Moisture damage and mould in our home

Mom: I splashed some water on the floor while taking a bath! Will mould start growing in the bathroom?

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Storyline

A comfortable indoor environment with high quality of indoor air is important for the good health and welfare of building occupants. People spend around 90% of their time in indoor environments, small children and elderly often even more, and therefore much of our exposure to environmental contaminants in the air happens indoors. Of course, not all contents of air are contaminants and not all exposure is bad - it is important to remember that indoor environments contain lots of microbes, for example, that are not harmful. Indeed, some microbial exposure even promotes good health, particularly so during early childhood, where the developing immune system needs microbial encounters in order to be well trained and prepared to sustain good health later in life. The indoor microbiome is typically mostly sourced from outdoor air, soil and vegetation, as well as from human and non-human building occupants. This "normal indoor microbiota*", in particular when coming from outdoors, can have positive effects on human health, as opposed to microbes growing on building materials due to moisture problems.

In contrast, microbial growth on surfaces and in building structures is considered an abnormal condition, which should always be prevented in the first place, via good construction, building operation and maintenance. Microbial growth and damage on exterior or interior building surfaces need to be removed and repaired thoroughly by qualified personnel, when appearing.

The main reason behind microbial growth is essentially the wetting – or in other words the increase of water content – of ordinarily dry materials, which then provides favourable conditions for metabolic activity, germination and proliferation of microbes. All cells consist primarily of water – up to 90% of the cell material – so all organisms need water to grow. Dry surfaces do not allow significant growth of microbes, which is why we dry foods like raisins, beans, flour, and so forth to allow them to be kept for long periods of time without deterioration by microbes, who would also love to use them as food.

Damp environments allow the growth of microbes and organisms that feed on microbes and, when distributed in indoor spaces, spores, cells and cell fragments, and microbial metabolites and also other organisms like amoebae and house dust mites may contribute to indoor biological pollution. In addition, there is a chemical component to moisture problems in buildings, in that surface materials, when confronted with excess moisture over extended periods of time, may release volatile chemicals (volatile organic compounds, or VOCs) into indoor air, which may also cause adverse health effects.

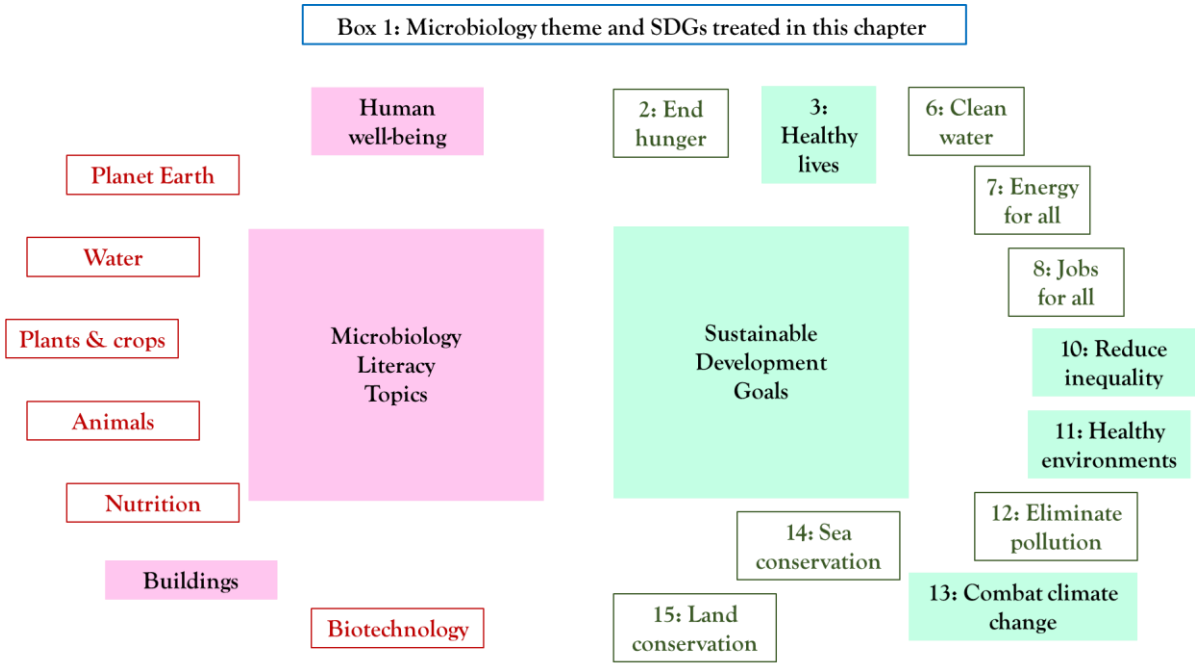
Moisture, dampness and mold problems are associated with different respiratory symptoms via irritant effects on the respiratory system and mucous membranes, including wheezing, cough, bronchitis, rhinitis, respiratory infections and, importantly, asthma exacerbation and development of new asthma. The location, severity and extent of the moisture or mold damage appear to be crucial in causing adverse health effects. For example, a small moisture damage in a cellar, where only little time is spent and with no air connections to the living quarters will likely have less negative health impact than extensive moisture damage in the living room of a home.

