uHoo™

Optimizing Indoor Air Quality:

A Framework for Influenza Virus Risk Reduction

Introduction

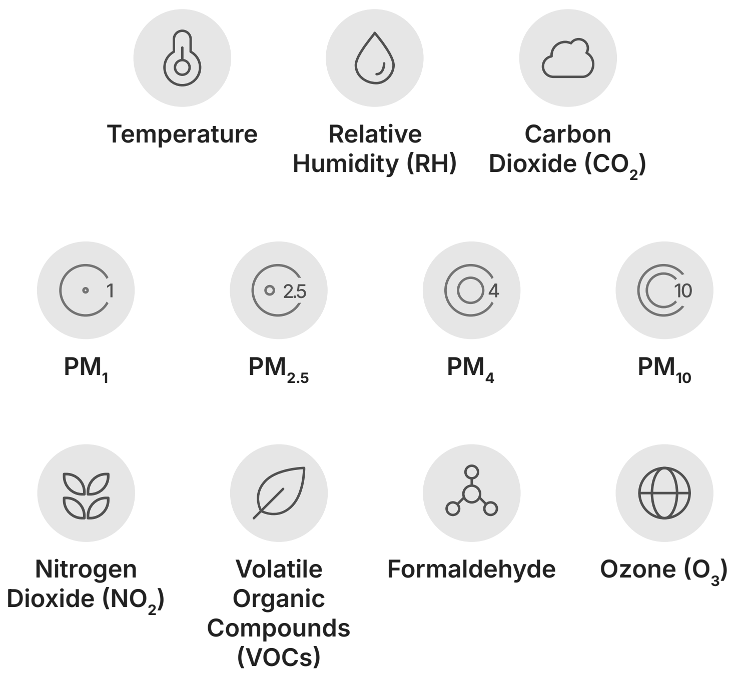
Influenza, a recurrent viral infection commonly known as the flu, imposes a significant public health burden globally each year. Seasonal influenza epidemics result in millions of infections, leading to substantial rates of morbidity, hospitalization, and mortality. The vulnerable populations disproportionately affected include older adults, infants, pregnant women, and immunocompromised individuals[1]. The impact extends beyond public health, generating staggering economic costs that encompass productivity loss, elevated medical expenditures, and widespread disruption to educational, corporate, and communal institutions.[2]

While preventive measures such as annual vaccination, antiviral medications, and personal hygiene practices remain essential, they do not fully address the environmental factors that influence the spread of influenza.[3] Increasing scientific evidence demonstrates that Indoor Air Quality (IAQ) plays a critical role in determining whether influenza viruses survive long enough to cause infection and how easily they can be transmitted from one person to another.[4]

Influenza viruses spread primarily through respiratory droplets and aerosols produced and expelled during respiration, coughing, sneezing, and speaking.[5] Large droplets tend to settle quickly onto nearby surfaces, but smaller aerosols can remain suspended in the air for extended periods, from minutes to hours, especially within poorly ventilated, enclosed environments.[6] Environmental factors, including temperature, relative humidity (RH), particulate matter (PM), and gaseous pollutants, determine how long these airborne particles remain infectious and how far they can travel.[7]

The uHoo Influenza Index is a science-based, real-time IAQ risk assessment tool designed to quantify and interpret environmental conditions pertinent to influenza virus survival and airborne transmission risk.

By providing continuous monitoring of key environmental indicators, the Index establishes a comprehensive profile of the indoor atmosphere. These indicators include:



The uHoo Influenza Index transforms complex environmental data into a clear, actionable score,[8] empowering individuals, facility managers, and organizations to make informed, timely decisions to proactively reduce influenza risk exposure, optimize IAQ, and safeguard occupant health.

2. The Environmental Determinants of Influenza Transmission

The conditions within an indoor environment profoundly influence both the survival of influenza viruses and the efficacy of their transmission.[9] Influenza transmission risk is affected by three interconnected environmental domains: physical conditions, air cleanliness, and gaseous pollutants.

