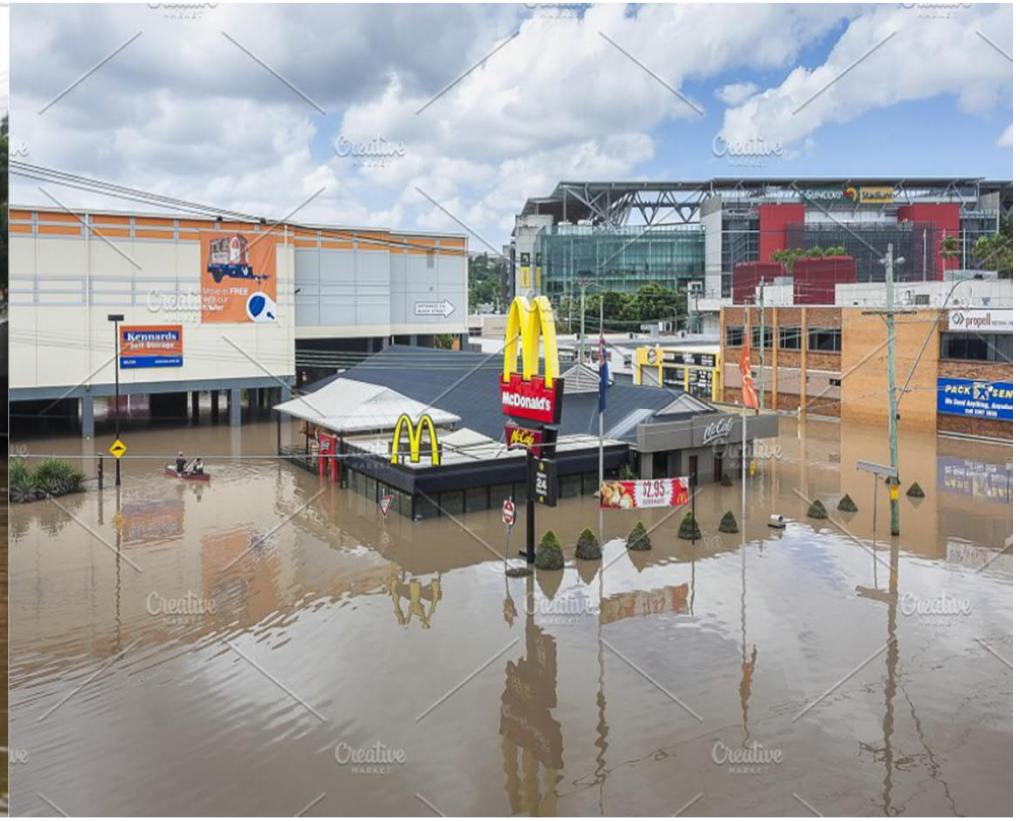
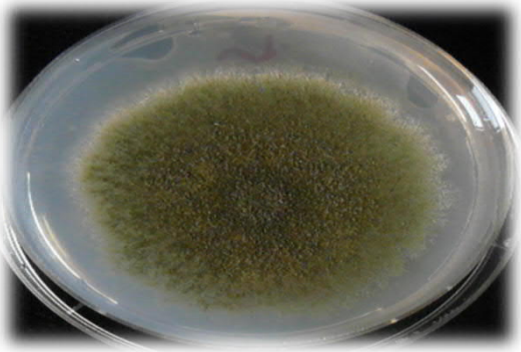


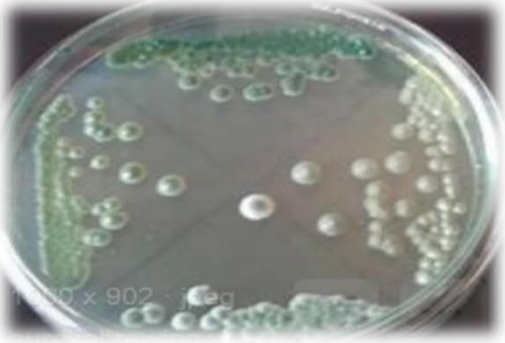

# Mold and moisture problems in residential and public buildings

.video https://www.youtube.com/watch?v=MUdN_HlUvrI

# In buildings without microbe sources in their structures

- Outdoor air is the main source of microbes
- *Common genera indoors*
  - *Cladosporium* (the most dominating genus in outdoor air)
  - *Penicillium* (the commonest)
  - *Aspergillus*
  - yeasts





- The seasonal variation is considerable
  - The highest concentrations are usually detected in summer.
  - In cold climates during winter outdoor concentrations of fungi are low.

Salonen et al. 2015.