Climate change is likely to increase moisture damages in buildings in some areas of the world, inflicted by for example more severe and frequent precipitation (e.g. wind-driven rain) and especially an increase in occurrence of extreme weather events including flooding. Also, efforts to create more energy efficient buildings have the potential to increase moisture problems by

adding insulation layers and making buildings more airtight. This is primarily an issue when energy retrofits are not done appropriately and exclusively have energy benefits as a target.

The Microbiology and Societal Context

The microbiology: the indoor microbiome*; microbial growth (germination and proliferation) and metabolic activity; microbial secondary metabolites; mycotoxins; microbial volatile organic compounds (MVOCs); water availability and microbial growth substrate; inhalation exposure to microbes and their metabolites. *Sustainability issues:* human health; housing; climate change; energy efficiency in buildings; inequality.



Moisture damage and mould in our home: the Microbiology

1. ***What is moisture damage?*** Moisture damage* in buildings can be caused by failures in structures, such as leakage on roofs or water pipes, by accumulation and condensation of moisture on surfaces due to poor ventilation, as a consequence of inadequate insulation, or due to occupant behavior such as careless use of water. Moisture damage may also result from floods, heavy rains or water rising from the ground into building structures by capillary force.

All these are mechanisms by which excess water will become available via the wetting of building materials (outer surfaces, inner constructions, insulation layers, etc.). This availability of excess water provides favorable conditions for microbial proliferation and is what links moisture damage to microbial growth. Water is usually the limiting factor for microbes to proliferate and exert metabolic activity on building surfaces – essentially any building material, including organic matter accumulating on such material, will provide the substrate to allow microbes to grow. Unlike the existence of microbes in indoor spaces as such, i.e. the existence of an indoor microbiome, microbial growth on surfaces and in building structures is considered an abnormal condition. Moisture damage in buildings is generally, but not always, linked to an increase in microbial exposure levels in the indoor environment, and to changes in the composition of the microbiota, the microbial ecology of a building. Occurrence of specific fungal

and bacterial taxa, such as *Aspergillus versicolor*, *Eurotium*, *Stachybotrys* and actinobacteria has been associated with moisture damage.

2. ***It's not just mould that's growing there.*** "Moisture damage*", "building dampness*" and "indoor mould*" are terms that are often used interchangeably. This illustrates well just how much moisture problems in buildings are linked first and foremost to fungal occurrence and growth. The reason for this assumption is that fungi* are the visible, macroscopic growth on wet building materials, much more so than bacterial growth that often remains microscopic. This visibility has credited fungi also the top spot candidate for being the drivers of adverse health effects associated with water damage. Today we know very well that bacteria, just as fungi, are present and proliferate on damp building materials. Specifically, certain bacterial groups that are able to form spores and endure long periods of scarce nutrient and water availability, e.g. the "actinobacteria" or "actinomycetes", but also many other bacterial groups are known to be part of the microbial response and growth, whenever water becomes available on a building substrate. Oftentimes microbial damage in a building is recognized via a musty odor, often referred to as mould odor. In fact, it is members of a specific bacterial group (actinomycetes), in addition to fungi, that produce some of the chemical compounds that we then recognize in the home as mould odor (one such compound is called geosmin). Toxicological studies with bacterial and fungal species isolated from moisture-damaged buildings have shown that bacterial groups can show equal or even higher potency for provoking immuno-toxicological and inflammatory responses in model cell lines, strongly suggesting a health relevance of also bacteria in this context. Beyond fungi and bacteria, increases in relative humidity and water availability in indoor spaces may also support the occurrence and levels of amoeba and house dust mites, which is also of possible health relevance.

