ASHRAE EPIDEMIC TASK FORCE

SCIENTIFIC DATA COMMITTEE | Updated 4-17-2020

Table of Contents:

I. Infectious Aerosol Position Document statements

A. Airborne transmission of SARS-CoV-2

Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures

B. Operation of heating, ventilating, and air-conditioning systems to reduce SARS-CoV-2 transmission

Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also lower resistance to infection. In general, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus

II. Short-list references associated with Position Document

Airborne Infectious Aerosol Transmission

- Detection of Air and Surface Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) in Hospital Rooms of Infected Patients. Chia P Y et al. medRxiv preprint doi: https://doi.org/10.1101/2020.03.29. 20046557.
- Seasonality of Respiratory Viral Infections. Moriyama M et al. Annu. Rev. Virol. (2020) 7:2.1–2.19
- Aerosol and surface stability of SARS-CoV-2 as compared to SARS-CoV-1. Doremalen N v et al. NEJM (2020)
- Deposition of respiratory virus pathogens on frequently touched surfaces at airports. Ikonen N et al. BMC Inf. Dis. (2018) 18:437-443
- The effects of temperature and relative humidity on the viability of the SARS coronavirus. Chan KH et al. Advances in Virology (2011) ID 734690

Virus Viability and IAQ

- Effects of humidity and other factors on the generation and sampling of a coronavirus aerosol. Kim S W et al. Aerobiologia (2007) 23:239–248
- Transmission of SARS and MERVs coronaviruses and influenza virus in healthcare settings: the possible role of dry surface contamination. Otter J A et al. Journal of Hospital Infection (2016) 92:235–250
- Microbes at surface-air interfaces: RH, surface hygroscopicity and oligotrophy for resistance. Stone W et al. Front. Microbiol. (2016) 7:1563
- Humidity as a non-pharmaceutical intervention for influenza. A. Reiman J et al. (2018) PLoS ONE 13(9): e0204337. https:// doi.org/10.1371/journal.pone.0204337
- Seasonality of Respiratory Viral Infections. Moriyama M et al. Annu. Rev. Virol. (2020) 7:2.1–2.19
- Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence. Marr L et al. J.R. Soc. Interface (2018) 16:20180298.
- The effects of temperature and relative humidity on the viability of the SARS coronavirus. Chan KH et al. Advances in Virology (2011) ID 734690

Human Immune System and IAQ

- Low ambient humidity impairs barrier function and innate resistance against influenza infection. Kudo E et al. PNAS (2019) April 4.
- Seasonality of Respiratory Viral Infections. Moriyama M et al. Annu. Rev. Virol. (2020) 7:2.1–2.19
- The effects of indoor-air relative humidity on health outcomes and cognitive function in residents in a long-term care facility. Taylor S and Tasi M. Indoor Air (2018) Paper #744