Physical conditions, specifically temperature and RH, directly impact virus stability. Low temperatures prolong the survival period of influenza viruses[10], while higher temperatures accelerate their inactivation.[11] Humidity alters droplet evaporation dynamics; at low levels, droplets shrink into droplet nuclei that can remain airborne for hours, while at high levels, droplets settle faster.

- **Humidity's Dual Effect:** RH alters the dynamic of respiratory droplet evaporation. At low RH, expelled droplets undergo rapid desiccation, shrinking into droplet nuclei (aerosols) that are capable of remaining suspended and infectious for extended durations. Conversely, at high RH, droplets settle faster but may retain infectivity for certain strains.[12]

Air cleanliness, measured primarily by PM concentrations, influences influenza transmission in two ways:

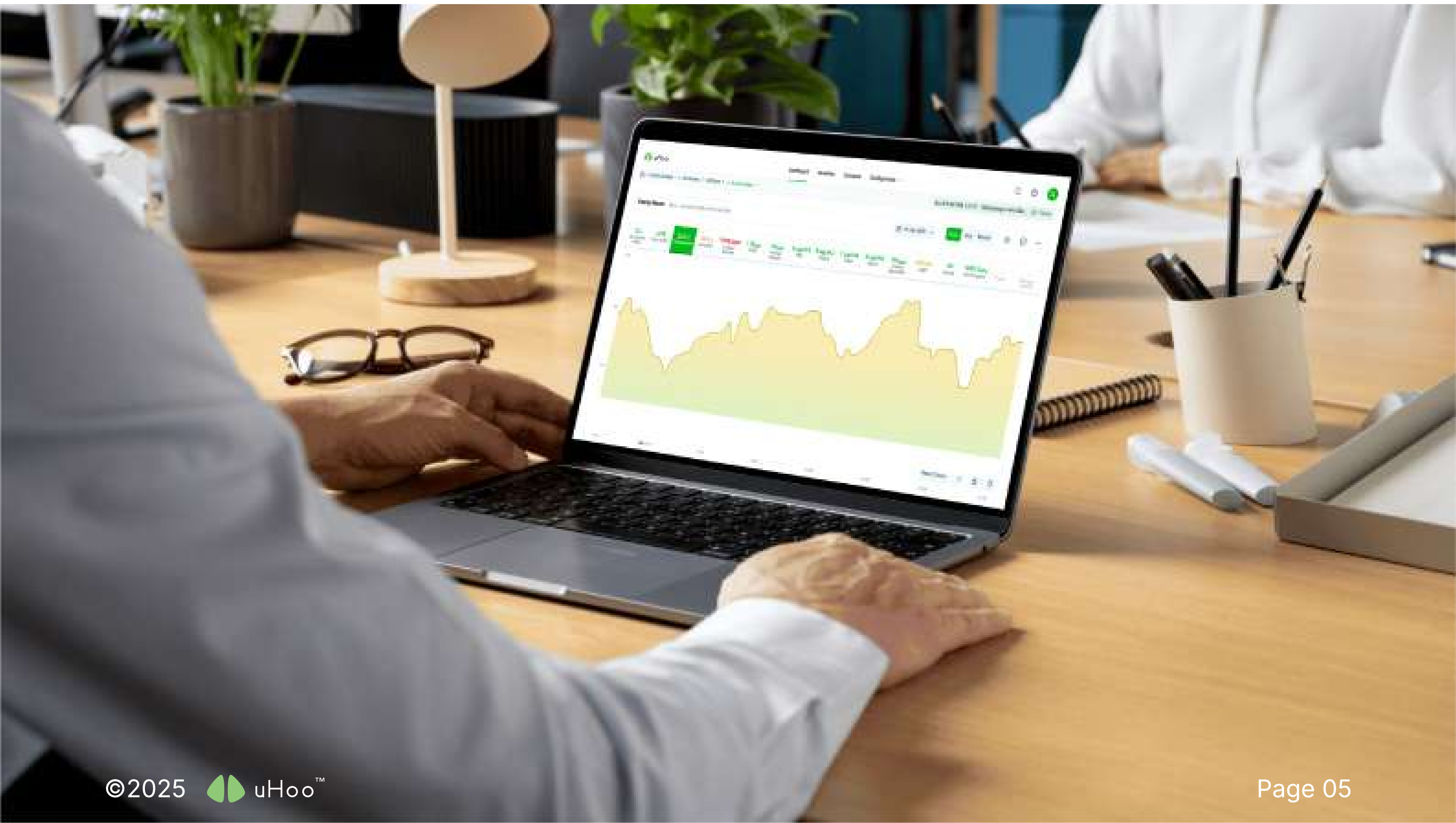
1. **Viral Carriage:** Fine and ultrafine PM acts as a substrate for viral aerosols, allowing them to remain suspended for longer periods and travel farther distances.[13]