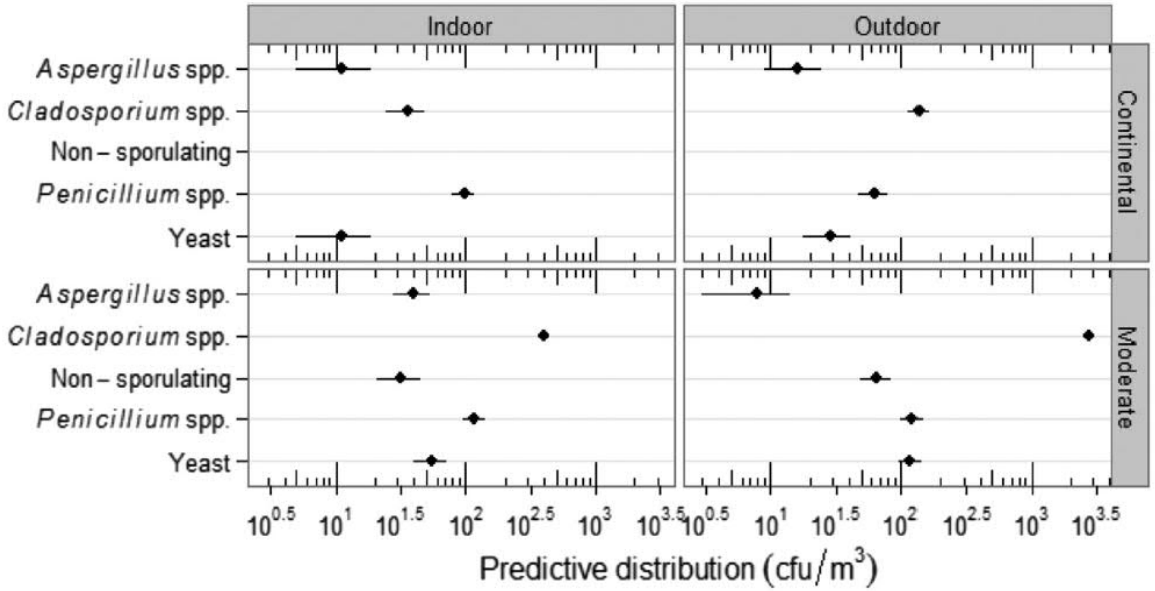


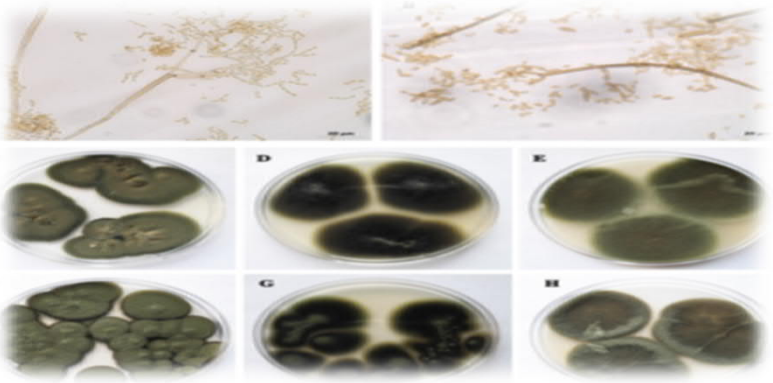

**Fig. 3.** Posterior predictive indoor and outdoor concentrations (means and 95% credible intervals) of *Cladosporium* spp. *Penicillium* spp., *Aspergillus* spp., non-sporulating isolates and yeasts in school environments in continental and moderate climate areas.

- The transport of fungal spores from outdoor air into indoor air is influenced by
  - the air tightness of the building envelope
  - type of ventilation
- Microbes may also drift indoors on the clothes of occupants
- The age of building gradually increase the concentration of airborne fungi

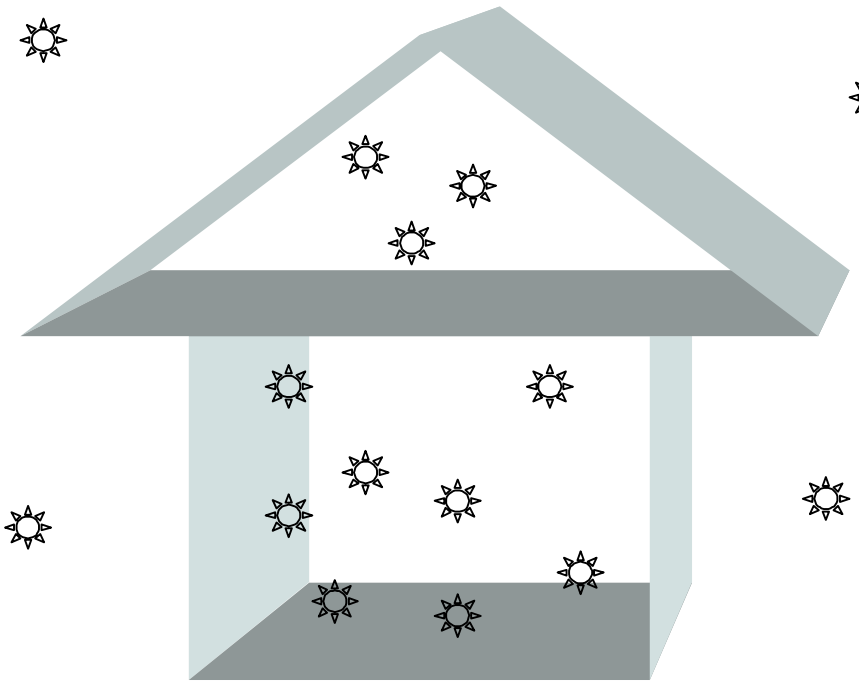
# In buildings with moisture and mould damage

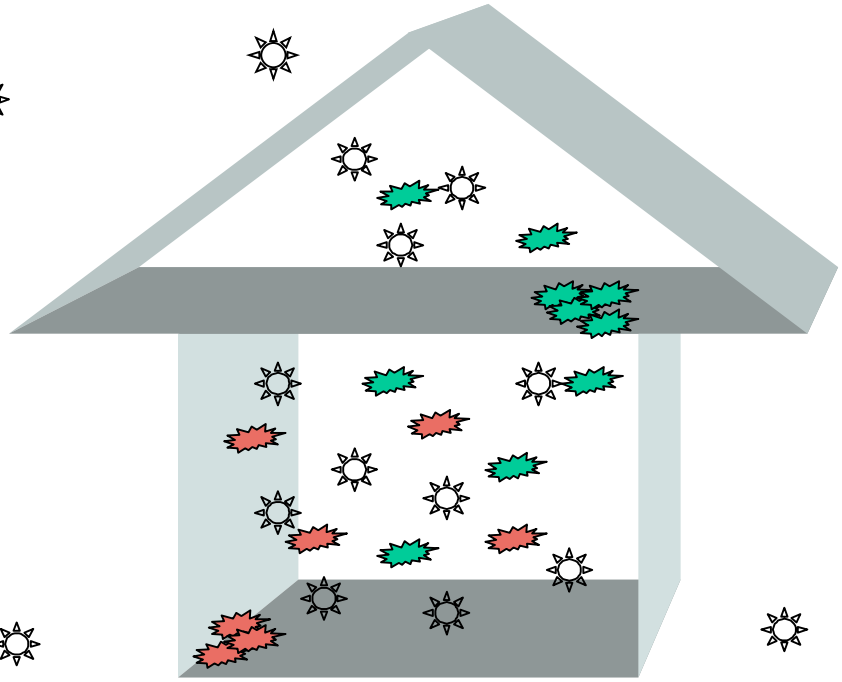
- Indoor sources of fungi can be significant
- The overall mycobiota indoors may be extensive
- Microbial growth starts in building materials and structures when moisture conditions permit
- Fungal diversity is large between moisture-damaged building materials

- Common fungi in damaged materials e.g.:
  - *Penicillium* (the commonest)
  - non-sporing isolates
  - *Aureabasidium*
  - *Acremonium*
  - *A. versicolor*
  - *Cladosporium*
  - *Chaetomium*
  - *Ulocladium*
  - yeasts.