3. ***Moisture damage can make you sick, but how?*** The short answer to this question is: science does not know very well. While health effects associated with moisture damaged buildings are well established and recognized, the mechanisms underlying these adverse health outcomes are poorly understood. Part of the challenge is that the causative agents of moisture damage-associated ill health have not been pinpointed thus far. Fungal and bacterial spores, cellular components such as glucans and endotoxins, and metabolic products, such as microbial volatile organic compounds (MVOCs*) and non-volatile secondary metabolites, such as fungal mycotoxins*, have been postulated to be involved in contributing to adverse health outcomes, but results from different observational studies are inconsistent. The strongest support for the health relevance of bacteria and fungi associated with moisture damage in buildings comes from toxicological studies that show a variety of inflammatory and immunotoxic responses after exposure to microorganisms isolated from damp buildings.

Occupying moisture-damaged buildings has been consistently linked with adverse health outcomes, specifically respiratory symptoms, respiratory infections and the exacerbation and development of asthma. There is increasing evidence that the location within the building (including air connections to the site of damage), severity and extent of the moisture damage may be crucial in causing adverse health effects. When assessing the health effect, the likelihood, frequency and duration of the exposure to moisture damage should be considered. Avoiding the exposure, removing the damage and correcting the source of the problem are crucial actions.

It is important to also acknowledge that there is a small group of people who suffer from so-called 'hypersensitivity' symptoms. These people experience symptoms of the central nervous system (e.g. dizziness, fatigue and respiratory symptoms) in environments where the exposure to microbes may be on normal or low levels. Stress and fear of abnormal exposure – such as to

moisture damage in a home or working environment - can increase the exacerbation of symptoms, even if they cannot be directly linked to an environmental exposure. Such phenomena have been described also in the context of other environmental exposures and can be explained via psychophysiological mechanisms, including stress-induced inflammation.

4. ***Many buildings have some damage, fewer buildings have damage that might make you sick.*** It is very normal that damages, such as water leakages, happen during a building's lifetime. If the problem is noticed immediately, dried and - if necessary - repaired, the moisture damage is resolved and there will not be any subsequent health problems. It is also typical that in those parts of the buildings that have high moisture load e.g. bathrooms, there may occur for example tiny mould spots in silicone seams, but the area of the damage is so small that it will not cause any health problem. One could argue that it is even rare for any small moisture or microbial damage to be completely absent in a building upon a thorough building inspection. Some damages can occur in parts of the house that are rarely occupied and that have no air-connections to the main living quarters within the building, so are less likely to cause any harm to health. As mentioned above, *where* the damage is located, *duration* of exposure, *how severe* and widespread the damage is – all those are factors that play a role when evaluating health risks associated with moisture damages. For example, the risk of asthma and wheezing in early childhood seems to increase with the severity of moisture damage and when visible mold is detected in the main living areas. Moisture damages in bathrooms or other interior spaces seems not have such an effect. However, also damages that are less likely to cause ill health effects due to their location or extent should nonetheless be remediated whenever possible.

5. ***Where there is water, microbes can live and grow.*** Literally any material in the buildings we live and work in can serve as a substrate and surface more or less favourable to support proliferation and growth of microorganisms. The basic determinants of such processes are surface structure of the material, nutrient content and water activity. One could say that the recipe is: "Take any building material (as a nutrient-rich medium), keep temperature between+5 and 35 °C (optimal temperature is +20 to 25 °C), and then just add water AND you will get microbial growth, resulting in microbial damage on that material". The materials most susceptible to microbial growth are those with a natural organic composition such as wood and paper. On the other hand, microbes can also flourish in house dust, on concrete or brick walls, or on steel and glass surfaces – even when the materials themselves are less favourable to support microbial growth, organic matter accumulating on such surface will do the trick and serve as substrate. Thus, the type of material is not highly important as long as there is enough moisture. Long-term moisture stress that exceeds a material's tolerance for moisture can cause moisture and subsequently microbial problems. This is usually not the case with short and temporary (dried out in couple of days) moisture stress. So the answer to the question of whether or not spilled water on the tiled bathroom floor causes mould problems is clear: it doesn't cause any harm, as long as it is dried more or less immediately. [Sticking to the example of bathrooms though: it is hard to comprehend people adding thick fluffy carpets that can retain a lot of moisture for extended periods of time into building spaces where water is typically handled less carefully and humidity conditions are often high … not a great idea!]

