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|---|---|
| ***Field*** | ***Central Heating*** |
| ***Chapter*** | ***Heating Theory & Heating Techniques*** |
| ***Subtitle*** | ***Fungal Bridge & Mold Formation*** |



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## Fungal

Fungal spores and fragments, which are typically very small, can be released from contaminated materials and pose a risk to human and animal health if they are inhaled. They are a common type of airborne biological aerosol in indoor environments and can cause respiratory problems. Dampness and moisture-related problems in buildings are a major cause of fungal contamination, which can be harmful to occupants. The characterization of fungal particles is important to understand the potential health effects associated with exposure. There are many sources of indoor air contaminants, and it is not clear which ones are associated with adverse health effects. Dampness and mold growth are prevalent in most homes and have been linked to respiratory and asthma-related health problems. Floods, wet seasons, building modernization, air conditioning systems, construction faults, and poor ventilation are among the reasons for increased indoor moisture levels. Various factors influence the microbial profile in indoor environments, and exposure to fungal particles has been linked to various diseases and symptoms among occupants of moisture-damaged buildings.

## Indoor sources of fungal

Fungi can be found in indoor environments through both exclusive indoor sources and outdoor infiltration. However, a significant proportion of indoor fungal particles and allergens are generated in the indoor environment itself. Indoor fungal composition can also be influenced by the building's characteristics, such as the presence of a basement, which can create a conducive environment for fungal growth due to high humidity and moisture content from sources such as leaky pipes or flooding. The kitchen and bathroom areas of a building can also provide a suitable substrate for fungal growth due to their high moisture content.



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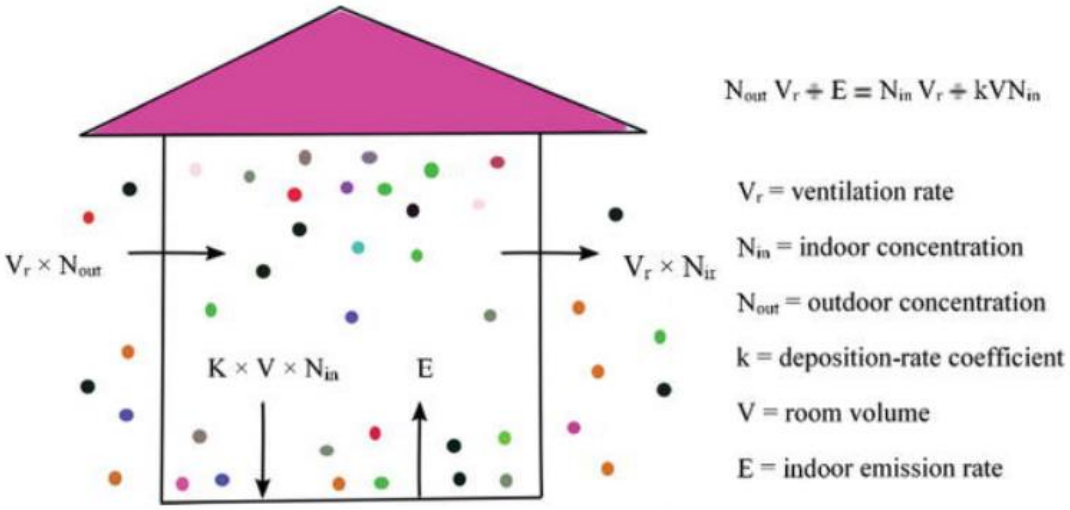
Ventilation systems can also contribute to indoor fungal growth, particularly when they are dirty or have inadequate air filters. Such systems can act as a reservoir for outdoor-generated fungi and can transfer them indoors. Dust and oil residues in ventilation ducts can also provide nutrients for fungal growth and serve as a source of indoor fungi. Therefore, it is crucial to maintain proper ventilation systems and control moisture in indoor environments to prevent fungal growth and reduce the risk of adverse health effects associated with indoor fungi.




