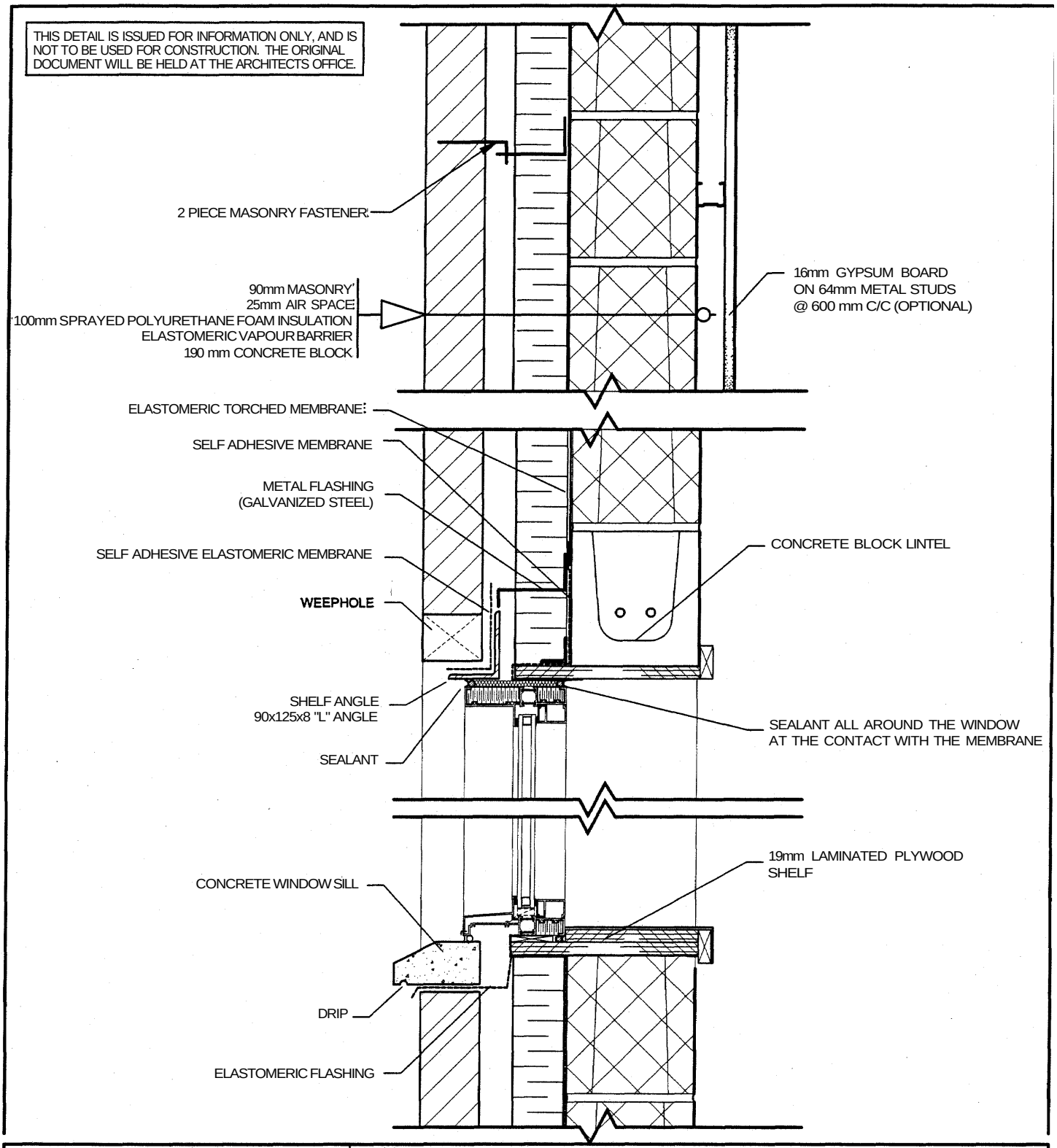

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Miscellaneous envelope details

MASONRY CONSTRUCTION WITH BRICK CLADDING

ECHELLE

1½" = 1'0"