6. ***Climate change and moisture problems in buildings.*** Climate change is relevant to moisture damages in buildings for obvious and less obvious reasons. Certain areas in the world will experience more precipitation, higher winds and subsequently wind-driven rain, increasing the moisture stress on the outer surfaces of buildings. Extreme weather events including flooding

are predicted to further increase in occurrence and severity, which will naturally increase incidents of severe moisture damages in the building stock. These changes will vary regionally and should be acknowledged in building structural design also geographically. More generally, a changing climate is confronting an existing building stock with climatic conditions that it has not been designed for, and this is true for large parts of the world. Efforts to mitigate climate change include increasing energy efficiency in buildings to reduce CO_2 emissions. For existing buildings this often means adding insulation layers and making buildings more air-tight. Such changes to buildings need to balance energy efficiency targets and indoor air quality, moisture problems and the health of building occupants in order to be sustainable. There are examples in the more recent history that have shown that when reduction of costs for heating and ventilation is the primary driver, moisture and microbial problems in buildings are likely to be exacerbated.

7. ***What can I do and what should I not do, if I find moisture damage or visible mold in my home?*** If you notice moisture damage (e.g. a leakage, moisture marks, signs of mould or mould odour) in the house, it is time to seek professional help in order to identify the source of the problem and to decide on necessary remediation. The building owner is responsible for ensuring that the damage is properly inspected and repaired. It is very important to locate the water damage and the sites of suspected microbial growth in the building material and remove it properly. There is no use to paint over problem areas or to apply biocides as the only response to the moisture problem. Biocides including ozonisation do not permanently remove the microbial growth on building and interior surfaces, in fact they can make the microbial growth more harmful by affecting the microbial metabolism. If there is an underlying moisture source that is not fixed, the microbial growth will reappear, even if surfaces are cleaned thoroughly. Biocides can be also harmful to different kinds of materials and to human health. Such substances are not an answer to moisture and mould problems and they could only be used in special situation e.g. after sewage damages, that need to be handled by professionals that adhere to safety precautions to avoid harmful health effects. Portable air cleaners can be sometimes useful to reduce harmful exposures in situations where people have to wait for a remediation to be started or before moving away from the damaged building, or during remediation activities, when the partitioning of the remediation site from other living quarters is done properly. It is important though to remember that air cleaners do not act on the source of the moisture problem and are not a permanent solution. In normal situations the most effective ways to improve your indoor air are to reduce or remove the sources of pollutants and to ventilate with clean outdoor air. Air cleaners do not replace the need to control pollutants and ventilate.

Remediation of moisture problems and microbial growth are likely to aggravate aerosolization and resuspension of damage related exposures and therefore require appropriate personal protection equipment. Building occupants should not be present during remediation whenever possible, in particular when partitioning and separation of the remediation site from other occupied areas is not effectively possible.

8. ***How can I prevent moisture damage and microbial growth in my home?*** It is highly important to take good care of your home, to keep it well maintained by following general maintenance intervals, and to keep the home clean and dry. Cleaning generally has a positive effect on indoor air quality, as it reduces dust loads on surfaces and thereby exposure to particles, allergens and chemicals. Use vacuum cleaner (preferably HEPA-filtered), cloths and water and, if needed, some general cleansing agents; disinfectants are not needed in cleaning normal houses. Avoid careless use of water. For example, hanging wet laundry in rooms that are not well ventilated will lead to moisture accumulation in the building structures and can cause microbial growth.