# Concentration of fungi in the buildings in Finland





## Non-damaged buildings:

Apartments < 100 cfu/m$^3$

Schools < 50 cfu/m$^3$

Offices < 50 cfu/m$^3$

## Damaged buildings:

Apartments > 100 cfu/m$^3$

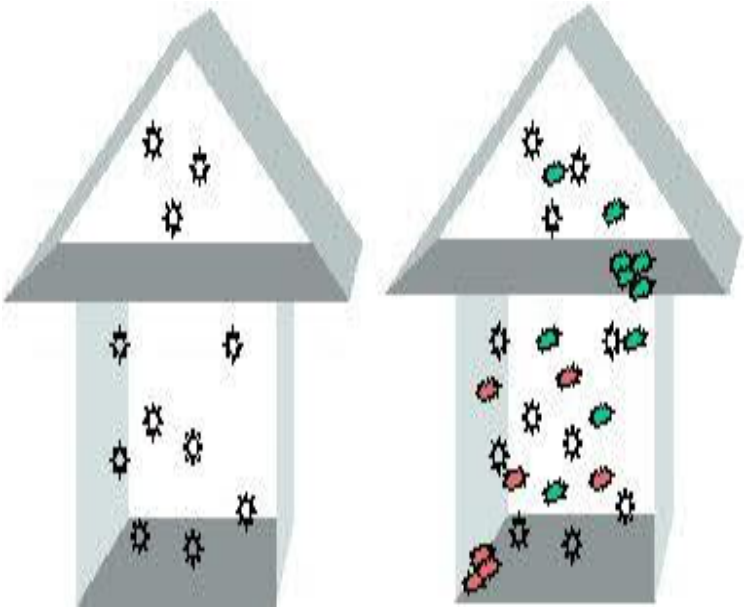
Schools > 50 cfu/m$^3$

Offices > 50 cfu/m$^3$

# Dominating fungal flora in the buildings

**Non-damaged buildings:**

- *Penicillium*
- *Cladosporium*
- *Aspergillus*
- Yeasts
- Human based-bacteria



**Damaged buildings:**

- *A. versicolor*
- *Fusarium*
- *Stachybotrys*
- *Trichoderma*
- *Ulocladium*
- *Phialophora*
- *Actinomycetes*

- There is a consensus about the indicator status (indicates dampness or moisture damage) for:
  - *Stachybotrys* (a sign of serious moisture problems and have serious health implications for occupants)
  - *Aspergillus versicolor*
- Other damage associated fungi:
  - *Ulocladium* spp.
  - *Tritirachum*
  - *Exophiala*
  - *Chaetomium* spp.

# Assessment of fungi and bacteria

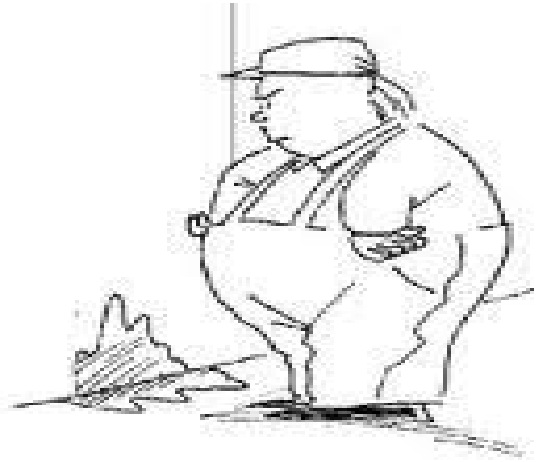
- Our knowledge of what the agents, the amount of exposure, and the mechanisms in damp indoor environments contribute to health effects is incomplete.

  →There are no uniformly accepted, or valid, quantitative environmental sampling methods (standard methods) or serologic tests with which to assess exposures to mould and other agents associated with damp indoor environments

- No single sampling method can be used to collect all of the airborne biological agents that may be present in a particular environment.

- Methods to estimate the presence of moisture damage in buildings can include

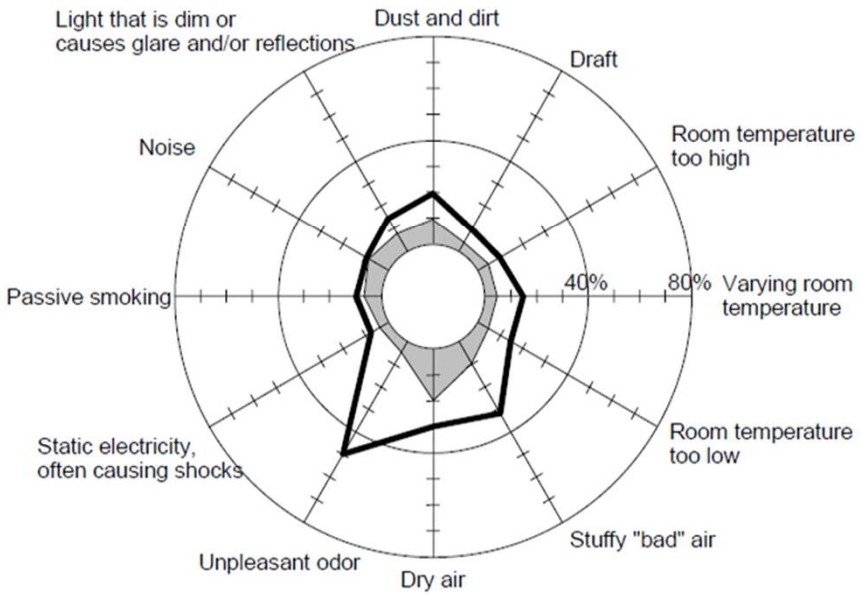
  - the use of questionnaires
  - visual inspection of buildings (walk through)
  - more specific investigation of the building construction and environmental sampling