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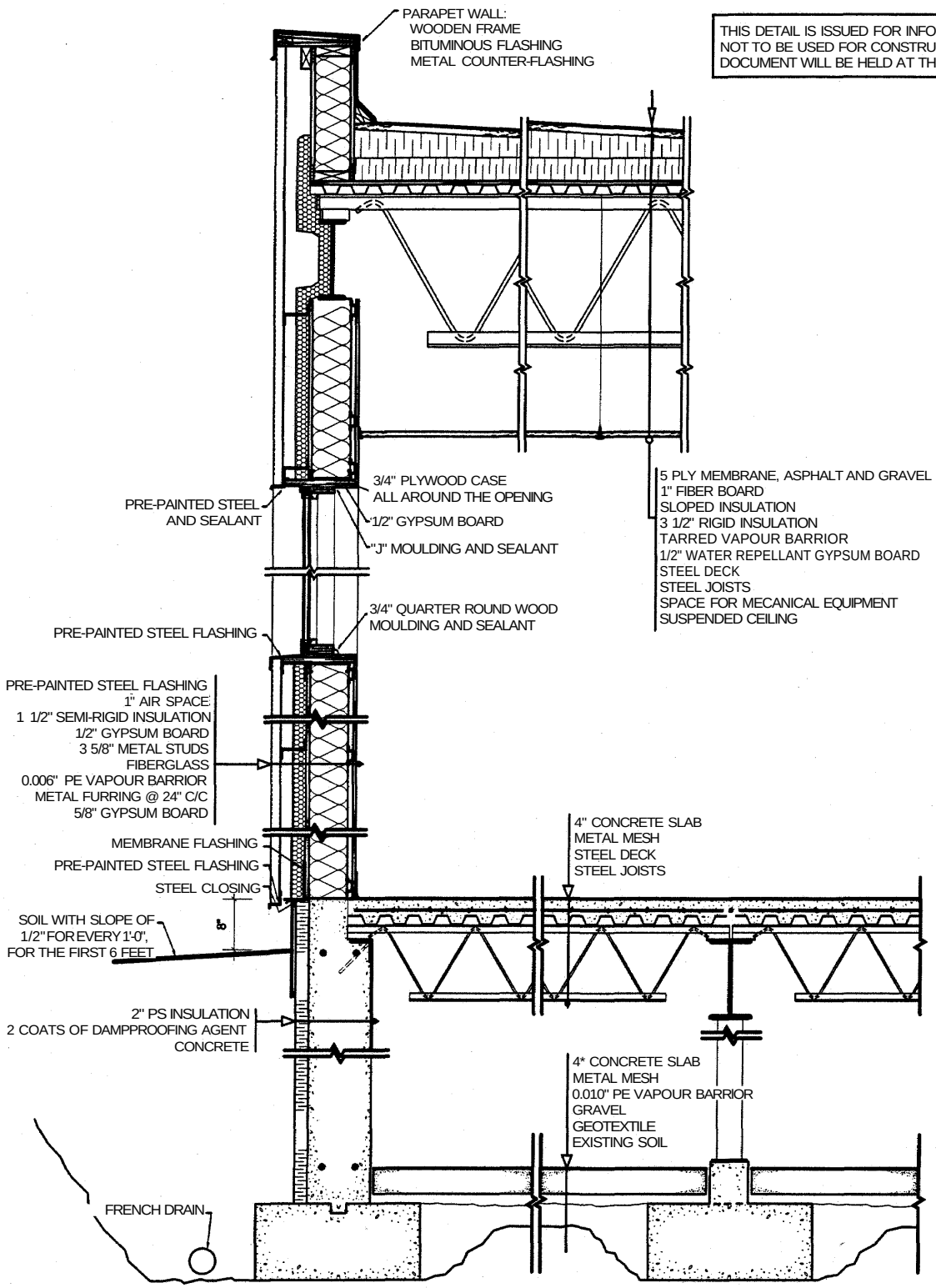

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INDUSTRIAL BUILDING
WITH METAL CLADDING AND FLAT ROOF

ECHELLE

½" = 1'-0"