Make sure that the ventilation in your home is working properly and it is efficient. In mechanically ventilated homes, ventilation system filters should be changed or cleaned regularly 2-4 times per year depending on the surrounding environment and outdoor pollutant levels. Increase the effectiveness of ventilation when you have heavy load of moisture e.g. during shower, cooking or drying laundry inside the house. It is also a good habit to dry the floor and walls in the bathroom after shower to reduce accumulation of standing water. Make sure that rainwater is directed away from the house. Gutters and drain pipes should be cleaned if they contain leaves or other materials, and need to be checked regularly for leaks or congestion. Ensure that water doesn't accumulate near the building structures, but is directed away from the building. The roof should be regularly inspected and maintained to avoid or discover early broken roof tiles, holes, or cracks that allow water to penetrate through the roof. Time and money spent on thorough building maintenance is well invested, as it will help to prevent moisture damages in your home, which then often can be costly to fix.

9. ***Putting things into perspective: microbial growth on building surfaces is an abnormal situation; but microbes in indoor spaces are ok and good!*** We have mentioned this before but want to stress this point again, since there are some false beliefs around microbes in indoor spaces. The presence of microbes – bacteria and fungi - in indoor spaces as such is normal, ok and good. There is good evidence that the existence and right composition of an indoor microbiome may in fact have health promoting potential. When microbes start growing on outer and inner building surfaces, this is an indication for and consequence of moisture damage in buildings – such condition is abnormal and needs to be prevented or corrected, if present. This chapter has provided extensive information on that topic. Here few words about what factors contribute to shaping a normal indoor microbiome.

Soil and vegetation are the main sources for microbes in outdoor air and as a consequence, there is large variation in composition of outdoor air in diverse climates and geographical regions. Outdoor air acts as one of the main sources for microbial content of indoor environments and hence, geographical and climatic factors have a great influence on the microbial concentrations and communities indoors. The main route for the transfer of outdoor air to indoors is usually ventilation, either via mechanical ventilation systems or through open windows and doors, but air also infiltrates through leakages in the building envelope. Having pets, potted plants or carpets affects the microbial levels indoors. Pets not only shed microbes, but they also transport microbes from outdoors to indoors on their paws and bodies, as we do on our clothes, shoes and hair. Human shedding is one of the main sources of microbes in buildings, especially of bacteria. In addition to human occupancy, occupant behavior and activities are also significant sources of microbes. For example, handling firewood and other organic materials, having organic waste bins inside the home and low bin-emptying frequency increase the microbial levels in the indoor environments. Resuspension of dust is more pronounced in places where the human activity occurs, such as floors and other low levels.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 3. Ensure healthy lives and healthy housing at all ages.** Improve health by good quality of housing, prevent diseases.
- **Goal 10. Reduce inequality within and among countries.** Inadequate housing, including moisture damage, affects hardest populations with low socioeconomic status and limited financial means to acquire and maintain a healthy home.

- **Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable.** This goal includes the creation and maintenance of a healthy building stock and the mitigation health risks associated with living, including moisture damages in buildings.
- **Goal 13. Take urgent action to combat climate change and its impacts.** Acknowledge climate change in building structural design to ensure buildings are fit to persevere and function well in a changing climate. Aim at reducing CO_2 emissions by making buildings more energy efficient, while balancing energy efficiency measures with good indoor air quality and occupant health.

Potential Implications for Decisions

1. Individual

a. Regular check-up and thorough maintenance of the building. Attention to moisture problems and remediate moisture damages immediately and with the help of experts.

2. Community policies

a. Health care economics: costs associated with possible moisture and mold damage e.g. respiratory symptoms, infections and the exacerbation and development of asthma. These costs can be decreased with quick action in remediation of moisture and mold damages and good quality of buildings.

3. National policies relating to moisture and mold damages

a. Preventing moisture and mold damages by building regulations and good quality of building structural design.

b. Taking into account climate change in building regulations.