Annotated References: Environmental Hygiene

TITLE	PRE-PRINT LINK	SUMMARY / RELEVANT EXCERPTS
Aerodynamic Characteristics and RNA Concentration of SARS-CoV-2 Aerosol in Wuhan Hospitals during COVID-19 Outbreak	https://www.biorxiv.org/content/10.1101/2020.03.08.982637v1	The ICU, CCU and general patient rooms inside Renmin, patient hall inside Fangcang had undetectable or low airborne SARS-CoV-2 concentration but deposition samples inside ICU and air sample in Fangcang patient toilet tested positive. The airborne SARS-CoV-2 in Fangcang MSA had bimodal distribution with higher concentration than those in Renmin during the outbreak but turned negative after patients number reduced and rigorous sanitization implemented. PUA had undetectable airborne SARS-CoV-2 concentration but obviously increased with accumulating crowd flow.
Temperature significant change COVID-19 Transmission in 429 cities	https://www.medrxiv.org/content/10.1101/2020.02.22.20025791v1	The study found that, to certain extent, temperature could significant change COVID-19 transmission, and there might be a best temperature for the viral transmission, which may partly explain why it first broke out in Wuhan. It is suggested that countries and regions with a lower temperature in the world adopt the strictest control measures to prevent future reversal.
Effects of temperature variation and humidity on the mortality of COVID-19 in Wuhan	https://www.medrxiv.org/content/10.1101/2020.03.15.20036426v1	A positive association with COVID-19 mortality was observed for diurnal temperature range (r = 0.44), but negative association for relative humidity (r = −0.32). In addition, each 1 unit increase in diurnal temperature range was only associated with a 2.92% (95% CI: 0.61%, 5.28%) increase in COVID-19 mortality at lag 3. However, both per 1 unit increase of temperature and absolute humidity were related to the decreased COVID-19 mortality at lag 3 and lag 5, respectively.
Closed environments facilitate secondary transmission of coronavirus disease 2019 (COVID-19)	https://www.medrxiv.org/content/10.1101/2020.02.28.20029272v1	Commissioned by the Minister of the Ministry of Health, Labour, and Welfare of Japan, we collected secondary transmission data with the aim of identifying high risk transmission settings. We show that closed environments contribute to secondary transmission of COVID-19 and promote superspreading events. Closed environments are consistent with large-scale COVID-19 transmission events such as that of the ski chalet-associated cluster in France and the church- and hospital-associated clusters in South Korea. Our findings are also consistent with the declining incidence of COVID-19 cases in China, as gathering in closed environments was prohibited in the wake of the rapid spread of the disease. Reduction of unnecessary close contact in closed environments may help prevent large case clusters and superspreading events.
Transmission Potential of SARS-CoV-2 in Viral Shedding Observed at the University of Nebraska Medical Center	https://www.medrxiv.org/content/10.1101/2020.03.23.20039446v2	During the initial isolation of 13 individuals confirmed positive with COVID-19 infection, air and surface samples were collected in eleven isolation rooms to examine viral shedding from isolated individuals. While all individuals were confirmed positive for SARS-CoV-2, symptoms and viral shedding to the environment varied considerably. Many commonly used items, toilet facilities, and air samples had evidence of viral contamination, indicating that SARS-CoV-2 is shed to the environment as expired particles, during toileting, and through contact with fomites. Disease spread through both direct (droplet and person-to-person) as well as indirect contact (contaminated objects and airborne transmission) are indicated, supporting the use of airborne isolation precautions.
Role of meteorological temperature and relative humidity in the January-February 2020 propagation of 2019-nCoV in Wuhan, China	https://www.medrxiv.org/content/10.1101/2020.03.19.20039164v1	Long-term trend of temperature and relative humidity was obtained with a 14-days adjacent-averaging filter, and lagged correlations of the number of daily confirmed cases were explored. The analysis showed negative correlations between temperatures with the number of daily confirmed cases. Maximum correlations were found for 6-day lagged temperatures, which is likely reflecting the incubation period of the virus. It was postulated that the indoor crowding effect is responsible of the high incidence of 2019-nCoV cases, where low absolute humidity and close human contact facilitate the transport of aerosol droplets.
Clinical Data on Hospital Environmental Hygiene Monitoring and Medical Staff Protection during the Coronavirus Disease 2019 Outbreak	https://www.medrxiv.org/content/10.1101/2020.02.25.20028043v2	Viruses could be detected on the surfaces of the nurse station in the isolation area with suspected patients and in the air of the isolation ward with an intensive care patient.
Analysis of epidemiological characteristics of coronavirus 2019 infection and preventive measures in Shenzhen China: a heavy population city	https://www.medrxiv.org/content/10.1101/2020.02.28.20028555v1	Shenzhen ranked the top cities outside Wuhan with reported 416 confirmed cases by February 20, 2020. Here, we analyzed the epidemiological characteristics of COVID-19 in Shenzhen and potential link to the preventive strategies for the whole city and inside hospitals. Based on the daily new cases, the epidemic of COVID-19 in Shenzhen can be classified into three phases: the slow increase phase from January 19 to January 28, the rapid increase and plateau phase from January 29 to February 5 and the decline phase since February 6. In the three phases, the number of patients from Hubei decreased, and the number of familial clustering cases increased.