Schematic diagram showing the sources of fungal particles in the indoor environment. Source from Yamamoto et al.

There are hundreds of thousands of fungal species living on our planet. They vary in size, appearance, and characteristics. Micro fungi, more often than not a form of mold, are invisible to the naked eye in small quantities. Whereas macro fungi, such as mushrooms or toadstools, are highly visible.

**Molds are a well-known type of fungi often found in residential homes.** There are thousands of mold species, each falling into one of three categories:

- allergenic,
- pathogenic and
- toxigenic.



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Allergenic molds produce allergic reactions. Pathogenic molds produce infection, particularly for immunocompromised individuals. And toxigenic molds produce deadly diseases.

However, mold spores are not the only common biological contaminant found in living spaces. Fungal toxins can also spread through home's indoor air and cause significant adverse health effects.

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**What Causes Fungi and Mold Growth Indoors**

In order for fungi to spread and mold to grow, there are several necessary conditions**: the presence of fungal toxins or mold spores, oxygen, darkness, warmth, moisture and a surface for growth.**

- **Humidity**: Homes in regions prone to high humidity are more likely to develop mold.
- **Leaks**: Severe weather and general wear can cause roofs and pipes to leak. If a leak is not addressed, mold will grow and spread beyond the leak area.

- **Poor Ventilation**: Stagnant air promotes the growth and spread of mold spores. Ensuring proper home ventilation, particularly **through mechanical ventilation**, is a helpful preventive step.

- **Condensation**: Walls, floors and pipes in homes all easily hold condensation when the seasons change.

- **Flooding**: If you thought leaks were partial to mold growth, consider floods! Clearing flood water can take days or weeks, providing mold ample time to grow and spread.

- **Dampness**: High humidity levels, darkness and poor ventilation combine to create the ideal damp environment for mold spores.

There are two indoor air quality solutions in particular that effectively address these causes. A whole-home dehumidifier will greatly reduce indoor relative humidity levels, condensation, and dampness. Humidity control is an ideal solution because fungi and molds require moisture to live. This device will hinder mold growth—even in the event of a leak or flood.

**Mold growth in buildings**



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**Mold is a fungal growth**. Whilst mold itself is not toxic, some molds can produce toxins that can have negative effects on human health, for example causing asthma, rhinitis, itchy eyes, respiratory symptoms, respiratory infection and eczema.

**Mold in buildings can be visible or can be hidden**, but it is generally an indication of a defect such as thermal bridging, condensation, leaks or penetrating or rising damp.

**Mold requires four factors for growth:**

1. Mold spores.
2. Food.
3. Appropriate temperature.
4. Moisture.
5. Spores

1.Mold spores are microscopic (ranging from 3 to 40 microns) and ubiquitous in the environment. Mold spores can be found floating in the air and in normal house dust. It is not generally practical therefore to eliminate mold spores and this is not a strategy for controlling mold growth.

2.Food

Mold will feed on any substance that contains carbon atoms (such as organic substances). Many of the natural materials found in the built environment provide suitable food for mold, such as timber and paper. Removing sources of food for mold from an environment is generally impractical.

3.Appropriate temperature

The majority of molds grow well in a range of temperatures similar to those that humans require. This temperature range is wide, and even temperatures close to freezing will not prevent growth. In warmer environments, moulds will thrive. It is generally impractical therefore to control mold growth through temperature.

4.Moisture

Most moulds require relatively high levels of moisture in order to grow. The majority require an equivalent of at least 70% relative humidity to thrive and most large mould outbreaks in buildings, occur where porous, cellulose-type materials contain persistent liquid water or condensation.



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**Methods for reducing moisture levels.**

In Europe, depending on the country, it is estimated that between 10% and 50% of buildings are damp (ref. WHO Europe, Damp and mold, Health risks, prevention and remedial actions 2009).