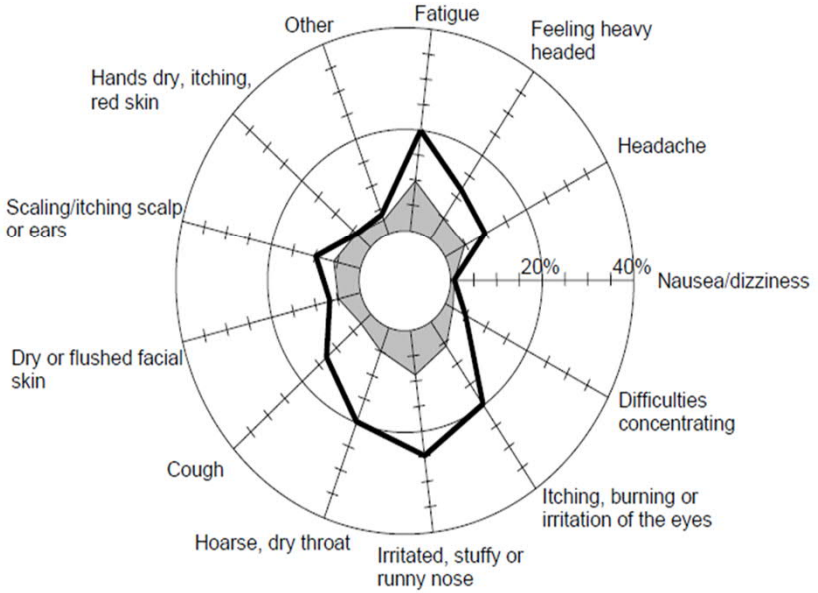
# Complaints about unpleasant smell, stuffy, “bad” air and increased frequency of symptoms from the mucous membranes point to pollution in the indoor air.

Note! It is not possible to decide if gases or particles are involved but, in such situation, it is advisable **to search for moisture problems**

**WORK ENVIRONMENT**
(often bothered) %

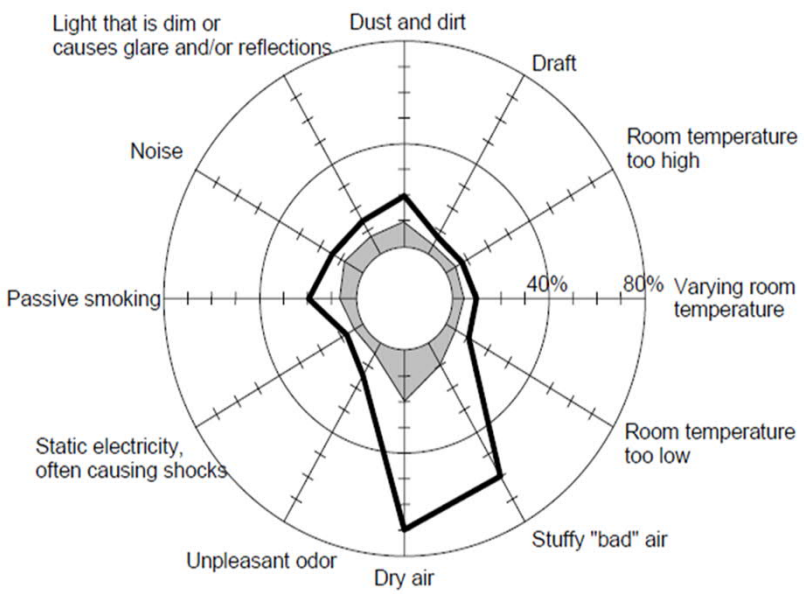



**SYMPTOMS**
(yes, often) %

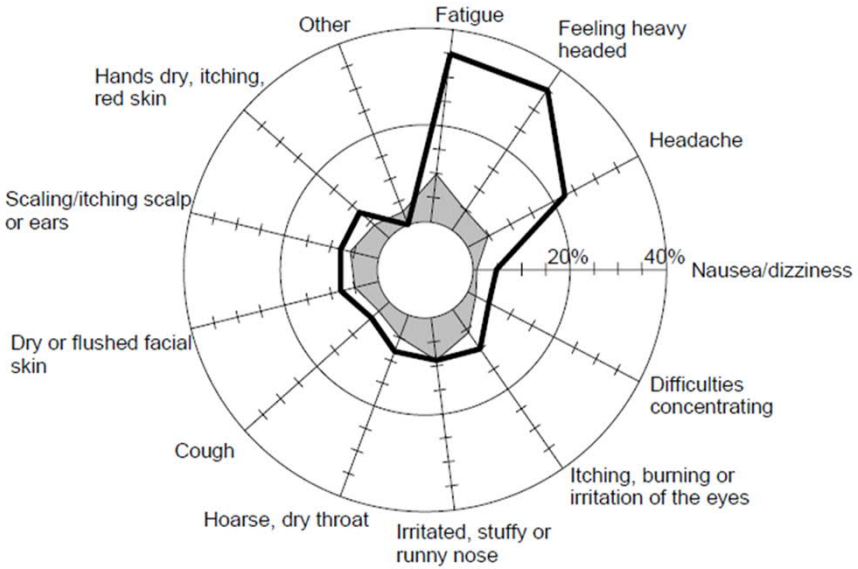


# Complaints about stuffy “bad” air, dry air and an increased frequency of general symptoms point to ventilation problems

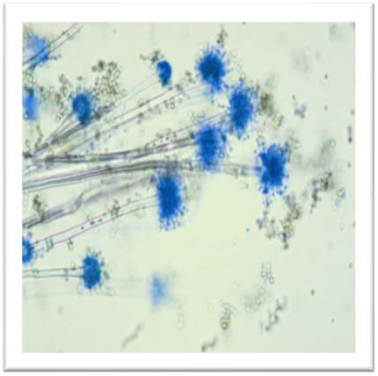
**WORK ENVIRONMENT**
**(often bothered) %**



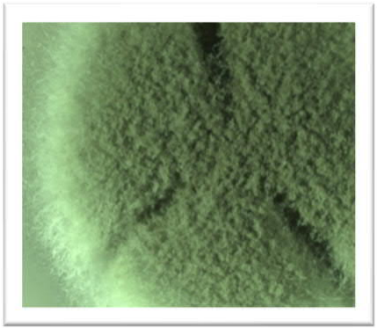

**SYMPTOMS**
**(yes, often) %**



- Microbial exposure assessments have been based generally on microenvironmental samples focussed on fungi and bacteria, but also on fungal by-products, including toxins.



- The detection and enumeration of moulds have been described in standard 16000-16 of the International Organization for Standardization (ISO, 2008).