Annotated References: Environmental Hygiene

TITLE	PRE-PRINT LINK	SUMMARY / RELEVANT EXCERPTS
The impact of temperature and absolute humidity on the coronavirus disease 2019 (COVID-19) outbreak - evidence from China	https://www.medrxiv.org/content/10.1101/2020.03.22.20038919v1	The number of new confirm COVID-19 cases in mainland China peaked on Feb 1, 2020. COVID-19 daily incidence were lowest at -10 ℃ and highest at 10 ℃,while the maximum incidence was observed at the absolute humidity of approximately 7 g/m3. COVID-19 incidence changed with temperature as daily incidence decreased when the temperature rose. No significant association between COVID-19 incidence and absolute humidity was observed in distributed lag nonlinear models. Additionally, A modified susceptible-exposed-infectious-recovered (M-SEIR) model confirmed that transmission rate decreased with the increase of temperature, leading to further decrease of infection rate and outbreak scale. CONCLUSION Temperature is an environmental driver of the COVID-19 outbreak in China. Lower and higher temperatures might be positive to decrease the COVID-19 incidence. M-SEIR models help to better evaluate environmental and social impacts on COVID-19.
Potential impact of seasonal forcing on a SARS-CoV-2 pandemic	https://www.medrxiv.org/content/10.1101/2020.02.13.20022806v2	While the uncertainty in parameters is large, the scenarios we explore show that transient reductions in the incidence rate might be due to a combination of seasonal variation and infection control efforts but do not necessarily mean the epidemic is contained. Seasonal forcing on SARS-CoV-2 should thus be taken into account in the further monitoring of the global transmission. The likely aggregated effect of seasonal variation, infection control measures and transmission rate variation is a prolonged pandemic wave with lower prevalence at any given time, thereby providing a window of opportunity for better preparation of health care systems.
Role of temperature and humidity in the modulation of the doubling time of COVID-19 cases	https://www.medrxiv.org/content/10.1101/2020.03.05.20031872v1	Results indicate that the doubling time correlates positively with temperature and inversely with humidity, suggesting that a decrease in the rate of progression of COVID-19 with the arrival of spring and summer in the north hemisphere. A 20oC increase is expected to delay the doubling time in 1.8 days. Those variables explain 18% of the variation in disease doubling time; the remaining 82% may be related to containment measures, general health policies, population density, transportation or cultural aspects.
The role of absolute humidity on transmission rates of the COVID-19 outbreak	https://www.medrxiv.org/content/10.1101/2020.02.12.20022467v1	Here, we examine province-level variability of the basic reproductive numbers of COVID-19 across China and find that changes in weather alone (i.e., increase of temperature and humidity as spring and summer months arrive in the North Hemisphere) will not necessarily lead to declines in COVID-19 case counts without the implementation of extensive public health interventions.
Climate affects global patterns of COVID-19 early outbreak dynamics	https://www.medrxiv.org/content/10.1101/2020.03.23.20040501v1	Growth rates peaked in temperate regions of the Northern Hemisphere with mean temperature of ~5 degrees, and humidity of approx 0.6-1 kPa during the outbreak month, while they decreased in warmer and colder regions. The strong relationship between local climate and COVID-19 growth rates suggests the possibility of seasonal variation in the spatial pattern of outbreaks, with temperate regions of the Southern Hemisphere becoming at particular risk of severe outbreaks during the next months.
Roles of meteorological conditions in COVID-19 transmission on a worldwide scale	https://www.medrxiv.org/content/10.1101/2020.03.16.20037168v1	Here, we examine the relationships of meteorological variables with the severity of the outbreak on a worldwide scale. The confirmed case counts, which indicates the severity of COVID-19 spread, and four meteorological variables, i.e., air temperature, relative humidity, wind speed, and visibility, were collected daily between January 20 and March 11 (52 days) for 430 cities and districts all over China, 21 cities/ provinces in Italy, 21 cities/ provinces in Japan, and 51 other countries around the world. Four different time delays of weather (on the day, 3 days ago, 7 days ago, and 14 days ago) as to the epidemic situation were taken for modeling and we finally chose the weather two weeks ago to model against the daily epidemic situation as its correlated with the outbreak best. Taken Chinese cities as a discovery dataset, it was suggested that temperature, wind speed, and relative humidity combined together could best predict the epidemic situation.

