To The Board of Directors of REHVA,

We will comment on your provisional “"REHVA COVID-19 guidance document, March 17, 2020”.

We are physicians and our work for the past decade has been on the impact of indoor climates on health, with the goal to create buildings that truly support occupant health.

Our activities toward this goal are:

Dr. Hugentobler:

- Initiating partner of a multidisciplinary research project of Swiss National Science Foundation. This project involves ETZ, EPFL and University Hospital Zurich on the topic “INFECTIVITY OF INFLUENZA VIRUSES IN EXPIRATORY AEROSOLS UNDER AMBIENT TEMPERATURES AND HUMIDITIES (IVEA) [1]
- Co-author of the publication, “Seasonality of Respiratory Viral Infections”, Annu. Rev. Virol. 2020. 7:2.1–2.19, https://doi.org/10.1146/annurev-virology-012420-022445 [2]
- Medical advisor to Condair through utilizing my expertise in the role of humidification, building physics and ventilation design to maintain the health of occupants.

Dr. Taylor:

- CEO Taylor Healthcare Consulting: a company focused on understanding the intersection of human health and the indoor built environment through research and consulting;
- Harvard Medical School, Boston, Massachusetts: strategic advisor for patient safety and hospital quality control for Partners Hospital Network;
- Harvard Medical School, Incite Health Fellow, Division of Primary Care;
- ASHRAE: member of Environmental Health Committee and Distinguished Lecturer;
- Medical advisor to Condair to educate engineers about the health effects of water vapor, and to explain research findings.

Preliminary remarks:

- SARS-CoV2 is a respiratory virus and shares many properties with other respiratory viruses as shown in the publication of Moriyama [2]. Similar to all known human pathogenic Coronaviruses, it has a winter seasonality. The REHVA guidelines apply therefore to the temperate climate in European winters. The consequence of our cold winters is that all buildings and means of transportation need heating during this time. To this end, cold outdoor air with little moisture is drawn into occupied spaces and warmed to comfort temperatures. Munich for example has a median absolute humidity of 3.4g/kg (1.2 – 7.4) in winter trimester.
- WHO does not give any recommendation on ventilation in residential or commercial buildings, to protect occupants from COVID-19 in residential or commercial buildings. WHO has, however, endorse natural ventilation by window and door opening for decades.
- We agree with REHVA that Public Health (PH) authorities underestimate the importance of opportunistic airborne transmission of SARS-CoV2 as discussed by van Doremalen in a very recent JAMA paper [3]. Over a dozen papers in the aftermath of SARS in 2002/2003 concluded that the SARS-CoV1 transmission in Amoy Gardens, hospitals, hotels and residential homes could only be explained by airborne transmission. The so called “super-spreader events”, where in fact near field airborne transmission events.
- To say, “this virus is transmitted by droplets" creates confusion. Does this route apply only to short distance spraying of droplets, or to long range airborne transmission as well? In documents from WHO, CDC and ECDC aerosol transmission is mentioned only related to medical procedures. Moreover, it should be noted that coughing, speaking, sneezing and even regular breathing produces 10 to 1000 fold more tiny droplets with diameters <10, <5 and < 1 µm compared to the production of larger “ballistic” droplets known to settle within 2 meters. Studies have now shown that these tiny, desiccated droplets with diameters <5 µm, called “droplet nuclei”, contain viable viruses and bacteria and are capable of transmitting infections for great distances through the airborne route. PH authorities currently only focus on curtailing long distance infectious droplet transmission during medical procedures known as "aerosolizing", for examples intubation and bronchoscopy.

- We know that any human interaction with water, including the recommended frequent handwashing, showering, cleaning, cooking and toilet flushing, result in aerosolization of tiny droplets, which float in air moving throughout buildings, driven by thermodynamic or convection forces . These aerosolized droplets may contaminate surfaces by settling, and then be re-suspended once again by air turbulence induced by ventilation or human activity. If these droplets contain infectious viruses and bacteria, inhalation by occupants distant from the initial source can result in disease. The Hong Kong Health Department suggested this scenario as explanation for the SARS outbreak in Amoy Gardens 2002 [4].
- Measuring viable and therefore potentially infectious viruses in the air surrounding an infected person is extremely demanding. The technology and specialized equipment needed for air sampling, virus detection and determination of infectivity were not available outside of specialized laboratories until several years ago. This limitation prevented field studies from being done in varied settings. Airborne transmission for influenza was proven in a whole bunch of animal experiments. From studies on tuberculosis (TBC), which is known as being the only obligate airborne transmitted bacterium and from a classic experiment using humans and aerosolized influenza virus (Alford, 1966), we know that a single TBC bacterium or a few influenza viruses are sufficient to start a respiratory infection. We hope that scientists around the world will strive for detection of viable SARS-CoV2 viruses in high volume samples of ambient air in hospitals and other relevant settings. The ultimate prove for airborne transmission from person-to-person is still missing because of serious technological barriers and lack of adequate studies. We urgently need more reliable data on the causal relationship between number concentration of viable viruses, humidity, temperature, ventilation design and air change rates (ACR). Our research group has sent a letter to the China Science and Technology Association with a call to perform corresponding experiments. Link to the letter: https://www.dropbox.com/s/elnsc5vg8zqnegd/Letter%20to%20President%20China%20Science%20and%20Technology%20Association%2C%20Proposal%20field%20campaign%20IVEA.pdf?dl=0 . We repeat this request for all scientists worldwide to implement such studies in order to increase the protection of health care workers and the whole population from airborne infectious microbes.
- When airborne transmission is involved such as with SARS-CoV2, ventilation plays an important role in determining the risk of bystander occupants (secondary hosts) becoming infected. We must realize that ventilation affects not only the dilution and removal of airborne droplets, but also the decay of viruses in the air and on surfaces through the impact of RH. Increasing the amount of fresh outdoor air and therefore the air change rate (ACR), can drastically lower indoor RH in winter. Serial measurements show that RH below 20%, to a maximum of 40% in residential and commercial buildings are common [7]. This mechanism links ventilation and RH in buildings and both have major impacts on the SARS-CoV2 virus and on the occupants.