**Moisture levels can be reduced through a number of measures:**

1. **Natural or mechanical ventilation.**
2. **Use of de-humidifiers or air conditioning units.**
3. **Insulation of cold surfaces, such as pipes.**
4. **Increasing air temperature.**
5. **Removing sources of moisture such as drying clothes and ensuring vented tumble dryers are appropriately vented to the outside.**
6. **Mending leaking pipes, wastes, and overflows.**
7. **Eliminating rising damp and penetrating damp.**

## Specific ways to minimize Mold Growth

The following practices help to minimize the growth of molds inside homes located in hot, humid climates .

- **Air Conditioner Operation:** Setting the fan mode switch of the air conditioner thermostat in the AUTO position, never in the ON position. Why? When set to the ON position the blower fan runs continuously and the moisture which has condensed on your air conditioner's evaporator coil during cooling is re-evaporated and blown back into your home before it can drain off the coil and out of your home. This causes the relative humidity in home to be significantly greater than if the air conditioner thermostat fan mode switch is set to the AUTO position. Even in the "auto" position, some air conditioners run the blower for 1-3 minutes after the compressor shuts off. To maximize dehumidification, it is best to disable this feature. A qualified mechanical contractor



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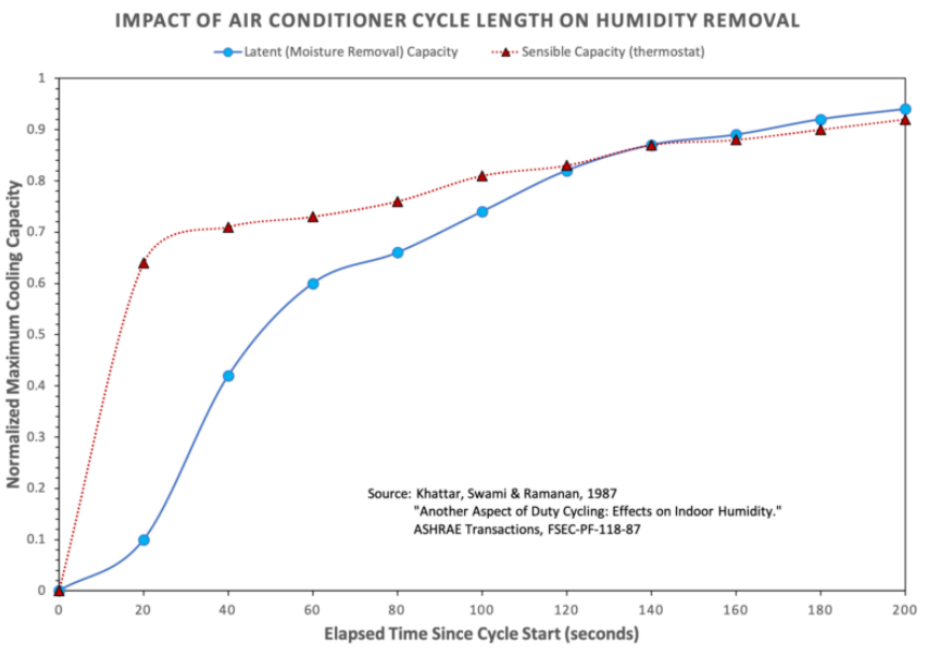
should be able to disable this feature so that the blower and compressor turn off simultaneously.

- **Air Conditioner Selection:** If the building is a new home, then during air- conditioning installation is recommended an air conditioning system with a variable speed air handler and an operating selection mode for “enhanced moisture removal.” This is a good option for multiple reasons: the units are SEER 14+, they are quiet, and they do a better job removing moisture, particularly under part load conditions. They accomplish this by starting the air handler fan at a lower speed during each cycle, which improves moisture removal.
- **Air conditioner sizing:** Oversizing of air conditioners is common. The more an air conditioner is oversized, the poorer its humidity removal performance, especially at higher thermostat settings. This is because, during each air conditioning on cycle, the moisture removal does not reach full capacity for about the first three minutes of operation. The more the system is oversized, the shorter the on-cycle during which moisture is removed. Remember, the shorter the air conditioner on-cycle, the less chance for effective moisture removal. This fact can be clearly seen in the figure below, which is taken from FSEC test data.