Annotated References: Environmental Hygiene

TITLE	PRE-PRINT LINK	SUMMARY / RELEVANT EXCERPTS
Preliminary evidence that higher temperatures are associated with lower incidence of COVID-19, for cases reported globally up to 29th February 2020	https://www.medrxiv.org/content/10.1101/2020.03.18.20036731v1	Using global line-list data on COVID-19 cases reported until 29th February 2020 and global gridded temperature data, and after adjusting for surveillance capacity and time since first imported case, higher average temperature was strongly associated with lower COVID-19 incidence for temperatures of 1°C and higher. However, temperature explained a relatively modest amount of the total variation in COVID-19 incidence. These preliminary findings support stringent containment efforts in Europe and elsewhere.
Simulation-based Estimation of the Spread of COVID-19 in Iran	https://www.medrxiv.org/content/10.1101/2020.03.22.20040956v1	The trajectory of the epidemic until the end of June could take various paths depending on the impact of seasonality and policies targeting social distancing. In the most optimistic scenario for seasonal effects, depending on policy measures, 1.6 million Iranians (90% CI: 0.9M-2.6M) are likely to get infected, and death toll will reach about 58,000 cases (90% CI: 32K-97K), while in the more pessimistic scenarios, death toll may exceed 103,000 cases (90% CI: 56K-172K). Implication: Our results suggest that the number of cases and deaths may be over an order of magnitude larger than official statistics in Iran. Absent extended testing capacity other countries may face a significant under-count of existing cases and thus be caught off guard about the actual toll of the epidemic.
Impacts of social and economic factors on the transmission of coronavirus disease (COVID-19) in China	https://www.medrxiv.org/content/10.1101/2020.03.13.20035238v1.full.pdf+html	We rely on meteorological data to construct instrumental variables for the endogenous variables. The National Oceanic and Atmospheric Administration (NOAA) provides average, maximum and minimum temperatures, air pressure, average and maximum wind speeds, precipitation, snowfall amount, and dew point for 362 weather stations at the daily level in China. To merge the meteorological variables with the number of new cases of COVID-19, we first calculate daily weather variables for each city on each day from 2019 December to 2020 February from station-level weather records following the inverse-distance weighting method. Second, we match the daily weather variables to the number of new cases of COVID-19 based on city name and date.
The Effects of "Fangcang, Huoshenshan, and Leishenshan" Makeshift Hospitals and Temperature on the Mortality of COVID-19	https://www.medrxiv.org/content/10.1101/2020.02.26.20028472v3	Mortality of confirmed cases was found to be significantly correlated with temperature both in Wuhan (r = -0.441, P = 0.012) and Hubei (r = -0.440, P = 0.012). Conclusions Our findings indicated that both the use of MSHs and the rise of AT were beneficial to the survival of COVID-19 cases. If air temp rises 1 Celsius, the mortality of confirmed cases would decrease 0.44% and the mortality of severe cases would decrease 0.42% on average.
Spread of SARS-CoV-2 Coronavirus likely to be constrained by climate	https://www.medrxiv.org/content/10.1101/2020.03.12.20034728v1	More probable is the emergence of asynchronous seasonal global outbreaks much like other respiratory diseases. People in temperate warm and cold climates are more vulnerable. Those in arid climates follow next in vulnerability, while the disease will likely marginally affect the tropics. Our projections minimize uncertainties related with spread of SARS CoV-2, providing critical information for anticipating the adequate social, economic and political responses.
Projecting the transmission dynamics of SARS-CoV-2 through the post-pandemic period	https://www.medrxiv.org/content/10.1101/2020.03.04.20031112v1	These dynamics will depend on seasonality, the duration of immunity, and the strength of cross-immunity to/from the other human coronaviruses. Using data from the United States, we measured how these factors affect transmission of human betacoronaviruses HCoV-OC43 and HCoV-HKU1. We then built a mathematical model to simulate transmission of SARS-CoV-2 through the year 2025. We project that recurrent wintertime outbreaks of SARS-CoV-2 will probably occur after an initial pandemic wave. We summarize the full range of plausible transmission scenarios and identify key data still needed to distinguish between them, most importantly longitudinal serological studies to determine the duration of immunity to SARS-CoV-2.
Aerosol and surface stability of HCoV-19 (SARS-CoV-2) compared to SARS-CoV-1	https://www.medrxiv.org/content/10.1101/2020.03.09.20033217v2	We found that the stability of SARS-CoV-2 was similar to that of SARS-CoV-1 under the experimental circumstances tested. This indicates that differences in the epidemiologic characteristics of these viruses probably arise from other factors, including high viral loads in the upper respiratory tract and the potential for persons infected with SARS-CoV-2 to shed and transmit the virus while asymptomatic.3,4 Our results indicate that aerosol and fomite transmission of SARS-CoV-2 is plausible, since the virus can remain viable and infectious in aerosols for hours and on surfaces up to days (depending on the inoculum shed). These findings echo those with SARS-CoV-1, in which these forms of transmission were associated with nosocomial spread and super-spreading events,5 and they provide information for pandemic mitigation efforts. (Published link: https://www.nejm.org/doi/full/10.1056/NEJMc2004973)

Annotated References: Environmental Hygiene

TITLE	PRE-PRINT LINK	SUMMARY / RELEVANT EXCERPTS
Defining the Epidemiology of Covid-19 — Studies Needed	https://www.nejm.org/doi/full/10.1056/NEJMp2002125?query=recirc_top_ribbon_article_1	First, what is the full spectrum of disease severity (which can range from asymptomatic, to symptomatic-but-mild, to severe, to requiring hospitalization, to fatal)? Second, how transmissible is the virus? Third, who are the infectors — how do the infected person's age, the severity of illness, and other characteristics of a case affect the risk of transmitting the infection to others? Of vital interest is the role that asymptomatic or presymptomatic infected persons play in transmission. When and for how long is the virus present in respiratory secretions? And fourth, what are the risk factors for severe illness or death? And how can we identify groups most likely to have poor outcomes so that we can focus prevention and treatment efforts?
Will coronavirus pandemic diminish by summer?	https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3556998	Therefore, even though currently available data is skewed by minimal testing per capita in many tropical countries, it is possible that weather plays a role in the spread of 2019-nCoV which warrants an investigation. In the last 10 days, thousands of new cases have been documented in regions with T >18C suggesting that the role of warmer temperature in slowing the spread of the 2019-nCoV, as suggested earlier might only be observed, if at all, at much higher temperatures. Unlike temperature, however, the range of AH across which most of the cases have been documented has consistently been between 3 and 9g/m3 . Current data, although limited, suggests that it is extremely unlikely that the spread of 2019-nCoV would slow down in the USA or Europe, due to environmental factors, because a large number of cases have already been reported in the range of AH and T experienced by these regions for most part of the year.