2 **Host Susceptibility:** The inhalation of elevated PM levels can impair the respiratory system's defenses, increasing susceptibility to infection.[14]

Gaseous pollutants indirectly facilitate influenza transmission by compromising respiratory health and immune resilience.

- **Ventilation Proxy:** Elevated Carbon Dioxide (CO_2) levels indicate poor ventilation, leading to the accumulation of infectious aerosols.[15]
- **Respiratory Irritants:** Other common indoor air contaminants, such as nitrogen dioxide (NO_2), volatile organic compounds (VOCs), formaldehyde, and ozone (O_3), can inflame or damage the respiratory tract, making individuals more vulnerable to infection.[16]

Understanding and controlling these determinants is therefore central to any strategy aimed at mitigating indoor influenza transmission. The uHoo Influenza Index is built on this understanding, integrating real-time monitoring of these parameters to deliver a comprehensive, actionable risk assessment.



Thermal Conditions (Temperature and Relative Humidity)

The stability of the viral structure is highly sensitive to the indoor climate:

Temperature: Influenza viruses are more stable and transmissible at cooler temperatures, specifically at or below 20°C (68°F).[4] This is partly due to the enhanced stability of the viral lipid envelope and slower droplet evaporation rates. Although viral inactivation increases at temperatures above 24 °C, sustaining such warm conditions is often incompatible with thermal comfort guidelines and building operational constraints. Accordingly, the recommended indoor temperature range of 21 °C to 23 °C (70 °F to 73 °F) represents a practical balance, not the temperature that minimizes viral survival, but the range that optimally supports occupant comfort while allowing other environmental controls

Relative Humidity: RH affects both droplet physics and virus viability. Viral survival is shown to be shortest near 50% RH.[7] Extremes pose unique risks: RH below 40% causes droplets to rapidly evaporate into fine aerosols that may remain airborne for prolonged periods [17], while very high RH (above 80%) virus survival for some strains.[12] Therefore, the optimal range to reduce influenza viability and support mucosal defenses is 40% to 60% RH with a target optimum of 50% RH.[16]

Air circulation must be sufficient to dilute infectious aerosols and mitigate the impact of irritant gases:

Carbon Dioxide: CO_2 concentration does not directly impact virus survival but serves as a crucial proxy for ventilation efficacy. Levels exceeding 800 ppm indicate poor ventilation, leading to an accumulation of infectious aerosols.[18] Maintaining CO_2 levels below this threshold ensures effective dilution of airborne pathogens.[19]

Nitrogen Dioxide: NO_2, a byproduct of combustion, impairs lung function and increases vulnerability to respiratory infections.[24] Indoor concentrations should be maintained below 53 ppb.[29]

VOCs and Formaldehyde: These chemical pollutants irritate the respiratory tract and may compromise immune function.[16] Total VOC (TVOC) levels should be kept below 0.3 mg/m^3, and formaldehyde concentrations should not exceed 0.1 mg/m^3 (100 µg/m^3).[25]

Ozone: While effective in controlled disinfection systems, ozone is harmful at ambient indoor levels and can impair lung function.[26] Indoor concentrations must be strictly controlled, remaining below 0.05 ppm (50 ppb).[27]

Particulate matter acts as a vector for viral transport and is categorized by size based on its respiratory impact:

Viral Carriage and Penetration: PM particles serve as airborne carriers of influenza viruses[20] with fine particles (PM_1, $PM_{2.5}$) remaining airborne for longer and penetrating deep into the lungs. Larger particles (PM_4, PM_{10}) primarily contribute to shorter-range transmission.[21]

Thresholds for Control: To minimize both viral vector carriage and respiratory impairment, rigorous filtration and source control are required. Target air cleanliness thresholds are:[22]

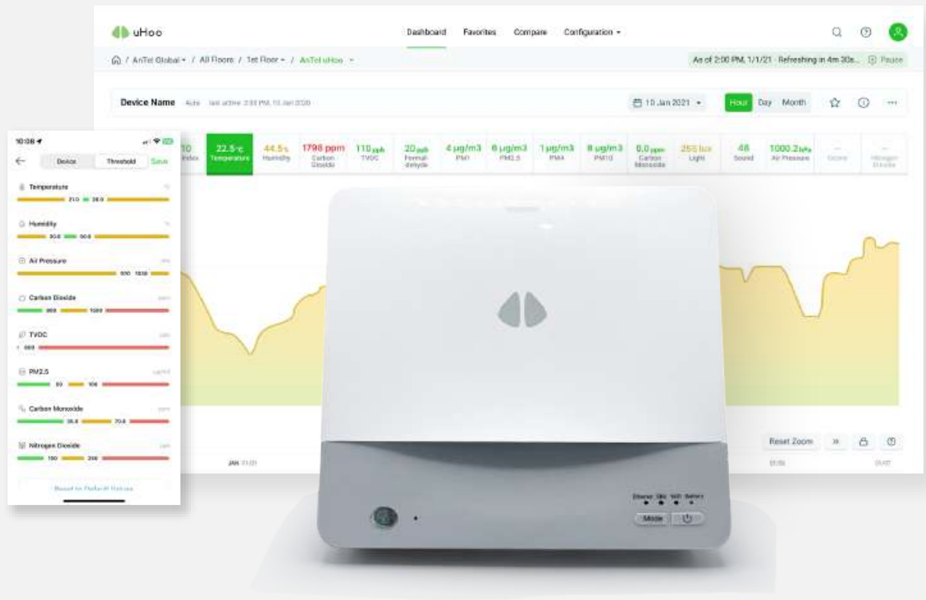
- **PM_1, $PM_{2.5}$, and PM_4:** below 15 µg/m^3
- **PM_{10}:** below 45 µg/m^3

4. Ideal Indoor Parameter Ranges for Influenza Risk Reduction

To make the recommendations clearer, Table 1 summarizes the ideal indoor parameter ranges used in the uHoo Influenza Index and their impacts on influenza risk. These thresholds align with international IAQ standards and influenza-specific research findings, and they are incorporated directly into the index calculation to enable real-time assessment and guidance.

Parameter	Ideal Range	Impact on Influenza Risk
Temperature	19–22 °C	Reduced virus stability and airborne persistence
Relative Humidity	40–60%	Shortens aerosol viability; supports mucosal immunity
Carbon Dioxide (CO_2)	<800 ppm	Indicates adequate ventilation and aerosol dilution
PM_1	<15 µg/m³	Virus carrier; deep lung penetration
$PM_{2.5}$	<15 µg/m³	Virus carrier; deep lung penetration
PM_4	<15 µg/m³	Short-range aerosol transport
PM_{10}	<45 µg/m³	Short-range droplet transport
Nitrogen Dioxide (NO_2)	<53 ppb	Reduces airway damage and susceptibility
VOCs	<0.3 mg/m³	Prevents airway irritation and immune suppression
Formaldehyde	<0.1 mg/m³	Prevents airway irritation and immune suppression
Ozone(O_3)	<0.05 ppm	Prevents lung irritation and susceptibility

5. The uHoo Influenza Index: A Predictive Metric for Assessing Influenza Risk



The uHoo Influenza Index provides a comprehensive, real-time evaluation of influenza risk by translating complex indoor environmental data into a single, intuitive score ranging from 1 to 10.[8] Rather than examining individual parameters in isolation, the Index integrates evidence-based environmental factors known to influence influenza virus stability, persistence, and transmission dynamics.