- **Interior Doors:** Interior doors should be kept open when air conditioning unless the heating and cooling system has a fully ducted return air system from each room of the home or unless specific and sufficient return air transfer pathways have been installed to ensure that closed interior doors do not result in space depressurization problems in the



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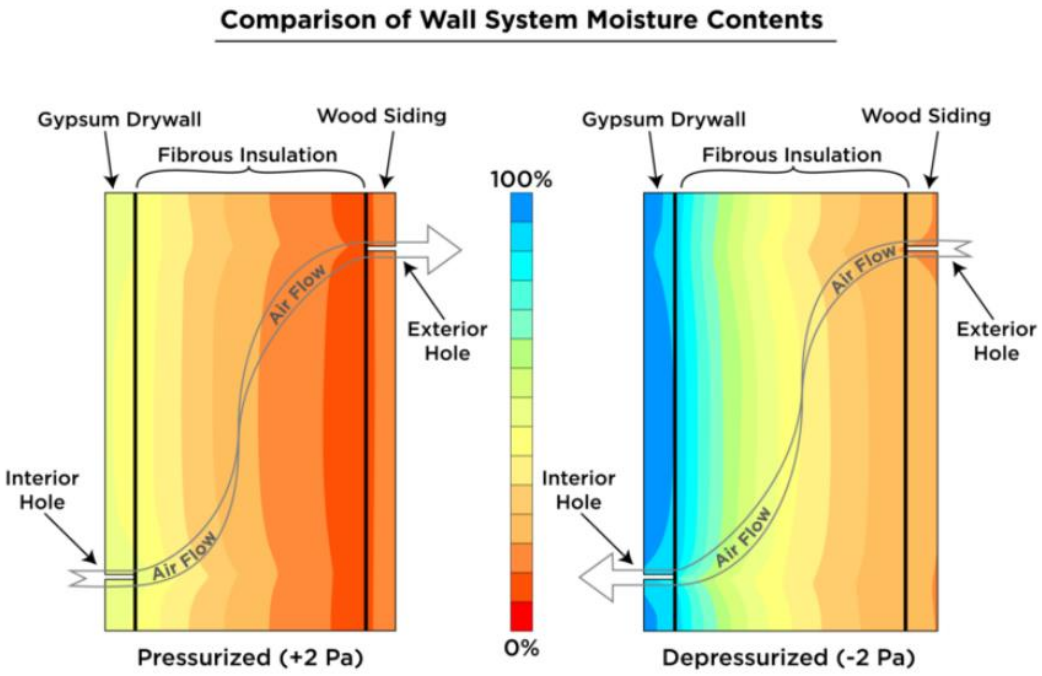
home.

- **Space Pressurization:** It is important that homes in hot, humid climates be pressurized slightly with respect to outdoors. The reason is fairly straightforward but not very obvious. If homes are depressurized with respect to the outdoors, then hot, humid outdoor air will be pulled through the very small air pathways that exist in all building envelopes (walls, ceilings, floors, etc.). To get from the outside of the home to the inside, this air often must follow circuitous pathways.
  For example, the air may enter the wall system high on the exterior where an outdoor light fixture is mounted and exit the wall system low on the indoors where an electrical outlet is located. If the home is air conditioned, the gypsum wallboard will be relatively cold — often colder than the dewpoint temperature of the humid outdoor air that must flow along that gypsum wallboard to that indoor electrical outlet. As illustrated in the figure below, this can result in moisture accumulation within the wallboard, which, in turn, can result in significant mold growth.