References: Humidity and Viruses

Authors	Title	Year	Link	RH Tested	Summarry of Findings	Methods	Virus Type	Notes	General Virus Type
M. K. IJAZ, A. H. BRUNNER, S. A. SATTAR, RAMA C. NAIR AND C. M. JOHNSON-LUSSENBURG	Survival Characteristics of Airborne Human Coronavirus 229E	1985	https://www.ncbi.nlm.nih.gov/pubmed/2999318	30%, 50%, 80%	Coronavirus 229E survives the best at 50% humidity, the worst at 80% humidity	Plaque Assay	Coronavirus 229E		Coronavirus
Seung Won Kim, M. A. Ramakrishnan, Peter C. Raynor & Sagar M. Goyal	Effects of humidity and other factors on the generation and sampling of a coronavirus aerosol	2007	https://link.springer.com/article/10.1007/s10453-007-9068-9	30%, 50%, 70%, 90%	The most and the least virus were recovered from filter media at 30% and 90% RH, respectively	inoculated cells and microscopic evaluation	TGEV (Coronavirus Proxy)		Coronavirus
Lisa M. Casanova,1,* Soyoung Jeon,2 William A. Rutala,3 David J. Weber,3 and Mark D. Sobsey1	Effects of Air Temperature and Relative Humidity on Coronavirus Survival on Surfaces	2010	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2863430/	20%, 50%, 80%	Greater survival at 20% RH and 80% RH compared to 50% RH	Innoculation in live carriers	TGEV and MHV (Coronavirus Proxy)		Coronavirus
K. H. Chan, J. S. Malik Peiris, S. Y. Lam, L. L. M. Poon, K. Y. Yuen, and W. H. Seto	The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus	2011	https://www.hindawi.com/journals/av/2011/734690/	40%-50%, 85%, 95%	more infective at 40-50% than at 95%	Innoculation in live carriers	SARS-CoV	Didn't study survival, examined infectivity	Coronavirus
N van Doremalen1, T Bushmaker1, V J Munster1	Stability of Middle East respiratory syndrome coronavirus (MERS-CoV) under different environmental conditions	2013	https://www.eurosurveillance.org/content/10.2807/1560-7917.ES2013.18.38.20590	40%, 70%	Reduced viability at 70% RH compared to 40% RH	Innoculation in Cell Culture	MERS and H1N1 (Mexico)	Inconsistent Temperatures make RH comparisons difficult	Coronavirus
JOHN N. MBITHI, V. SUSAN SPRINGTHORPE, AND SYED A. SATTAR*	Effect of Relative Humidity and Air Temperature on Survival of Hepatitis A Virus on Environmental Surfaces	1991	https://aem.asm.org/content/aem/57/5/1394.full.pdf	5%, 25%, 55%, 85%, 95%	Highest survival at 5%, lowest survival at 95%, survival decreased with rising humidity	Plaque Assay	Hepatitus A		Hepatitus
Joseph P. Wood*†Young W. Choi‡Daniel J. Chappie‡James V. Rogers‡Jonathan Z. Kaye§	Environmental Persistence of a Highly Pathogenic Avian Influenza (H5N1) Virus	2010	https://pubs.acs.org/doi/10.1021/es1016153	~30%, ~80%	Best survival at low humidity	Innoculation in Cell Culture	H5N1		Influenza
James McDevitt,* Stephen Rudnick, Melvin First, and John Spengler	Role of Absolute Humidity in the Inactivation of Influenza Viruses on Stainless Steel Surfaces at Elevated Temperatures	2010	https://aem.asm.org/content/aem/76/12/3943.full.pdf	25%, 50%, 75%	Inactivation of influenza virus on surfaces increased with increasing temperature, RH, and exposure time.	Fluorescent focus reduction assay	Influenza Virus		Influenza
A. D. Coulliette, K. A. Perry, J. R. Edwards, J. A. Noble-Wang	Persistence of the 2009 Pandemic Influenza A (H1N1) Virus on N95 Respirators	2013	https://aem.asm.org/content/79/7/2148	20%, 58.5%	Virus survival decreased with increased humidity	ELISA	H1N1 Influenza		Influenza