By synthesizing temperature, relative humidity, carbon dioxide concentration, particulate matter levels, and other IAQ indicators into a unified metric, the Index allows users to rapidly assess overall environmental conditions and identify periods of heightened influenza risk.[4]

Higher scores indicate conditions that are more conducive to viral survival or airborne transmission, signaling the need for timely intervention.

This approach enables building operators, clinicians, and occupants to interpret environmental health risks at a glance, prioritize mitigation strategies, and take proactive measures to maintain safer indoor environments.

Table 2 presents the qualitative interpretation of the Index score ranges. These categories have been chosen to support timely decision-making and align with the practical actions that building operators and occupants can take.

Score Range	Risk Level	Interpretation
1–3	Good	Environmental conditions and personal susceptibility factors together indicate a low overall risk of influenza acquisition.
4–6	Mild	Combined environmental and host-related factors suggest a moderate level of risk, with transmission possible depending on exposure and individual vulnerability.
7–8	Bad	Elevated risk driven by unfavorable environmental conditions and/or increased susceptibility, making influenza transmission more likely without timely mitigation.
9–10	Severe	High-risk conditions in which environmental factors and host susceptibility together create a strong likelihood of influenza transmission, requiring urgent preventive action.

Scores of **1 to 3** indicate that the overall influenza risk is low, reflecting environmental conditions that are generally unfavorable to viral persistence combined with typical population susceptibility levels.

Scores of **4 to 6** reflect a moderate level of risk, wherein influenza transmission is possible depending on exposure duration, crowding, and individual vulnerability such as age, pre-existing health conditions, or immune status.

Scores of **7 to 8** suggest heightened risk, where environmental factors and host susceptibility interact to create conditions in which influenza transmission becomes more likely, warranting timely corrective measures.

Scores of **9 to 10** indicate severe risk. In this range, the combination of environmental conditions and personal susceptibility factors substantially increases the probability of influenza transmission, and urgent interventions are recommended.[7]

6. Influenza Control and Mitigation Measures

Effective reduction of indoor influenza transmission requires a multi-layered strategy integrating engineering controls, administrative practices, and personal protective behaviors.[6]

Engineering controls are foundational, focusing on modifying the physical environment to minimize viral viability and accumulation:

- **Ventilation and Air Exchange:** Ventilation systems must be optimized to maintain CO_2 levels below 800 ppm. This often translates to achieving an outdoor air exchange rate of at least five Air Changes per Hour (ACH) in general occupancy spaces, increasing to six to twelve ACH in high-risk or healthcare environments.[28]
- **Air Filtration:** Central Heating, Ventilation, and Air Conditioning (HVAC) systems should be upgraded to MERV 13 or higher where equipment allows.[29]. In spaces where central systems cannot achieve adequate filtration, supplemental portable HEPA air cleaners are recommended.
- **Climate Control:** To minimize the infectious half-life of influenza, environmental parameters should be tightly controlled:
    - **Relative Humidity (RH):** Maintained between 40% and 60%.
    - **Temperature:** Maintained between 21°C and 23°C (70°F and 73°F).[30]
- **PM Reduction:** Source control measures are critical for reducing PM, which acts as a viral carrier. These include prohibiting indoor smoking, improving kitchen and local exhaust ventilation, utilizing high-efficiency vacuum filtration, and ensuring rigorous HVAC component maintenance to prevent particle re-entrainment.[31]

Administrative controls establish the protocols necessary for sustained risk management:

- **Continuous Monitoring:** Implementation of continuous IAQ monitoring with automated alert systems is essential to flag deviations from ideal parameter ranges in real-time.
- **Proactive Maintenance:** This includes scheduled HVAC maintenance and proactive filter replacement in accordance with manufacturer specifications or performance data.
- **Occupancy Management:** Implementing strategies for occupancy management or density reduction during peak influenza seasons can further reduce viral load in the air.[32]

Personal measures complement environmental controls by reducing the emission and acquisition of viral particles:

- **Masking and Hygiene:** Personal Protective Behaviors (PBB) include the appropriate use of face masks in crowded or high-risk settings, adherence to rigorous respiratory etiquette (covering coughs and sneezes), and consistent hand hygiene.
- **Symptom-Based Exclusion:** A critical administrative and personal measure is symptom-based exclusion, requiring individuals who are symptomatic to remain home, to reduce the initial opportunity for community exposure and transmission.[33]

7. Why uHoo's Solutions Help You Take Control and Ensure Safety

The uHoo Influenza Index serves as a critical operational tool, rendering invisible environmental risks visible by transforming real-time data into a concise, scientifically aligned risk metric.[34]

Because the index identifies which specific parameters are elevating risk, for example, low humidity, elevated carbon dioxide, or high fine particulate levels, it enables targeted interventions rather than broad, inefficient responses.

Integration with building automation systems allows corrective actions such as adjusting outdoor air intake, activating humidification, or switching air cleaners to higher settings to occur automatically when the score rises beyond acceptable thresholds.[35] Historical data, trend analytics, and seasonal benchmarking support long-term IAQ planning, capital prioritization, and continuous improvement across portfolios of buildings.[36]

8. Conclusion

Influenza thrives under specific and measurable indoor environmental conditions.[7] The uHoo Influenza Index serves as a vital tool, translating peer-reviewed scientific findings into a real-time, operational metric.

By enabling the continuous assessment of key parameters, including temperature, RH, ventilation effectiveness, PM levels, and gaseous pollutant concentrations, the Index empowers owners, operators, and occupants to mitigate transmission risk proactively.

Maintaining indoor environments within the ideal ranges detailed throughout this paper allows organizations to establish spaces that create indoor environments that are healthier, more comfortable, and more resilient against influenza, not only during peak season but year-round.[37]

9. References

1. World Health Organization. Influenza (Seasonal). WHO, 2024. https://www.who.int/news-room/fact-sheets/detail/influenza-(seasonal)

2. Molinari, N. A., et al. The annual impact of seasonal influenza in the US. Vaccine, 2007. https://doi.org/10.1016/j.vaccine.2007.03.046

3. Centers for Disease Control and Prevention. Preventing Seasonal Flu. CDC, 2023. https://www.cdc.gov/flu/prevent/index.html

4. Lowen, A. C., et al. Influenza virus transmission is dependent on relative humidity and temperature. PLoS Pathogens, 2007. https://doi.org/10.1371/journal.ppat.0030151

5. Tellier, R., et al. Recognition of aerosol transmission of infectious agents. BMC Infectious Diseases, 2019. https://doi.org/10.1186/s12879-019-3707-y

6. Morawska, L., et al. How can airborne transmission of COVID-19 indoors be minimised? Environment International, 2020. https://doi.org/10.1016/j.envint.2020.105832

7. Shaman, J., & Kohn, M. Absolute humidity modulates influenza survival, transmission, and seasonality. PNAS, 2009. https://doi.org/10.1073/pnas.0806852106

8. uHoo. Using Indoor Air Quality Data to Create the uHoo Virus Index. uHoo, 2020. https://getuhoo.com/virus-index

9. Chan, K. H., et al. The effects of temperature and relative humidity on the viability of the SARS coronavirus. Advances in Virology, 2011. https://doi.org/10.1155/2011/734690

10. Steel, J., et al. Transmission of the influenza virus in a mammalian host is increased at low temperatures. PLoS Pathogens, 2008. https://doi.org/10.1371/journal.ppat.0041001

11. Barreca, A. I., & Shimshack, J. P. Absolute humidity, temperature, and influenza mortality. American Journal of Epidemiology, 2012. https://doi.org/10.1093/aje/kws259

12. Yang, W., & Marr, L. C. Dynamics of airborne influenza A viruses indoors and dependence on humidity. PLoS ONE, 2011. https://doi.org/10.1371/journal.pone.0021481 doi.org/10.1186/s12940-016-0115-2

13. Feng, C., et al. Impact of ambient fine particulate matter (PM2.5) exposure on the risk of influenza-like illness. Environmental Health, 2016. https://doi.org/10.1186/s12940-016-0115-2