The above wall diagrams from detailed computer simulations that model the combined impacts of heat, moisture and air transport illustrate the importance of this air flow phenomena. The wall on the left bounds a space that is pressurized with respect to the outdoors and the one on the



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right bounds a space that is depressurized. The 2 Pa (Pascal) pressure gradient is very, very small — there are 101,325 Pa in one atmosphere. Clearly, it is the direction of the pressure gradient rather than its magnitude that is critically important here. If a home slightly over pressurized in hot, humid climates so that dry, cool indoor air is pushed out of the home through the walls (figure on left) rather than have hot, humid outdoor air sucked into the home through the walls (figure on right). Fortunately, it is relatively easy to pressurize a home — all that is necessary is that slightly more air be brought into the home than is exhausted. This normally requires a positive mechanical ventilation system.

**Things that may cause space depressurization in homes:**

1. Exhaust fans (bathroom, kitchen, attic, crawlspace, etc.)
2. Clothes dryers
3. Supply duct leaks
4. Insufficient return air pathways due to interior door closure

- **Ceiling Fans:** Using ceiling fans in the summer — they allow people to be comfortable at higher air conditioning thermostat temperatures. And they save air conditioning energy costs if it is used the most efficient ones and they are turned off when no one is in the room.

- **Measure the RH in Homes:** Invest in a digital temperature and relative humidity (RH) sensor and observe homes' indoor relative humidities. Two sources for these sensors are Radio Shack and Therma-Stor Products (1-800-533-7533). During the hot summer months, with the air conditioning on, the RH should not exceed 55% during the day on a regular basis. If it does, may occurred problems either with leaks in the duct system or with the air conditioner unit itself – it could be too large, improperly charged or have insufficient air flow across the coil. Consult with a qualified air conditioning expert or mechanical engineer to determine the problem. The highest relative humidities in homes are likely to occur during mild weather when the air conditioner is not needed during the day.



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***Note the pink "splotch" at the bottom-center of this photo. It is the telltale warning sign that there is a likely mold "bloom" behind the vinyl wall covering.***

- **Vinyl Wall Covering:** Impermeable interior surfaces like vinyl wall coverings can result in severe mold problems in hot humid climate. Moisture coming from outdoors can accumulate within the gypsum wallboard that is behind the vinyl wall covering. This normally occurs as a result of house depressurization where outdoor air is being sucked into the home through the very minute air pathways that exist in all normal wall systems. Where this problem occurs, outbreaks of mold often occur beneath the wall covering on the surface of the gypsum wallboard. This mold growth is normally characterized by pinkish to yellowish "splotches" on the vinyl wall covering. The moisture accumulation also can be severe enough to cause the gypsum wallboard to badly deteriorate and become "mushy." Positive pressurization of the problematic home is one method of minimizing the potential occurrence of this problem.



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- **Return Air Pathways:** It is important that there be sufficient air flow pathways for the supply air that is delivered to each room of a home to return to the air conditioner's air handler unit (the box with the blower fan). Otherwise, the part of the home containing the main return to the air handler unit will be "starved" for air, resulting in depressurization of this space with respect to the outdoors. If this occurs, outdoor air will be drawn through the small pathways that exist in the exterior building envelope. In hot, these air flows can result in the accumulation of moisture within the gypsum wallboard, especially if it has vinyl wall covering. This, in turn, can result in the rapid and abundant growth of molds — remember, the cellulose (paper) on gypsum wallboard makes an excellent, preferred mold food. If room doors are kept open, there will be sufficient return air pathways. However, if rooms doors are closed, the rule-of-thumb is that there should be about 320 $cm^2$ of "free" air transfer area for each 170 $m^3$ of supply air to the room. In this case, the term "free" means a simple, clear hole in the wall between the room and the remainder of the home. If, for appearance and privacy reasons, this hole is to be covered by grilles on each side of the wall, then the overall return air pathway area needs to be increased by about 40% to account for the air flow resistance of the grilles, or about 450 $cm^2$ per 170 $m^3$ of supply air flow.