References: Humidity and Viruses

John D. Noti ,Francoise M. Blachere,Cynthia M. McMillen,William G. Lindsley,Michael L. Kashon,Denzil R. Slaughter,Donald H. Beezhold	High Humidity Leads to Loss of Infectious Influenza Virus from Simulated Coughs	2013	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0057485	7%-73%	At low relative humidity, influenza retains maximal infectivity and inactivation of the virus at higher relative humidity occurs rapidly after coughing ... "maintaining indoor relative humidity >40% will significantly reduce the infectivity of aerosolized virus	Plaque Assay/qPCR	influenza	Influenza
A.I.Donaldson, N.P.Ferris	The survival of some air-borne animal viruses in relation to relative humidity	1976	https://www.sciencedirect.com/science/article/pii/0378113576900560	20%, 30%, 40%, 50%, 60%, 70%, 80%	Lowered viability in the 30%-70% range	Plaque Assay	feline herpesvirus (FHV); feline calicivirus (FCV); vesicular exanthema virus (VEV); infectious bovine rhinotracheitis virus (IBRV); parainfluenza 3 virus (PI-3 virus); vesicular stomatitis virus (VSV); equine herpesvirus type 1 (EHV-1), equine arteritis virus (EAV); equine rhinovirus (ERV-1), and African swine fever virus (ASFV).	Mix
S. J. Webb, , R. Bather, and , R. W. Hodges	THE EFFECT OF RELATIVE HUMIDITY AND INOSITOL ON AIR-BORNE VIRUSES	1963	https://www.nrcresearchpress.com/doi/abs/10.1139/m63-009#.Xn1zItNKjUI	10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%	most survival at 70%, sensitive at 30%	Innoculation in live carriers	Pigeon pox and R.S.V.	Pigeon pox and R.S.V.
SYED A. SATTAR,* MOHAMMAD K. IJAZ, C. MARGARET JOHNSON-LUSSENBURG, AND V. SUSAN SPRINGTHORPE	Effect of relative humidity on the airborne survival of rotavirus SA11.	1984	https://aem.asm.org/content/47/4/879.short	25%, 50%, 80%	Highest survival at 50% RH, lowest at 80%	Plaque Assay	Rotavirus SA11	Rotavirus
J. E. Benbough	The Effect of Relative Humidity on the Survival of Airborne Semliki Forest Virus	1969	https://www.microbiologyresearch.org/content/journal/jgv/10.1099/0022-1317-4-4-473	20%, 49%, 59%, 68%, 84%, 90%	Virus survival decreased with increased humidity	Plaque Assay	Semliki Forest Virus	Semliki Forest Virus
T. G. Akers, Sheila Bond, L. J. Goldberg	Effect of Temperature and Relative Humidity on Survival of Airborne Columbia SK Group Viruses	1966	https://aem.asm.org/content/14/3/361.short?casa_token=_dBRFZg952EAAAAA:AGPPGSzhu63CGTzdf5RcJ-q3VtagpbKZxekMGqDmo13AxD-gXHrzOJvgFCAnRLLMGQ55WMCqKA	5%-95%	Virus survival lowest between 40%-60%	Plaque Assay	Columbia SK Group Virus	SK Group Virus

References: Humidity and Viruses

Anice Lowen* and Peter Palese†	Transmission of influenza virus in temperate zones is predominantly by aerosol, in the tropics by contact A hypothesis	2009	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2762697/	35%, 85%	Higher infectivity at 35% RH	Observational	Influenza	Metaanalysis	Influenza
Wan Yang,Subbiah Elankumaran,Linsey C. Marr	Relationship between Humidity and Influenza A Viability in Droplets and Implications for Influenza's Seasonality	2009	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0046789	~20%-100%	-Mainly salts: lowest ~50% -Salts+Proteins: Lowest ~75% -Mucus: Lowest ~80%	Microcope observation	Influenza		Influenza
Anice C Lowen,1,* Samira Mubareka,1 John Steel,1 and Peter Palese1,2,*	Influenza Virus Transmission Is Dependent on Relative Humidity and Temperature	2007	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2034399/	20%-80%	Least stable at 50%	Live host infection	Influenza		Influenza
Kortney M. Gustin,Jessica A. Belser,Vic Veguilla,Hui Zeng,Jacqueline M. Katz,Terrence M. Tumpey,Taronna R. Maines	Environmental Conditions Affect Exhalation of H3N2 Seasonal and Variant Influenza Viruses and Respiratory Droplet Transmission in Ferrets	2015	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0125874	30%, 50%, 70%	Mist infectiousness at 30%	Live host infection	Influenza		Influenza
G. J. HARPER	Airborne micro-organisms: survival tests with four viruses	1961	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2134455/pdf/jhyg00130-0099.pdf	~20%-~80%	Most viable at 20%-30%	Live innoculation	Vaccinia virus, influenza, Venezuelan equine encephalomyelitis virus		Mix
WILLIAM S. MILLER AND MALCOLM S. ARTENSTEI	Aerosol Stability of Three Acute Respiratory Disease Viruses.	1967	https://www.ncbi.nlm.nih.gov/pubmed/4290945	20%, 50%, 80%	-Adenovorus type 4: Most stable at 80% -Adenovirus type 7: Most stable at 80% -Influenza: Most stable at 20%	Uranine tracer dye	Adenovirus type 4, adenovirus type 7, influenza		Mix
Linsey C. Marr, Julian W. Tang, Jennifer Van Mullekom and Seema S. Lakdawala	Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence	2019	https://royalsocietypublishing.org/doi/full/10.1098/rsif.2018.0298	20%-80%	Increasing humidity decreases viral survival	Modeling	Influenza		Influenza
LESTER W Jr.	The influence of relative humidity on the infectivity of air-borne influenza A virus, PR8 strain.	1948	https://www.ncbi.nlm.nih.gov/pubmed/18881494	30%, 50%, 80%	atomized virus suspension which produced a 100 per cent mortality rate in animals exposed at 30 and 80 per cent relative humidity, respectively, resulted in the death of only 22.5 per cent of mice at a humidity of 50 per cent.	Live host infection	Influenza		Influenza
Jennifer M. Reiman,et al*	Humidity as a non-pharmaceutical intervention for influenza A	2018	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6155525/pdf/pone.0204337.pdf	1/1 - 3/18 absolute humidity	Virus survival trough at 2/12 AH	PCR	Influenza		Influenza