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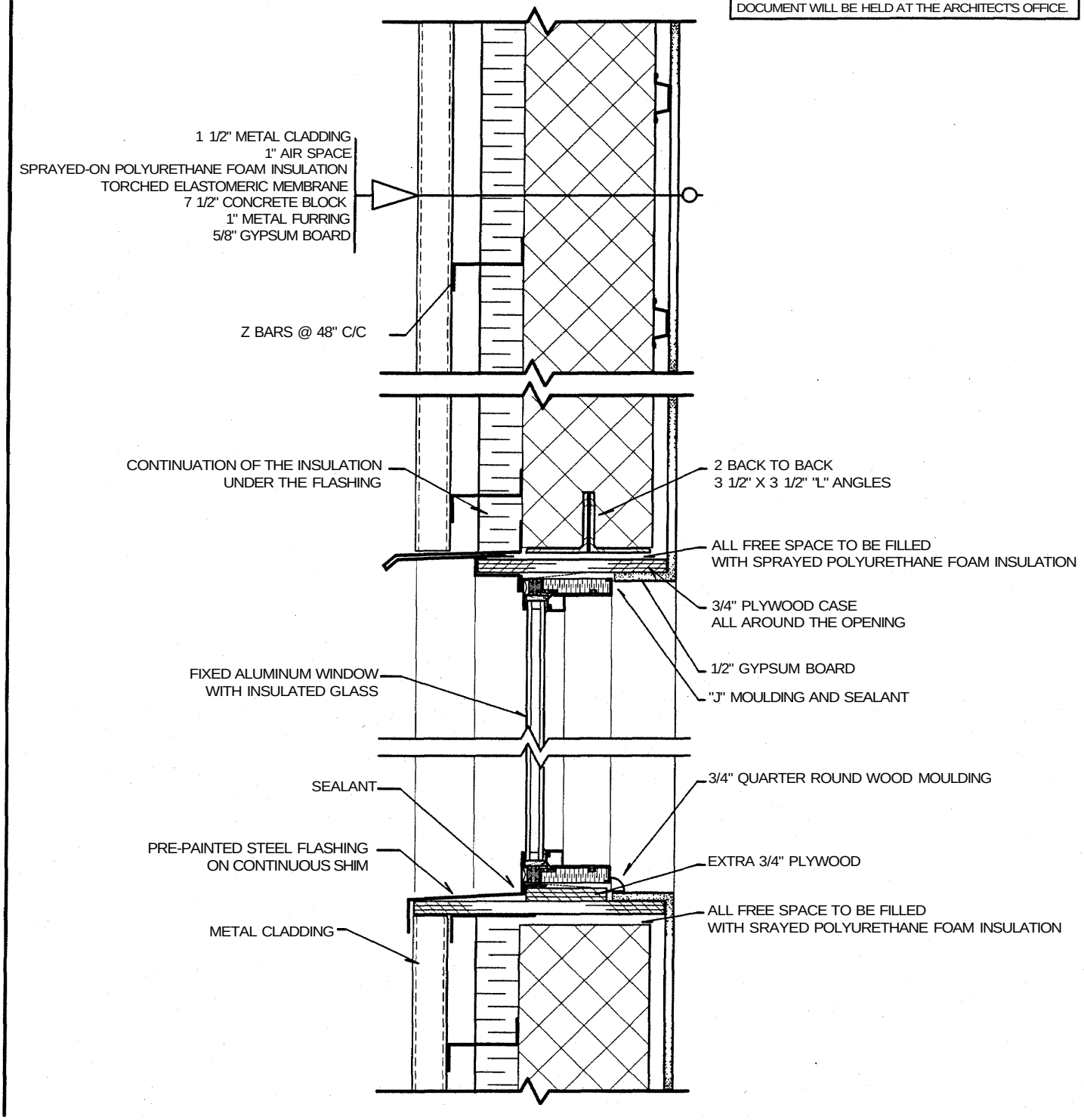

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MASONRY CONSTRUCTION WITH METAL CLADDING

ECHELLE

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