Effects of indoor air humidity

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This article is not intended to be a scientific review of many effects of indoor air humidity. Its purpose is to stimulate discussion and research on the effects of indoor air humidity.

Introduction

Indoor air humidity has a large variety of effects both positive and negative. These must be carefully considered when recommendations on indoor air humidity are given.

This short summary is intended for the discussion on the possible need to control the humidity indoors. More detailed overview on the effects have been published scientific papers e.g. [1], and engineering magazines e.g. [2].

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Nordic Ventilation Group is a group of academics sharing the same interest and concerns regarding the indoor climate and ventilation. The objective of the Nordic Ventilation Group (NVG) is to develop Nordic ventilation technologies and services for good and healthy indoor environment with an energy efficient and environmentally friendly way. The work is 100% voluntary and free from commercial interest. Possible outcomes of the work can be published through various channels with the common agreement of the group. Nordic Ventilation Group was very active in 80s and 90s when mechanical ventilation became more common in Nordic counties. The group published several guidelines for measuring air flow rates and evaluating of the performance of ventilation. The group is integrated with Scanvac activities. The history and objectives of the group are described in more details at www.scanvac.eu.

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Conception of indoor air humidity

Relation between temperature, absolute humidity, and relative humidity (RH) is presented in the **Figure 1**. Maximum water contents in air depends on the partial pressure of water vapor in the air, which decreases rapidly with falling temperature, at the same time the absolute amount of water in the air deceases. Even if the relative humidity of outdoor air would be 100%, the absolute humidity of the air could be very low. As illustrated in **Figure 1**, when the cold air is warming up to the room temperature, its relative humidity falls, during the cold winter days towards, or even below, 10%RH. As shown in the figure, when the outdoor temperature is –10°C, the absolute humidity has to be increased by 2.5 grams of water per kg of air in order to increase the indoor relative humidity from 10%RH to 25%RH at room temperature. If the ventilation airflow rate is 1 m^3/s, just as an example, these values correspond to adding 10 kg of water per hour to the air.

Corona virus

During the pandemic of COVID-19 disease many possibilities to slow down the spreading of the corona virus have been investigated. Indoor air humidity has been one of the environmental factors which has been studied. How does the indoor air humidity influence the viability and spread of the virus and other factors of human wellbeing?

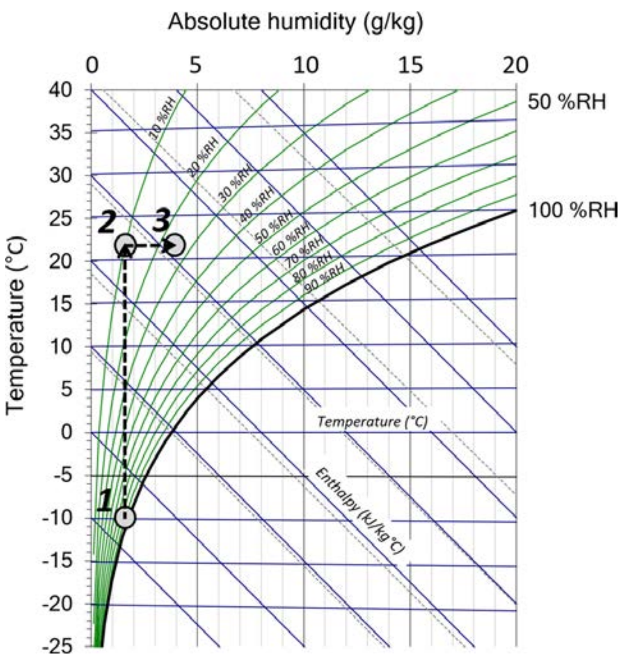

Figure 1. Psychrometric chart showing examples of three conditions of the air: 1) outdoor air (–10°C/100%RH; 2) room air heated from outdoor condition without adding any humidity (22°C/10%RH); 3) room air after adding 2.5 g of water per kg of air (22°C/25%RH).

Effect of environmental factors on the viability of corona virus has been under investigations all over the world mainly in laboratory set-ups. SARS-CoV-2 decay in aerosols has been tested at 20°C in 20 to 70% range of RH showing that decay was not dependent on relative humidity [3]. Models have been developed based on laboratory tests, one of the most comprehensive is the model developed by a group at MIT [4], published at https://indoor-covid-safety.herokuapp.com/. This model includes many environmental and behavioral variables that have influence on the potential viability of corona virus, SARS-CoV-2, including humidity, ventilation, recirculation, breathing rate, occupant density etc. It shows that many other factors have much greater influence than humidity. Humidity and temperature must be so high (80% RH and 30°C) to have meaningful effect that the values are not feasible indoors. This is also the conclusion in the REHVA COVID guidance document based on wide international consensus [5].