- **Bathrooms:** Most bathrooms, particularly tile in and around showers and tubs is regularly wet. As a result, most bathrooms grow mold and require regular cleaning. A weak solution of water and common household bleach can be used to regularly clean these areas and keep them free of mold. Low-noise bathroom fans are also recommended to remove excess moisture during periods when it is being generated by bathing or showering.

- **Whole-House Ventilation Fans — Opened Windows:** Avoid the use of these fans when it is humid outdoors, especially if it has been noticed mold growth in home or if there are trouble controlling the relative humidity in home. In addition, avoid opening windows for long periods when it is humid outside (e.g. during nights and evenings).

- **Air Conditioner Maintenance:** Changing the filters regularly and using pleated filters. Once a year air-conditioners need professionally serviced.

- **Exterior Water Management:** Redirect water away from the home's exterior — redirect sprinklers so that they don't spray on the walls. Do not landscape with hills that direct water flow towards the home.

- **Small Leaks:** Even small water leaks will cause mold problems. Rainwater leaks from improperly flashed windows, wall and roof penetrations and plumbing leaks should be promptly repaired. Periodically inspect under sinks and vanities for signs of water leakage.



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- **Water Damage:** Water damage from flooding or other major water intrusion in homes should be dried within 24 hours if possible. For severe flooding and severe water damage for more than 48 hours, a trained restoration professional should be consulted regarding cleanup procedures.

- **Moisture Condensation:** Single-pane, metal windows, generally condense water on the inside in winter. It is good practice to remove this condensation before it can run off and be absorbed by porous materials like wood casing or gypsum wallboard. Condensation can also occur on other surfaces in homes. If condensation is noticed on interior surfaces in summer, it may indicate a number of problems, including inability to control indoor humidity; air conditioner supply registers aimed directly at interior surfaces; duct leakage problems and pressure imbalances; or all of the above

- **Exhaust Fans:** It is important the clothes dryer vent goes all the way to the outside of the home, not to the crawlspace or to the inside of the attic or the house. The same goes for bathroom vent fans. It is also important for the kitchen range hood to vent to the exterior as well. Recirculating stove and kitchen vents provide no removal of stovetop moisture and inferior control of cooking related pollutants compared with venting completely to the outdoors. Kitchen and bath exhaust fans should only be used while cooking or using the bathroom to remove excess moisture generated by these activities. It is best practice to either have bathroom vent fans interlocked with the light switch so they do not get left on or have them switched by a manual timer that will shut them off after a period of time, or control them by humidistat.

- **Closets:** Fungi like the dark and closets are rarely supplied with conditioned air as a standard part of air conditioning systems. As a result it is not all that uncommon to have mold or mildew occur in closets, especially on leather. Leaving the closet doors open to provide more conditioned air circulation or leaving the closet lights on with the door closed so as to raise the temperature (which lowers the RH) can reduce these problems.

- **House Plants:** Minimize live house plants, especially if you have any trouble controlling the relative humidity in your home.



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**Multiple Choice**

1. What is a common source of moisture that leads to mold growth in buildings?
a) Leaky pipes or roofs
b) Overuse of air conditioning
c) Too much sunlight exposure
d) Lack of plants in the building
Answer: a) Leaky pipes or roofs

2. Which area of a building is most prone to mold growth due to high moisture content?
a) Bedroom
b) Living room
c) Kitchen and bathroom
d) Dining room
Answer: c) Kitchen and bathroom

3. What is the role of ventilation systems in mold formation in buildings?
a) They help prevent mold formation by circulating fresh air
b) They act as a reservoir for indoor fungi when dirty
c) They have no impact on mold formation
d) They contribute to mold growth by creating moisture
Answer: b) They act as a reservoir for indoor fungi when dirty

4. Which of the following is NOT a factor that can contribute to mold growth in buildings?
a) High humidity or moisture content
b) Lack of ventilation
c) Adequate sunlight exposure
d) Organic matter or substrates for fungi to grow on
Answer: c) Adequate sunlight exposure