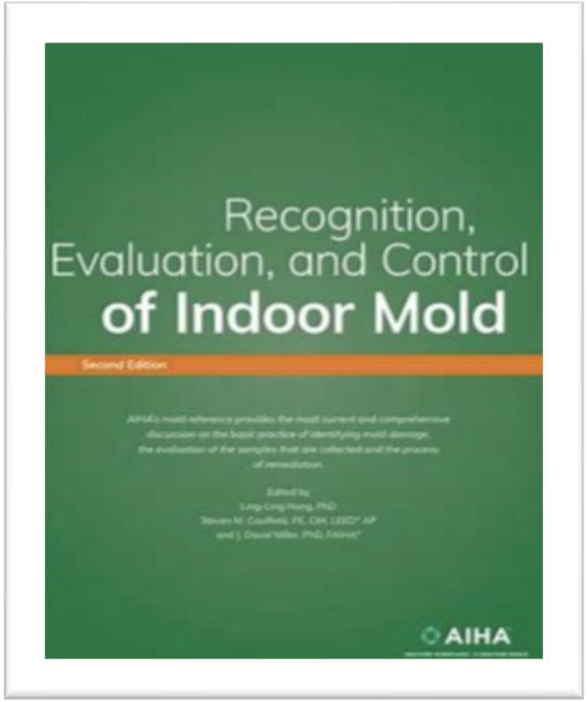
- Environmental inspection and sampling may be useful in identifying a source if there is a suspicion of mould (e.g. musty odour) but no visible mould growth.
- The extent of any water damage and mould growth should be visually assessed and the affected building materials identified.
- A visual inspection should also include observations of hidden areas where damages may be present.

Aalto University
School of Engineering

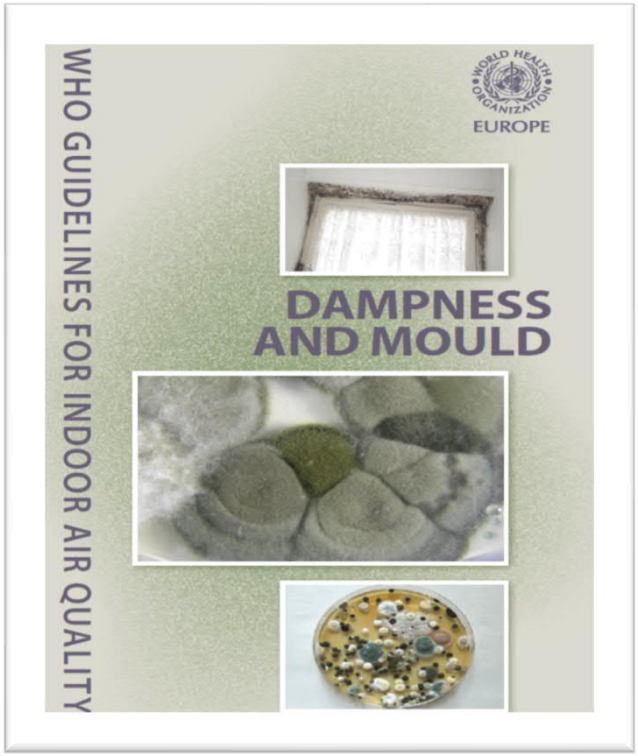
# Measurement instruments/methods e.g.

# Useful books and journal papers:

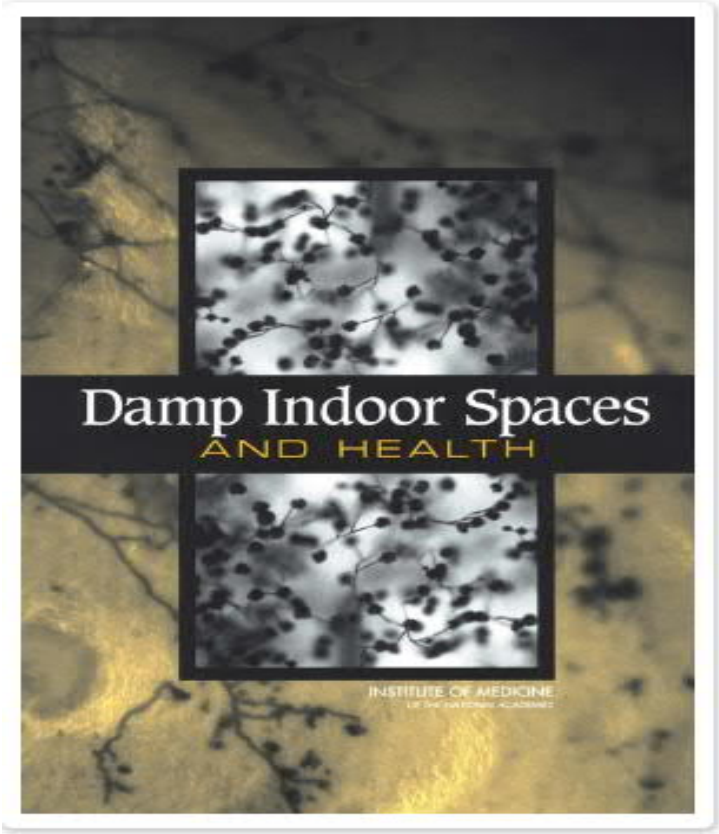
AIHA “Recognition, Evaluation, and Control of Indoor Mold” 2020



# WHO. 2009. WHO Guidelines for Indoor Air Quality. Dampness and mould.



# Institute of Medicine (IOM). 2004. Damp Indoor Spaces and Health



# Mendell et al. 2011

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Environ Health Perspect. 2011 Jun; 119(6): 748–756.
PMCID: PMC3114807
Published online 2011 Jan 26. doi: 10.1289/ehp.1002410
Review

## Respiratory and Allergic Health Effects of Dampness, Mold, and Dampness-Related Agents: A Review of the Epidemiologic Evidence

Mark J. Mendell,[1,2] Anna G. Mirer,[3] Kerry Cheung,[4] My Tong,[1] and Jeroen Douwes[4]

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# Nevalainen, Täubel, and Hyvärinen, 2015

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INDOOR AIR
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**Invited Review**

## Indoor fungi: companions and contaminants

**Abstract** This review discusses the role of fungi and fungal products in indoor environments, especially as agents of human exposure. Fungi are present everywhere, and knowledge for indoor environments is extensive on their occurrence and ecology, concentrations, and determinants. Problems of dampness and mold have dominated the discussion on indoor fungi. However, the role of fungi in human health is still not well understood. In this review, we take a look back to integrate what cultivation-based research has taught us alongside more recent work with cultivation-independent techniques. We attempt to summarize what is known today and to point out where more data is needed for risk assessment associated with indoor fungal exposures. New data have demonstrated qualitative and quantitative richness of fungal material inside and outside buildings. Research on mycotoxins shows that just as microbes are everywhere in our indoor environments, so too are their metabolic products. Assessment of fungal exposures is notoriously challenging due to the numerous factors that contribute to the variation of fungal concentrations in indoor environments. We also may have to acknowledge and incorporate into our understanding the complexity of interactions between multiple biological agents in assessing their effects on human health and well-being.