14. Xing, Y. F., et al. The impact of PM2.5 on the human respiratory system. Journal of Thoracic Disease, 2016. https://doi.org/10.21037/jtd.2016.06.04

15. Rudnick, S. N., & Milton, D. K. Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. Indoor Air, 2003. https://doi.org/10.1034/j.1600-0668.2003.00189.x

16. Wolkoff, P. Indoor air humidity, air quality, and health – An overview. International Journal of Hygiene and Environmental Health, 2018. https://doi.org/10.1016/j.ijheh.2018.01.015

17. Noti, J. D., et al. High humidity leads to loss of infectious influenza virus from simulated coughs. PLoS ONE, 2013. https://doi.org/10.1371/journal.pone.0057485

18. Rudnick, S. N., & Milton, D. K. Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. Indoor Air, 2003. https://doi.org/10.1034/j.1600-0668.2003.00189.x

19. ASHRAE. Position Document on Infectious Aerosols. ASHRAE, 2020. https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

20 Feng, C., et al. Impact of ambient fine particulate matter (PM2.5) exposure on the risk of influenza-like illness. Environmental Health, 2016. https://doi.org/10.1186/s12940-016-0115-2

21. Xing, Y. F., et al. The impact of PM2.5 on the human respiratory system. Journal of Thoracic Disease, 2016. https://doi.org/10.21037/jtd.2016.06.04

22. World Health Organization. WHO Air Quality Guidelines: Global Update 2021. WHO, 2021. https://www.who.int/publications/i/item/9789240034228

23. Becker, S., & Soukup, J. M. Effect of nitrogen dioxide on respiratory viral infection in airway epithelial cells. Environmental Research, 1999. https://doi.org/10.1006/enrs.1999.3963

24. WHO Regional Office for Europe. Air Quality Guidelines: Nitrogen Dioxide. WHO, 2000. https://www.euro.who.int/__data/assets/pdf_file/0017/123083/AQG2ndEd_7_1nitrogendioxide.pdf

25. World Health Organization. WHO Guidelines for Indoor Air Quality: Selected Pollutants – Formaldehyde. WHO, 2010. https://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf

26. WHO Regional Office for Europe. Review of evidence on health aspects of air pollution – REVIHAAP Project. WHO, 2013. https://www.ncbi.nlm.nih.gov/books/NBK361809/

27. U.S. EPA. Ozone's Impact on Indoor Air Quality. EPA, 2023. https://www.epa.gov/indoor-air-quality-iaq/ozones-impact-indoor-air-quality

28. ASHRAE. Position Document on Infectious Aerosols. ASHRAE, 2020. https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

29. U.S. EPA. Ventilation and Air Quality in Offices. EPA, 2023. https://www.epa.gov/indoor-air-quality-iaq/ventilation-and-air-quality-offices

30. Noti, J. D., et al. High humidity leads to loss of infectious influenza virus from simulated coughs. PLoS ONE, 2013. https://doi.org/10.1371/journal.pone.0057485

31. California Air Resources Board. Sources of Indoor Particulate Matter. CARB, 2023. https://ww2.arb.ca.gov/resources/sources-indoor-particulate-matter

32. Centers for Disease Control and Prevention. Ventilation in Buildings. CDC, 2023. https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html

33. Centers for Disease Control and Prevention. How Flu Spreads. CDC, 2023. https://www.cdc.gov/flu/about/disease/spread.htm

34. uHoo. Using Indoor Air Quality Data to Create the uHoo Virus Index. uHoo, 2020. https://getuhoo.com/virus-index

35. ASHRAE. Guideline 36-2021: High Performance Sequences of Operation for HVAC Systems. ASHRAE, 2021. https://www.ashrae.org/technical-resources/bookstore/guideline-36-2021

36. U.S. EPA. Indoor Air Quality Management Practices. EPA, 2023. https://www.epa.gov/indoor-air-quality-iaq/iaq-management-practices

37. World Health Organization. Roadmap to Improve and Ensure Good Indoor Ventilation in the Context of COVID-19. WHO, 2021. https://www.who.int/publications/i/item/9789240021280