References: General

- **Adan O, Samson R**, Fundamentals of mold growth in indoor environments and strategies for healthy living, Wageningen Academic Publishers 2011
- **Arundel AV, Sterling EM, Biggin JH, Sterling TD**, Indirect Health Effects of Relative Humidity in Indoor Environments, Environmental Health Perspectives vol. 65, pp. 351-361, 1986
- **Blaser MJ et al**, Toward a predictive understanding of earth's microbiomes to address 21st Century challenges, MBio. 2016 May 13;7(3)
- **Blaser M**, Antibiotic overuse: Stop the killing of beneficial bacteria, Nature volume 476, pages 393–394 (25 August 2011)
- **Bloomfield SF et al**, Time to abandon the hygiene hypothesis: new perspectives on allergic disease, the human microbiome, infectious disease prevention and the role of targeted hygiene, Perspectives in Public Health, July 2016 Vol 136, No 4
- **Boor KJ**, Bacterial stress responses - what doesn't kill them can make them stronger, PLoS Biol, Jan. 2006, vol 4 (1)
- **Butt HJ, Kappl M**, Normal capillary forces, Advances in Colloid and Interface Science 146 (2009) 48–60
- **Brodie EL et al**, Urban aerosols harbor diverse and dynamic bacterial population, Proc Natl Acad Sci U S A. 2007 Jan 2;104(1):299-30
- **Brown GZ et al**, Making microbiology of the built environment relevant to design, Microbiome (2016) 4:6
- **Chase J et al**, Geography and location are the primary drivers of office microbiome composition, mSystems 1(2)
- **Cho I, Blaser MJ**, The Human Microbiome: at the interface of health and disease, Nat Rev Genet. 2012 Mar 13; 13(4): 260–270
- **Chopra A, Lineweaver CH**, The case for a gaian bottleneck: The Biology of Habitability, ASTROBIOLOGY Volume 16, Number 1, 2016
- **Dannemiller KC, Weschler CJ, Peccia J**, Fungal and bacterial growth in floor dust at elevated relative humidity levels, Indoor Air 2016; 0: 1–10
- **Davies J, Davies D**, Origins and Evolution of Antibiotic Resistance, Microbiology and Molecular Biology Reviews, Sept. 2010, p. 417–433
- **Dedesko SJ**, Thesis, Indoor Environmental measurements of occupancy from the hospital microbiome project, Civil Engineering, University of Toronto, 2015
- **Dedesko S, Siegel JA**, Moisture parameters and fungal communities associated with gypsum drywall in buildings, Microbiome (2015) 3:71
- **D'Costa VM et al**, Antibiotic resistance is ancient, Nature, 2011, vol 477 , 457-461
- **Ebinesh A**, Conspiracy of domestic microenvironment, bacterial stress response and directed mutagenesis towards antimicrobial resistance: Lessons for health care, J Infectious Disease Med Microbiol. 2017;1(1):1-3
- **Ebinesh A**, Bacterial Stress Response and Cross Resistance to Antibiotics in the Light of Natural Selection, J Infect Dis Immune Ther 2017, 1:1
- **Ending the War Metaphor**: The changing agenda for unravelling the host-microbe relationship—Workshop Summary (2006), THE NATIONAL ACADEMIES PRESS
- **Fuller RA et al**, Psychological benefits of greenspaces increase with biodiversity, Biol. Lett. (2007) 3, 390–394
- **Ghoul M, Mitri S**, The ecology and evolution of microbial competition, Trends Microbiol. 2016 Oct.
- **Gilbert JA, Jansson JK, Knight R**, The Earth Microbiome project: successes and aspirations, BMC Biology 2014, 12:69
- **Green JL**, Can bioinformed design promote healthy indoor ecosystems? Indoor Air 2014; 24: 113–115
- **Horve PF et al**, Building upon current knowledge and techniques of indoor microbiology to construct the next era of theory into microorganisms, health, and the built environment, J Expo Sci Environ Epidemiol. 2019 Jul 15
- **Hospodsky D et al**, Characterizing airborne fungal and bacterial concentration and emission rates in six occupied children's classrooms, Indoor Air 2015; 25: 641–652
- **Iwasaki A, Foxman EF, Molony RD**, Early local immune defenses in the respiratory tract, Nat Rev Immunol. 2017 January; 17(1): 7–20