Corona virus seems to survive well in the cold due to protecting layers of fatty acids on its exterior surface. This feature has been suggested to be one reason of the spread of the virus in cool indoor environments like in the meat processing industry, maybe also for the frequent COVID-19 cases in ice hockey sport?

Humidity and health

Indoor air humidity affects also the infections caused by the expose to viral particles and other pathogens. Low indoor air humidity deteriorates the natural defense mechanism of the breathing tract. Mucociliary clearance** is a key mechanism for eliminating the

** Airways are lined with the gooey substance and, below that, with cilia, tiny fingerlike paddles used across the animal kingdom for movement. These two components work together like a conveyor belt: The mucus traps gunk, and the cilia beat together to move the mucus back out through the nose and mouth.

This process is called mucociliary clearance, and cold, dry air is not its friend. As low humidity dries out the mucus layers in our faces and throats, it disrupts the movement of the cilia, making it harder for the body to kick out any invaders." Citation from Fedor Kosakovski. National Georaphic."The winter surge in COVID-19 is due to more than merely spending time indoors." National Geography, Dec 15, 2020.

inhaled pathogens and irritants from the respiratory tract. The effectiveness of this self-clearing mechanism may decrease significantly with low humidity of the breathing air.

The general opinion amongst the professionals has been for years that dry air is not a health hazard if it does not contain any specific contaminants. But how often the air is 100% clean? The question is also what the definition of health hazard is. Dry air may cause discomfort. Dry air (below 15%) increases the sensation of dry eyes, skin dryness and blinking rate of the eyes. Commonly experienced eye symptoms may have increased also the number of products in the market of dry air eye drops. Prevalence of SBS-symptoms seem to increase with low humidity and decrease with high humidity. In some studies, in controlled environments, dry air (below 15%) reduced also the cognitive performance. Old studies from the 70s also showed a reduction of absenteeism due to respiratory infections at schools.

During the winter even a small increase in the humidity may be beneficial. According to the REHVA Guidance document a modest humidification of indoor air from the typical winter values of 10–20%RH to the level 20–30%RH may be beneficial. Higher humidity may not bring any additional benefits, vice versa, the risks related to the condensation of moisture will increase. The widely recommended humidity range 40–60% RH in the US may not be appropriate for the cold North European climate. More appropriate is the recommendation in the European CEN-standard EN 16798-1: "Humidification or dehumidification of room is usually not required but, if used, excess humidification and dehumidification shall be avoided." Default design value of indoor humidification is 20–30%. Dehumidification is usually not needed as the high humidity periods are so short in North Europe. One exception is dehumidification in conjunction with waterborne comfort cooling, e.g. by means of chilled beams. In such systems it may be necessary to periodically dehumidify the supply air in the central air handling unit to avoid condensation on the chilled beams in the rooms.

Absolute and relative humidity

Above, the humidity is given as relative humidity values, as this is typically the measure used in various publications on the topic. However, the driving force of the evaporation from any wet surface is the partial pressure differential of the air between the surface and the surrounding air. The partial pressure is proportional to the absolute humidity expressed as grams of water vapor per kg of dry air (g/kg). The relationship between relative and absolute humidity values is shown in **Figure 2**. During Nordic winter climate both the outdoor and indoor air typically contains just a few grams of water vapor per kg of air. For comparison, it can be noted that the air exhaled by humans contains around 35 g/kg. This difference in absolute humidity is a basic mechanism behind drying of the mucous membranes in the airways.