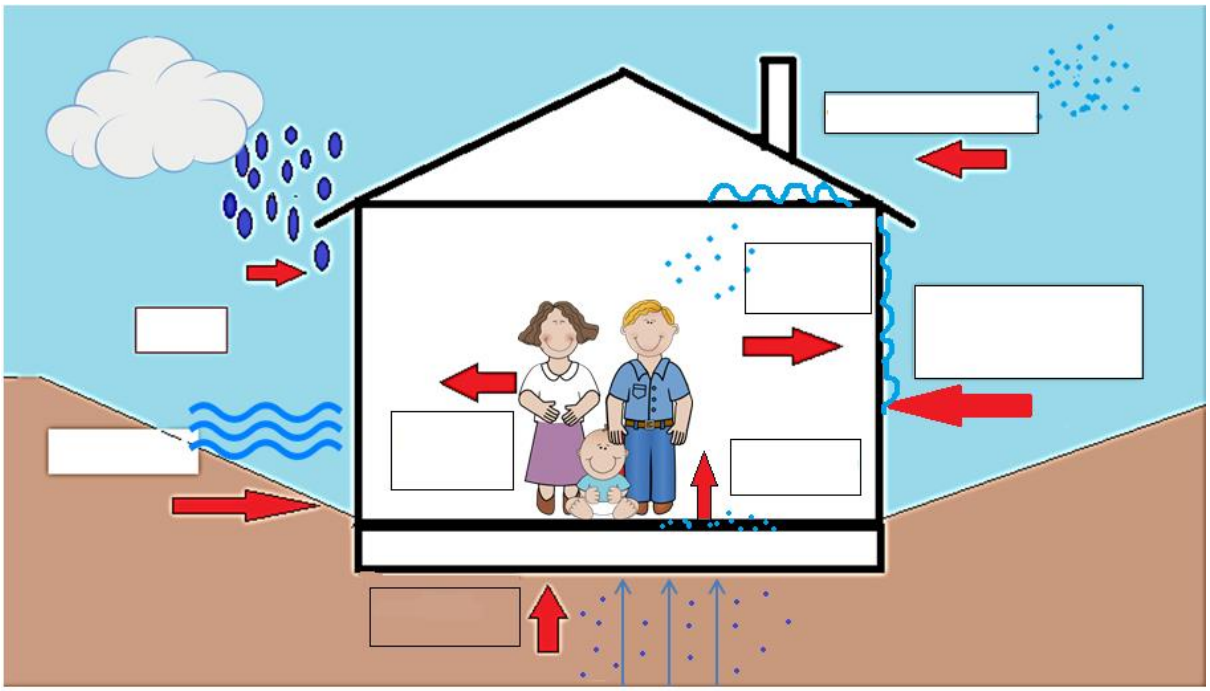
c. National economics: costs associated with remediation of moisture and mold damaged buildings, health care economics.

Pupil participation

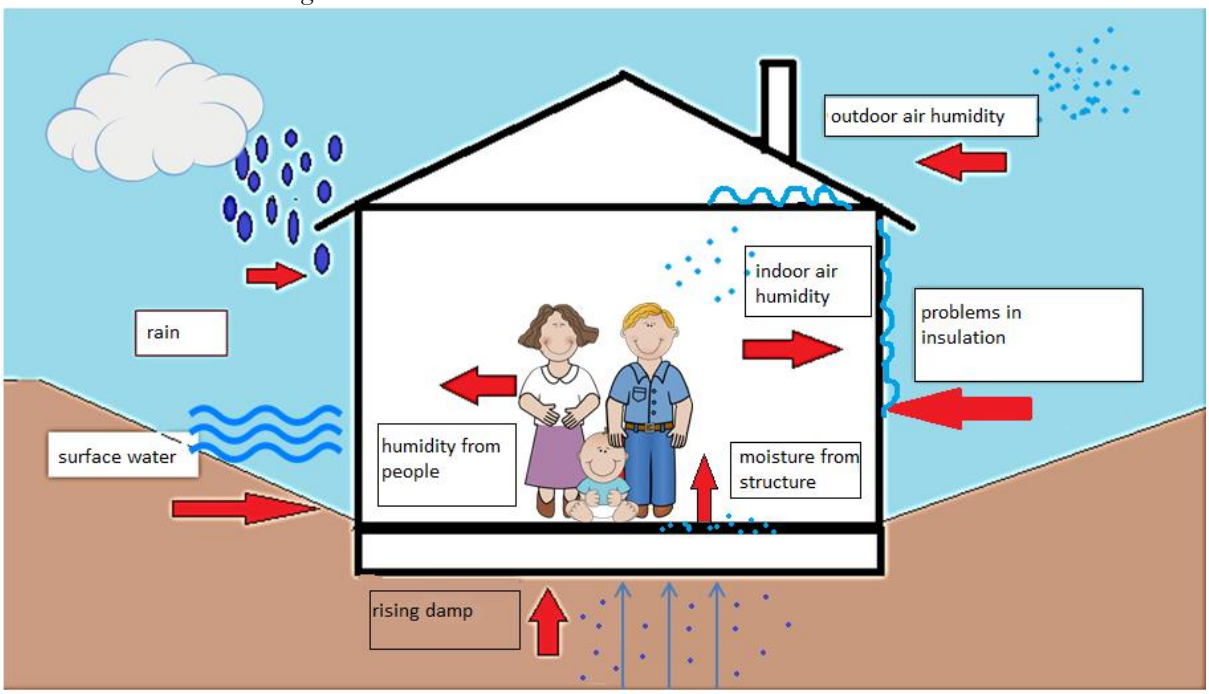
1. Class discussion of the difference between normal microbial situations in a home versus abnormal condition of microbial growth following moisture damage.