References: General

- Kaldalu N, Hauryliuk V, Tenson T, Persisters—as elusive as ever, Appl Microbiol Biotechnol (2016) 100:6545–6553
- Kembel SW et al, Architectural design influences the diversity and structure of the built environment microbiome, 2012, International Society for Microbial Ecology
- Kembel S.W. et al, Architectural Design Drives the Biogeography of Indoor Bacterial Communities, PLoS ONE 9 (1
- Klepeis NE et al, The National Human Activity Pattern Survey (NHAPS), Journal of Exposure Analysis and Environmental Epidemiology (2001) 11, 231-252
- Kramer A, Schwebke I, Kampf G, How long do nosocomial pathogens persist on inanimate surfaces, a systematic review, BMC Infectious Diseases 2006, 6:130
- Kudo E et al, Low ambient humidity impairs barrier function and innate resistance against influenza infection, PNAS May 28, 2019 vol. 116 no. 22, 10905–10910
- Lax S et al, Bacterial colonization and succession in a newly opened hospital, Sci. Transl. Med. 9, May 2017, 1-11
- Lax S, Gilbert JA, Hospital-associated microbiota and implications for nosocomial infections, Trends Mol Med. 2015 Jul;21(7):427-3
- Lazar V et al, Aspects of gut microbiota and immune system interactions in infectious diseases, immunopathology, and cancer. Front Immunol. 2018 Aug 15;9:1830
- Lowen AC et al, Influenza virus transmission is dependent on relative humidity and temperature, PLoS Pathog 3(10)
- Mahnert A et al, Man-made microbial resistances in built environments, NATURE COMMUNICATIONS (2019) 10:968
- McCann CM et al, Understanding drivers of antibiotic resistance genes in High Arctic soil
- Microbiomes of the Built Environment: A research agenda for indoor microbiology, human health, and buildings. The National Academies Press, 2017
- Niehus R, Thesis, 2016, Evolution on the microbial battlefield, University of Oxford
- Noti JD et al, High humidity leads to loss of infectious influenza virus from simulated coughs, PLoS ONE 8 (2)
- Or D et al, Physical constraints affecting bacterial habitats and activity in unsaturated porous media – a review, Advances in Water Resources 30 (2007) 1505–1527
- Peccia J, Kwan SE, Buildings, beneficial microbes, and health, Trends in Microbiology, August 2016, Vol. 24, No. 8
- Poole K, Bacterial stress responses as determinants of antimicrobial resistance, J Antimicrob Chemother 2012; 67: 2069–2089
- Prussin AJ, Garcia EB, Marr LC, Total virus and bacterial concentrations in indoor and outdoor air, Environ Sci Technol Lett. 2015 ; 2(4): 84–88
- Rook GA. Regulation of the immune system by biodiversity from the natural environment. PNAS. 2013;110(46):
- 18360–7
- Sharma A, Gilbert JA, Microbial exposure and human health, Current Opinion in Microbiology 2018, 44:79–87
- Schweizer C et al, Indoor time-microenvironment-activity patterns in seven regions of Europe, Journal of Exposure Science and Environmental Epidemiology (2007) 17, 170–181
- Scudellari M, Cleaning up the hygiene hypothesis, PNAS, February 14, 2017, vol. 114, no. 7, 1433–1436
- Simon AK, Hollander GA, McMichael A, Evolution of the immune system in humans from infancy to old age. Proc Biol Sci. 2015 Dec 22;282(1821):20143085
- Stone W et al, Microbes at surface-air interfaces: the metabolic harnessing of relative humidity, surface hygroscopicity and oligotrophy for resilience, Front Microbiol. 2016 Sep 30;7:1563
- The National Academy of Science Engineering Medicine, Microbiomes of the Build Environment, The National Academies Press, 2017
- Turnbaugh PJ et al, The human microbiome project: exploring the microbial part of ourselves in a changing world, Nature. 2007 Oct 18;449(7164):804-10
- Vandegrift R, Cleanliness in context: reconciling hygiene with a modern microbial perspective, Microbiome (2017) 5:76
- Vandini A, Hard surface biocontrol in hospitals using microbial-based cleaning products, PLoS ONE 9(9)
- Wolkoff P, Indoor air humidity, air quality, and health – An overview, Int J Hyg Environ Health. 2018 Apr;221(3)
- WHO Publication/Guidelines 2009, Natural ventilation for infection control in health-care setting.

Disclaimer

This ASHRAE guidance document is based on the evidence and knowledge available to ASHRAE as of the date of this document. Knowledge regarding transmission of COVID-19 is rapidly evolving. This guidance should be read in conjunction with the relevant government guidance and available research. This material is not a substitute for the advice of a qualified professional. By adopting these recommendations for use, each adopter agrees to accept full responsibility for any personal injury, death, loss, damage or delay arising out of or in connection with their use by or on behalf of such adopter irrespective of the cause or reason therefore and agrees to defend, indemnify and hold harmless ASHRAE, the authors, and others involved in their publication from any and all liability arising out of or in connection with such use as aforesaid and irrespective of any negligence on the part of those indemnified.