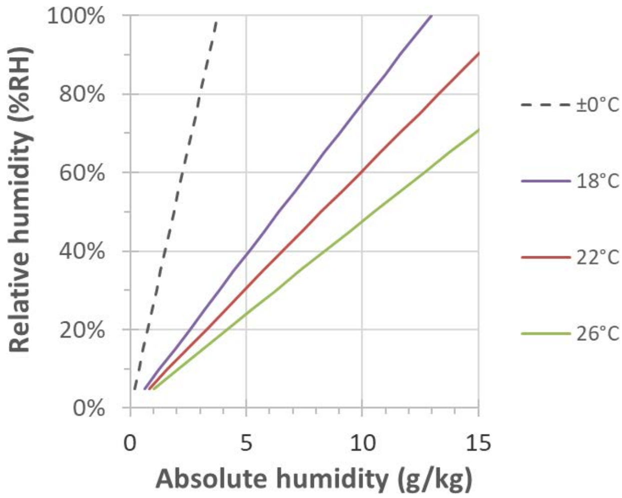

Figure 2. The relationship between relative and absolute humidity values at three typical indoor air temperatures and an example of a Nordic outdoor winter temperature (±0°C).

Droplets

During the COVID-19 pandemic the role of large droplets, airborne small droplets and droplet nuclei have been discussed, including also the effect of indoor air humidity and other environmental factors on the size and life time of droplets. Viruses do not travel in the air alone. They are carried by droplets from breathing, speaking, singing etc. The size of droplets from the respiratory tract of an infected person depends on many personal, behavioral, and environmental factors. In the close range a susceptible person is exposed to large and small droplets. All droplets will dry in seconds and become airborne and spread with air currents in the room. Only the largest droplets will be removed from the air by settling. Drying of large droplets is so fast that the effect of air humidity on drying process is negligible. The final size of the airborne droplets decreases with lower humidity of room air. The remaining potentially virus containing material will be dispersed under the influence of air movements. These particles are significantly bigger (1–50 µm) than the single virus (0.14 µm). People in the same room or space, as the infected person room, are exposed to these particles.

Microbial growth

High humidity of indoor air (over 40–50%RH) may be harmful especially during the winter. Indoor air humidity may condense on cold surfaces and increase the risk of microbial growth on surfaces, and further in structures and deteriorate indoor air quality. Condensation of moisture, particularly on window-panes has been related to the indoor air problems linked to inadequate ventilation or wrong pressure difference over the building envelope. Moisture damages due to high indoor air humidity are, however, not so common as damages caused by other sources of water.

Critical indoor air humidity for microbial growth depends on several factors like temperature, time, species of microbes, type of surface and possible nutrients on the surface. Typically, lack of moisture restricts the growth of environmental fungi indoors. Increase of humidity on the surfaces enables microbial growth and proliferation of molds. For many of the fungal species a relative humidity of 80%RH (in equilibrium water activity 0.8) is sufficient for growth. For bacteria, the critical moisture level to promote growth is higher. High indoor air humidity is also favorable for house dust mites which may cause allergic reactions for sensitive people. Regarding the mites the indoor relative humidity indoors should not be over 50% for long periods in the winter.

Humidification

Room air can be humidified. Humidification may decrease the prevalence of typical SBS symptoms but can also increase them. In office environments even a small increase of the indoor air humidity has deceased the prevalence of symptoms. But data also shows that symptoms are more common in buildings where air conditioning system includes humidification than in buildings without. According to the REHVA COVID guidance document humidifiers have been found to increase short- and long-term sick leaves.

A humidifier is a high-risk component regarding the hygiene of air handling system. A poorly maintained humidifier can be a source of microbial contamination as the presence of water is the critical factor for microbial growth. Humidifiers have caused severe indoor air quality problems and caused humidifier fever or even legionnaire's disease. Due to these health risks and energy use humidifiers not commonly used in Nordic countries.

It is sometimes claimed that reduced air flow is a possible way to reduce the magnitude of problems with dry air indoors, during periods with winter outdoor climate. However, in many cases the feasibility of this method seems limited. For example, for typical office or school activities it shows that a 50% reduction of the outdoor air supply, from a rather high flow rate to a "nominal" flow of 10 ℓ/s per person, leads to an increase of the relative humidity by few percent-units only. A further halving down to 5 ℓ/s per person gives an additional 5 percentage points higher relative humidity indoors. Thus, the effect of ventilation rate reductions on the relative humidity of the indoor air is limited, as long as nominal ventilation rates are to be ensured. In residences the effect of the ventilation rate maybe significant with higher moisture generation due to household activities.

Energy use

Humidification of the air means in general also increase in energy use. Heat for humidification (latent heat of water) will be taken from somewhere, from the air handling unit, portable air humidifier or from the room air. In the example illustrated in **Figure 1**, the absolute humidity was increased by 2.5 grams of water vapor per kg of air. In order to achieve this, a certain amount of water has to be vaporized per unit time. If, for example, the ventilation rate is 1 m^3/s the humidification corresponds to vaporizing about 10 kg of water per hour. This requires about 7 kW of heat per m^3/s. Thus, over time, the increase of energy use may be significant.