2. Perform a "walk-through inspection" of your home with attention to potential locations and sources of moisture problems. Discuss with your family what you could do to prevent moisture damage in your home.

3. Write in the boxes in the picture what are the possible factors causing moisture stress to the building.



Right answers:



The evidence base, further reading and teaching aids

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Mendell, M.J., Mirer, A.G., Cheung, K., Tong, M.and Douwes, J. (2011) Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence, *Environ. Health Perspect.*, **119**, 748–756.

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Glossary

Highlighted with "*" in the text at first use

Building dampness: defined by the WHO as any visible, measurable or perceived outcome of excess moisture that causes problems in buildings, such as mould, leaks or material degradation, mould odour or directly measured excess moisture (in terms of relative humidity or moisture content) or microbial growth (WHO 2009).
Fungi: are eukaryotic, heterotrophic microorganisms that can occur as yeasts, moulds, or as a combination of both forms
Indoor Mould: also sometimes referred to as mildew is fungal growth that develops on wet materials. Oftentimes the observation of indoor mould might include not only fungal but also bacterial growth, but it is typically the macroscopic fungal growth that is more easily observed by the eye.
Microbial volatile organic compounds (MVOCs): are a variety of compounds formed as secondary metabolites in the metabolism of fungi and bacteria. They belong to different chemical classes, such as alcohols, alkenes or terpenes, and are typically small compounds with low molecular mass, high vapor pressure and low boiling point, facilitating evaporation and diffusion in gas phase.
Microbiome: may be defined as a characteristic microbial community occupying a reasonably well-defined habitat which has distinct physio-chemical properties, including not only the microorganisms in that space, but also their "theatre of activity", involving the spectrum of molecules produced by the microorganisms. Based on this definition, also mobile genetic elements, such as phages, viruses, and extracellular DNA, would be included in the term microbiome, but not in the term microbiota. This said, there are numerous more or less varying definitions of what could referred to as "microbiome"
Microbiota: usually defined as the assemblage of living microorganisms present in a defined environment. Since phages, viruses, plasmids, prions, viroids, and free DNA are usually not considered living microorganisms, they do not belong to the microbiota according to the strict definition.
Moisture damage: is defined by the WHO as any visible, measurable or perceived outcome caused by excess moisture (eg. via water leaks, condensation, etc.) indicating indoor climate problems or problems of durability in building assemblies (WHO 2009). Often and probably

correctly synonymously used for “moisture problem” or “water damage”, but this term is different from what we refer to as “indoor mould” or “dampness”.

Mould: Moulds are multicellular fungi that occur in long filaments know as hyphae which grow by apical extension, unlike yeasts, which are microscopic and unicellular fungi that reproduce by budding.

Mycotoxin: originates from the Greek mykes, i.e. "fungus" and toxini, i.e. "toxin", and refer to a toxic secondary metabolite produced by organisms of the fungus kingdom that is capable of causing disease and/or death in humans or other animals.