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Key words: Fungi; Mold; Indoor environment; Health effects; Exposure; Mycotoxin.

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# Nevalainen et al. 2015

**Table 1** Fungal components and products relevant for indoor air sciences

| Fungal agent | Short description | Applications in indoor air research | References |
|---|---|---|---|
| Fragments | Particles of fungal origin that are smaller than whole spores (typically <1 $\mu$m) | May have relevance as exposure agents related to health effects | Górny et al. (2002) |
| Ergosterol | Sterol specific to fungal cells<br>Present in most fungal cells, underrepresented in yeasts<br>No specific role as health-relevant agent | Ergosterol content used as a proxy for fungal biomass | Axelsson et al. (1995), Miller et al. (1988), Miller and Young (1997), Pasanen et al. (1999) |
| Glucans | Major structural components of fungal cells<br>(1-3) and (1-6) linked polymers of D-glucose<br>Non-allergenic but possess proinflammatory properties | Glucan content is used as a proxy of bioactive portion of fungal biomass | Douwes (2005), Iossifova et al. (2008) |
| Extracellular polysaccharides (EPS) | Stable, high molecular weight sugar polymers on the surface of fungal cells, produced during growth | Marker of fungal biomass (mainly *Penicillium* and *Aspergillus*)<br>No longer widely used | Douwes et al. (1999), Noterman and Soentoro (1986) |
| Fungal allergens | Antigenic substances of fungi capable of stimulating an IgE-mediated response | Indoor exposure and role in health effects insufficiently known | Green et al. (2003), Green et al. (2005), Horner et al. (1995), Salo et al. (2009) |
| MVOC | Highly volatile low molecular weight chemicals, produced by growing fungi (and bacteria) as primary and secondary metabolites<br>Include alcohols, aldehydes, amines, ketones, terpenes and aromatic hydrocarbons<br>Relatively low toxicity | Recognized as odor of mold<br>Measurement of MVOCs is not a good indicator of fungal growth as there are very few VOCs specific to microbial sources only | Korpi et al. (2009), Schleibinger et al. (2008) |
| Mycotoxins | Nonvolatile fungal secondary metabolites with a variety of chemical structures<br>Chemically stable, and some of them are thermally stable<br>Many are bioactive, and some are acutely toxic by ingestion<br>May be present airborne attached to other particles | Occurrence in indoor air has been shown<br>Role as causative agents of symptoms possibly due to their toxicity and inflammatory potential<br>Specific studies on their connection to health still lacking | Bloom et al. (2009b), Brasel et al. (2005a), Täubel et al. (2011) |
| Fungal nucleic acids DNA and RNA | Polymeric macromolecules composed of nucleotides<br>Contains the genetic information of a fungal cell (DNA) or acts in converting of the genetic information (RNA)<br>Located in the different cellular organelles and the mycoplasm | No relevance as a potential causative agent of health outcomes<br>Widely used as a target in DNA-based methods that are increasingly applied in indoor air research (including quantitative PCR, DNA fingerprinting, and sequencing applications) | Adams et al. (2013b, 2013c), Amend et al. (2010b), Haugland and Vesper (2002), Pitkäranta et al. (2008, 2011) |

# Ghosh et al. 2015

Ghosh B, Lal H, Srivastava A. Review of bioaerosols in indoor environment with special reference to sampling, analysis and control mechanisms. Environment International. 2015. Volume 85. Pages 254-272. https://www.sciencedirect.com/science/article/pii/S0160412015300581

Aalto-yliopisto

# Tiina Reponen et al.

ROYAL SOCIETY OF CHEMISTRY

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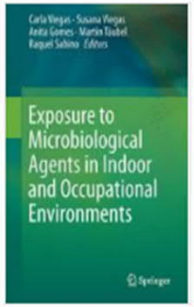
DOI: 10.1039/C7EM00257B (Paper) *Environ. Sci.: Processes Impacts*, 2017, **19**, 1312-1319

## Comparison of indoor air sampling and dust collection methods for fungal exposure assessment using quantitative PCR†

**Jennie Cox** [a], **Reshmi Indugula** [a], **Stephen Vesper** [b], **Zheng Zhu** [a], **Roman Jandarov** [a] **and Tiina Reponen** [*a]

University of CINCINNATI




Exposure to Microbiological Agents in Indoor and Occupational Environments pp 85-96 | Cite as

## Sampling for Microbial Determinations

Authors | Authors and affiliations

Tiina Reponen

Environment International 69 (2014) 9–17

Contents lists available at ScienceDirect

Environment International

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# The impact of flood and post-flood cleaning on airborne microbiological and particle contamination in residential houses

Congrong He [a], Heidi Salonen [a,b], Xuan Ling [a], Leigh Crilley [a], Nadeesha Jayasundara [a], Hing Cho Cheung [a], Megan Hargreaves [a], Flavia Huygens [a], Luke D. Knibbs [a,c], Godwin A. Ayoko [a], Lidia Morawska [a,*]

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Indoor dust

ABSTRACT

In January 2011, Brisbane, Australia, experienced a major river flooding event. We aimed to investigate its effects on air quality and assess the role of prompt cleaning activities in reducing the airborne exposure risk. A comprehensive, multi-parameter indoor and outdoor measurement campaign was conducted in 41 residential houses, 2 and 6 months after the flood. The median indoor air concentrations of supermicrometer particle number (PN), $PM_{10}$, fungi and bacteria 2 months after the flood were comparable to those previously measured in Brisbane. These were 2.88 p $cm^{-3}$, 15 μg $m^{-3}$, 804 cfu $m^{-3}$ and 177 cfu $m^{-3}$ for flood-affected houses (AFH), and 2.74 p $cm^{-3}$, 15 μg $m^{-3}$, 547 cfu $m^{-3}$ and 167 cfu $m^{-3}$ for non-affected houses (NFH), respectively. The I/O (indoor/outdoor) ratios of these pollutants were 1.08, 1.38, 0.74 and 1.76 for AFH and 1.03, 1.32, 0.83 and 2.17 for NFH, respectively. The average of total elements (together with transition metals) in indoor dust was 2296 ± 1328 μg $m^{-2}$ for AFH and 1454 ± 678 μg $m^{-2}$ for NFH, respectively. In general, the differences between AFH and NFH were not statistically significant, implying the absence of a measureable effect on air quality from the flood. We postulate that this was due to the very swift and effective cleaning of the flooded houses by 60,000 volunteers. Among the various cleaning methods, the use of both detergent and bleach was the most efficient at controlling indoor bacteria. All cleaning methods were equally effective for indoor fungi. This study provides quantitative evidence of the significant impact of immediate post-flood cleaning on mitigating the effects of flooding on indoor bioaerosol contamination and other pollutants.