A rough estimation for the increase of the heating energy in a 100 m^2 residential house due to humidification is 20% when the minimum relative humidity indoors is 30%RH, increase of 50% when minimum relative humidity is 40%RH, and increase of 80% when minimum humidity is 50%RH (IDA simulation for Helsinki, Stockholm, Oslo for an energy efficient house).

Humidification is often required in museums and opera houses. Energy needed for humidification at the Museum of Modern Arts in Stockholm has been estimated to 270 MWh/year if the relative humidity is required to be maintained above 40%RH and 350 MWh/year if the requirement instead is a minimum of 45%RH. Thus, in this case a slightly higher humidity setpoint (5 percentage points RH) leads to about 30% higher use of energy for humidification. The example is valid for a constant ventilation air flow rate of 10 m^3/s, heat recovery efficiency 50% and moisture recovery efficiency of 40%.

Internal moisture sources and possible moisture recovery may decrease, of course, the required humidification capacity and the energy use.

Moisture recovery

An energy efficient alternative to active humidification is moisture recovery using rotary heat exchangers or other types of regenerative heat exchangers. At very cold outdoor air temperatures then even non hygroscopic surfaces have rather high moisture recovery capacity due to condensation on cold surfaces. In combination with decreased ventilation air flow rates during periods of low internal moisture generation, normally coinciding with periods of low or no presence of persons, the number of hours with relative humidity lower than 20% can be radically reduced. However, to avoid too high relative humidity during periods of high internal moisture generation it may instead be necessary to increase the air flow rates and/or decrease the rotary speed of the recovery wheel (or lowering the switching frequency in other types of regenerative heat exchangers). Modern sorption coated rotary heat exchanger can, however, recover 60-80% of the exhaust air humidity in all conditions. One of the purposes of ventilation is often also to remove excess moisture. Sorption coated heat exchangers should therefore normally only be used in premises with very low moisture generation.

It should be noted that regenerative heat exchanger may also transfer pollutants and odor from exhaust air to supply air. Transfer of some pollutants (bi-polar) may increase with the moisture transfer.

Other effects

Air humidity has even more effects on indoor environment than dealt with above. Humidity affects the dust concentration of room air indirectly by influencing the strength of the fibers and static electricity of materials; humidity has an effect on the heat balance of the human body, odor, thermal sensation and sweating, use of voice, perceived air quality and many other human responses. Humidity may also have synergistic effects with VOCs.

Increased humidification of the spaces in the buildings, especially during the hot seasons and arid regions, will increase water consumption which could lead to increasing the stress on water resources. As the energy intensity of buildings increases (resulting from increased ventilation and humidification) the carbon inventory of buildings could increase depending on the share of fossil fuels in local sources of energy.

Summary

As a summary we can say that humidity has many positive effects but also negative. Regarding the COVID-19 transmission the current evidence shows that increasing humidity to the levels typically occurring indoors do not reduce significantly risks of COVID transmission. Other measures like limiting the occupant density indoors, keeping physical distances, wearing masks, and improving ventilation are more effective for reducing transmission risks than adding humidity to the air. However, if humidification is used, the humidifiers must always be clean and well maintained. Humidification over 35% shall be avoided and it must be realized that humidification significantly increases the energy use. ■

References

[1] Wolkoff, Peder. Indoor air humidity, air quality, and health. International Journal of Hygiene and Environmental Health. 2211 (2018) 376-390.)

[2] Taylor, Stephanie et. al. Improving IEQ to reduce transmission of airborne pathogens in cold climate. ASHRAE J, September 2020.

[3] Schuit et al. The Journal of Infectious Diseases, Volume 222, Issue 4, 15 August 2020, Pages 564–571, https://doi.org/10.1093/infdis/jiaa334.

[4] M.Z. Bazant, J.W. M. Bush: Beyond Six Feet: A Guideline to Limit Indoor Airborne Transmission of COVID-19, COVID-19 SARS-CoV-2, preprints from medRxiv and bioRxiv, 2020.

[5] Kurnitski, Jarek. REHVA COVID guidance document 4.0. The REHVA European journal. Vol 57. December 2020.