5. What is a common source of indoor fungi particles?
a) Outdoor sources only
b) Indoor sources only
c) A combination of both outdoor and indoor sources
d) None of the above
Answer: c) A combination of both outdoor and indoor sources

6. Which of the following is a common source of moisture that can lead to mold growth in buildings?



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a) Properly sealed windows
b) Regular use of exhaust fans in bathrooms and kitchens
c) Leaky pipes or roofs
d) Regular cleaning of air ducts

7. Which of the following is NOT a common type of mold found in indoor environments?
a) Cladosporium
b) Aspergillus
c) Stachybotrys
d) Penicillium

8. What temperature range is considered optimal for mold growth?
a) 0-10°C
b) 10-20°C
c) 20-30°C
d) 30-40°C

9. Which of the following is NOT an effective method for preventing mold growth in buildings?
a) Proper ventilation
b) Fixing water leaks promptly
c) Regularly cleaning and maintaining HVAC systems
d) Allowing standing water to accumulate in basements or crawl spaces

10. Which of the following is a common symptom of mold exposure in humans?
a) Muscle weakness
b) Memory loss
c) Headaches
d) Broken bones



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**References**


- Chew GL, Rogers C, Burge HA, Muilenberg ML, Gold DR. Dustborne and airborne fungal propagules represent a different spectrum of fungi with differing relations to home characteristics. Allergy. 2003;58(1):13-20
- Mendell MJ, Mirer AG, Cheung K, Tong M, Douwes J. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: A review of the epidemiologic evidence. Environmental Health Perspectives. 2011;119(6):748-756
- Yamamoto N, Hospodsky D, Dannemiller KC, Nazaroff WW, Peccia J. Indoor emissions as a primary source of airborne allergenic fungal particles in classrooms. Environmental Science & Technology. 2015;49(8):5098-5106
- Gold DR et al. Ambient pollution and heart rate variability. Circulation. 2000;101(11):1267-1273
- Green BJ, Tovey ER, Sercombe JK, Blachere FM, Beezhold DH, Schmechel D. Airborne fungal fragments and allergenicity. Medical Mycology. 2006;44(sup 1):245-255
- Magari SR, Hauser R, Schwartz J, Williams PL, Smith TJ, Christiani DC. Association of heart rate variability with occupational and environmental exposure to particulate air pollution. Circulation. 2001;104(9):986-991
- Pekkanen J et al. Particulate air pollution and risk of ST-segment depression during repeated submaximal exercise tests among subjects with coronary heart disease: The exposure and risk assessment for fine and ultrafine particles in ambient air (ULTRA) study. Circulation. 2002;106(8):933-938
- Institute of Medicine (IOM). Committee on damp indoor spaces and health. In: Damp Indoor Spaces and Health. Washington, D.C.: National Academies Press; 2004
- Heseltine E, Rosen J. WHO Guidelines for Indoor Air Quality: Dampness and Mould. Europe: WHO Regional Office; 2009
- Flannigan B, Samson RA, Miller JD, editors. Microorganisms in indoor air. In: Microorganisms in Home and Indoor Work Environments: Diversity, Health Impacts, Investigation and Control. London: Taylor & Francis; 2001. pp. 17-31
- Norback D et al. Mould and dampness in dwelling places, and onset of asthma: The population-based cohort ECRHS. Occupational and Environmental Medicine. 2013;70(5):325-331
- Bauer H et al. Significant contributions of fungal spores to the organic carbon and to the aerosol mass balance of the urban atmospheric aerosol. Atmospheric Environment. 2008;42(22):5542-5549
- https://ec.europa.eu/research-and-innovation/en/horizon-magazine/why-future-homes-could-be-made-living-fungus
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7400204/
- https://academic.oup.com/mmy/article/45/1/1/993620




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