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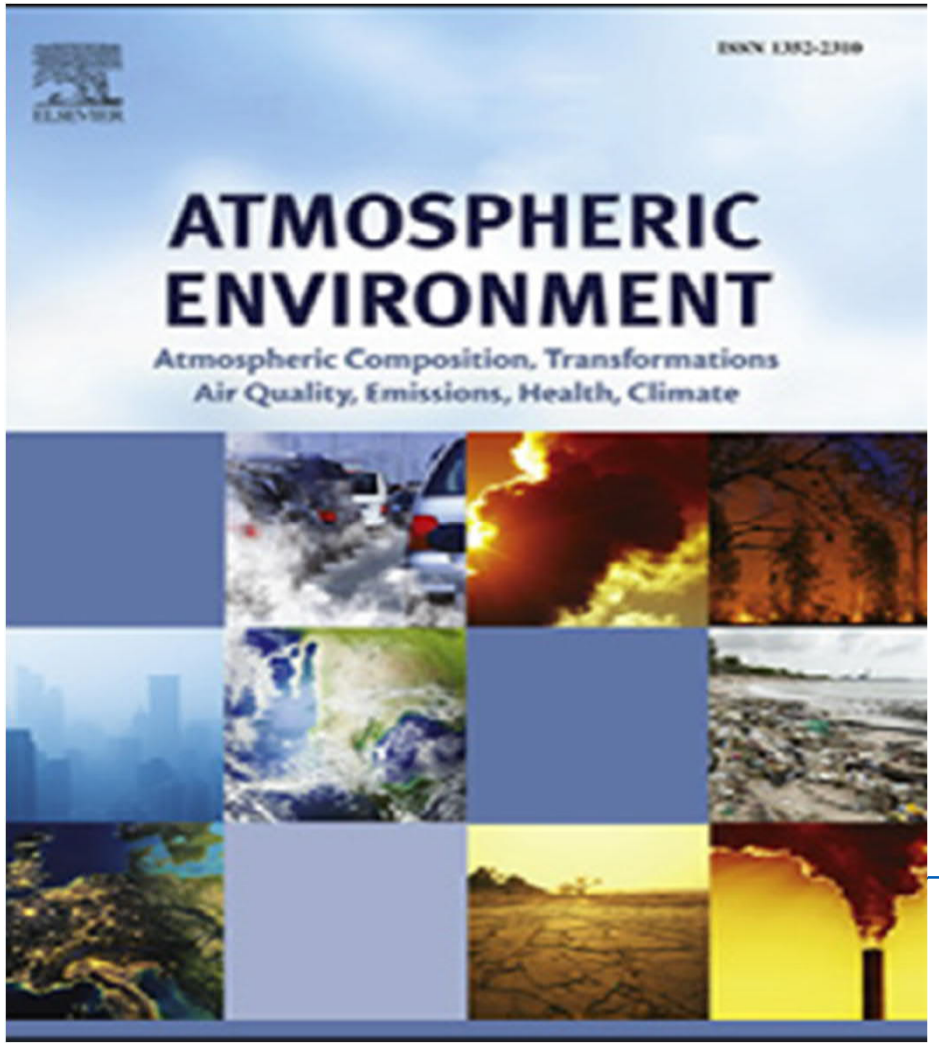
# Review article:
# Airborne viable fungi in school environments in different climatic regions




Atmospheric Environment 104 (2015) 186–194

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Review

## Airborne viable fungi in school environments in different climatic regions – A review

Heidi Salonen [a, b, c, *], Caroline Duchaine [d], Mandana Mazaheri [c], Sam Clifford [c], Sanna Lappalainen [b], Kari Reijula [e, f], Lidia Morawska [c]

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### HIGHLIGHTS

- The concentration and flora of viable fungi in school environments were reviewed.
- Meta-regression was performed to estimate the average behaviour for each analysis.
- The climatic condition was a determinant of concentrations of airborne viable fungi.
- Published indoor guidelines for total viable fungi were 50–2000 cfu/m$^3$.

### ARTICLE INFO

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Viable fungi
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Climate areas
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Flora
Guidelines

### ABSTRACT

Elevated levels of fungi in indoor environments have been linked with mould/moisture damage in building structures. However, there is a lack of information about "normal" concentrations and flora as well as guidelines of viable fungi in the school environment in different climatic conditions. We have reviewed existing guidelines for indoor fungi and the current knowledge of the concentrations and flora of viable fungi in different climatic areas, the impact of the local factors on concentrations and flora of viable fungi in school environments. Meta-regression was performed to estimate the average behaviour for each analysis of interest, showing wide variation in the mean concentrations in outdoor and indoor school environments (range: $10^1$–$10^3$ cfu/m$^3$). These concentrations were significantly higher for both outdoors and indoors in the moderate than in the continental climatic area, showing that the climatic condition was a determinant for the concentrations of airborne viable fungi. The most common fungal species both in the moderate and continental area were *Cladosporium* spp. and *Penicillium* spp. The suggested few quantitative guidelines for indoor air viable fungi for school buildings are much lower than for residential areas. This review provides a synthesis, which can be used to guide the interpretation of the fungi measurements results and help to find indications of mould/moisture in school building structures.

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# The Effects of Local Factors on the Concentrations and Flora of Viable Fungi in School Buildings

H. Salonen, E. Castagnoli, C. Vornanen-Winqvist, R. Mikkola, C. Duchaine, L. Morawska, J. Kurnitski

*Abstract*— A wide range of health effects among occupants are associated with the exposure to bioaerosols from fungal sources. Although the accurate role of these aerosols in causing the symptoms and diseases is poorly understood, the important effect of bioaerosol exposure on human health is well recognized. Thus, there is a need to determine all of the contributing factors related to the concentration of fungi in indoor air. In this study, we reviewed and summarized the different factors affecting the concentrations of viable fungi in school buildings. The literature research was conducted using Pubmed and Google Scholar. In addition, we searched the lists of references of selected articles. According to the literature, the main factors influencing the concentration of viable fungi in the school buildings are moisture damage in building structures, the season (temperature and humidity conditions), the type and rate of ventilation, the number and activities of occupants and diurnal variations. This study offers valuable information that can be used in the interpretation of the fungal analysis and to decrease microbial exposure by reducing known sources and/or contributing factors. However, more studies of different local factors contributing to the human microbial exposure

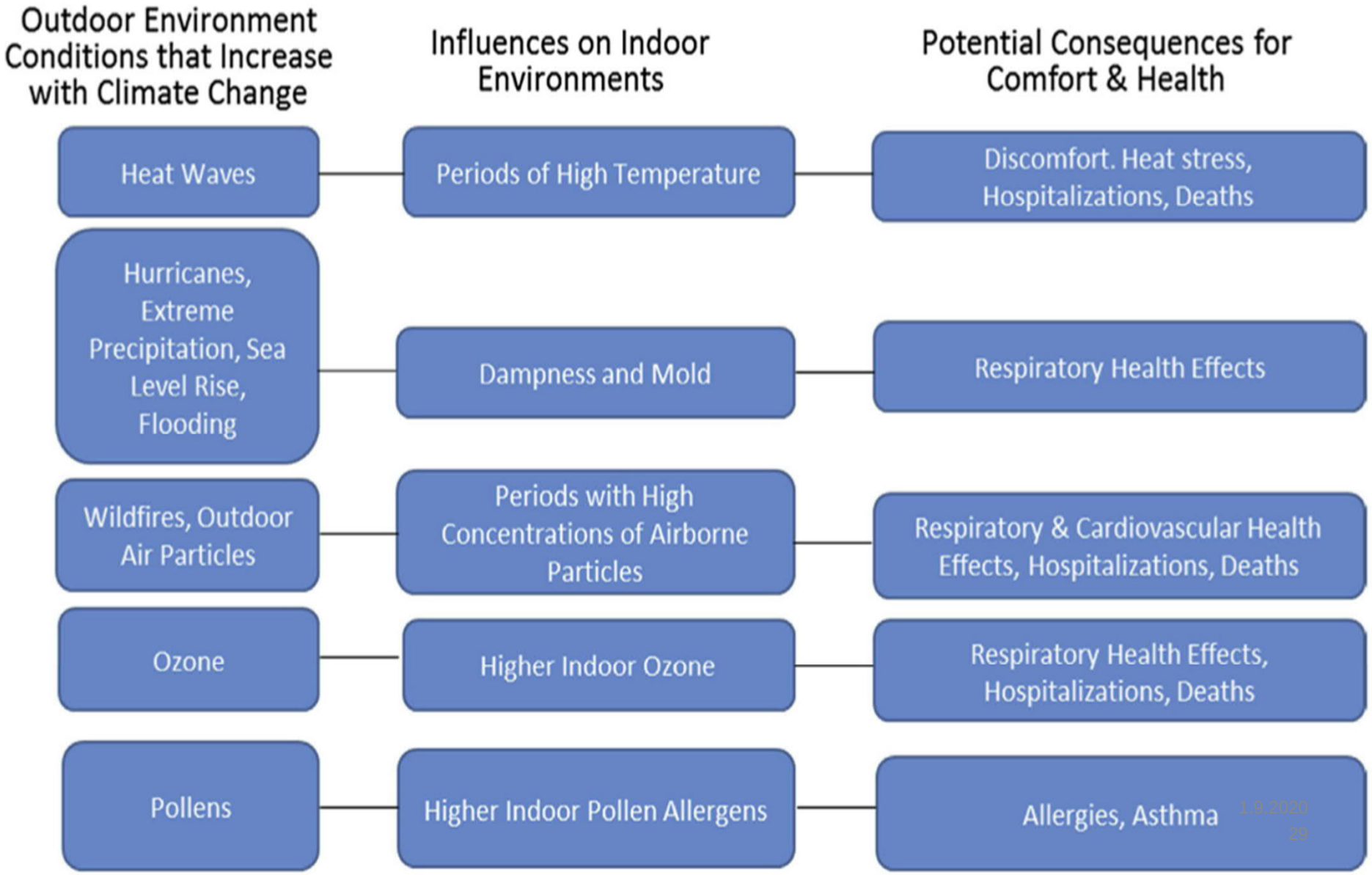
1.9.2020

symptoms related to microbial exposure is supported by the observation that the symptoms decrease after the exposure has been eliminated [7], [8]. However, the causal links between the exposing agents and disease are poorly understood [9], and there are no established health-based guidelines or standards related to fungal concentrations in indoor air [10].

Despite the lack of knowledge about the causal links and dose–response relationship in microbial exposure and disease, air samples from indoor settings are commonly collected to assess human exposure to fungi and find hits of abnormal sources of microbes [11], [12]. Air samples are also collected for the detection and quantification of fungi if there are concerns about the abnormal presence of fungi in the absence of any visible mold growth (e.g., musty odor), to identify fungi release from sources, and to monitor the effectiveness of control measures [13]-[15].

Based on residential studies, statistical associations suggest that factors governing indoor bioaerosols include excess

# Examples of how climate change may affect indoor environments and health (Fisk, 2015)



# Upcoming defences

**4.9.2020 Camilla Vornananen-Winqvist.** Indoor air contaminants, symptoms and effects of mechanical ventilation in school buildings.

**10.9.2020 Emmanuelle Castagnoli.** Novel detection methods and knowledge of indoor emissions from building materials, fungi, and cleaning agents.

**7.10.2020 Katja Tähtinen.** Perceived indoor environment and probability of abnormal indoor air exposure in health care workplaces.

**9.10.2020 Kati Järvi.** Improved methods for assessing and reducing health effects of poor indoor air.

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# Exposure to indoor air contaminants in school buildings with and without reported indoor air quality problems

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## Conclusions

“The concentrations of airborne cultivable fungi and identified fungal species in dust demonstrated most clearly the differences between schools in which occupants did or did not report IAQ-related problems.

“Pathogenic/toxigenic *Trichoderma* strains were found only in the problematic schools (in the dust samples from exhaust air filters ).

Mycoparasitic and mycotrophic *T. atroviride* strains were the most frequently isolated *Trichoderma* species, which could indicate hidden excess moisture and mould growth of other fungi.”

# Thank you!

*"When the waters subside, the problem's going to be mold."*