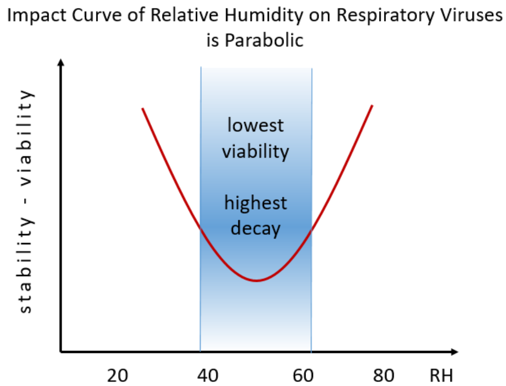
An overly bold claim: “Humidification and air-conditioning have no practical effect”

The guidelines say “… the SARS-CoV2 virus is quite resistant to environmental changes and is susceptible only for a very high RH above 80% and a temperature above 30 °C, which are not attainable and acceptable in buildings for other reasons (e.g. thermal comfort).

What the paper does not mention is a key effect of very low humidity versus intermediate humidity on Coronaviruses. Tests on the half-life of viruses on surfaces were performed in 21-23 °C and 40% RH, and at 65% RH for viruses in aerosols. The publication does not draw attention to the different RH’s used in surface and aerosol experiments [see Supplementary Appendix, 5].

Median half-lives (hrs) of SARS-CoV2 on different surfaces were between 0.774 and 6.91.

SARS-CoV1 and SARS-CoV2 remained detectable and infectious after three hours in the air. This clear finding astonished scientists worldwide. The half-life (hrs) of SARS-CoV2 was 1.09 (0.64 to 2.64, 2.5%-97.5% quartile range) in 65% RH. This finding is extremely scaring, since all respiratory viruses with the exception of non-rhinovirus enteroviruses have their lowest viability in intermediate humidity of 40-60% [2]. In ongoing experiments, the research team will study the two SARS viruses in different matrices as well as in different humidity.



Respiratory viruses have the highest viability and infectivity on surfaces and in the air when humidity is below RH 40%. Conversely, median range RH 40 to 60% inactivates these viruses. All studies from 1985 on confirm this relationship between RH ranges and viral infectivity, as shown in the graph to the left. This parabolic effect, rather than linear, continues to perplex scientists. Only the study by Iljaz in 1985 had different results. He found higher Coronavirus viability in medium RH using the human pathogenic strain 229E. The study reported a half-life in aerosols of 27 hrs at 20°C/30%RH, compared to 67 hrs at 50%RH.

In 2010, Casanova studied the stability and infectivity of Coronavirus on surfaces in varying levels of ambient RH. Using strains that cause disease in animals, he found that the Coronaviruses were extremely stabile at room temperature and very low humidity, yet not in medium humidity conditions. See graphs with the results of Casanova: https://www.dropbox.com/s/a1zw1t03t27744z/Coronavirus%20Casanova%20engl_.pdf?dl=0 . In the midrange humidity of 50% RH, less than 1% of Coronaviruses were viable after 2 days. Conversely, Coronaviruses in ambient RH 20% showed 80% viability after 7 days.

A subsequent study in 2013 by van Doremalen found the same virus viability and RH relationship for MERS CoV. She found that MERS CoV carried in aerosols were more active in 40% RH, and inactive at 70% RH. Again, this shows the same trend: lower inactivation (more infectivity) in lower RH. She wrote, “The relative stability of MERS CoV at 20°C – 40% RH and the rapid decrease in virus viability at higher temperatures and higher humidity suggests that MERS-CoV and SARS-CoV share relatively similar stability characteristics”.

Again in 2007, Kim revealed the same trend for TGEV (Transmissible gastroenteritis Coronavirus) in aerosols and wrote, “The results suggest that TGEV, and perhaps other Coronaviruses, remain viable longer in an airborne state and are sampled more effectively at low RH than at high humidity”.

If SARS-CoV2 behaves like other Coronaviruses described in studies, the upcoming results from the lab of van Doremalen will demonstrate that in dry air of 20% or 30% RH, the half-life of SARS-CoV2 on surfaces and in the air will be even longer than in the existing published experiments. This virus appears to spread efficiently by both contact and airborne transmission, remaining viable and infectious on surfaces and in aerosols for extended periods of time. This is especially true when the indoor humidity is low. We create indoor environments which increase our risk of becoming sick from COVID-19 disease when we heat without appropriate humidification and when ventilation rates are excessively high for occupancy numbers. Unfortunately, this is not only true for SARS-CoV2 but also for influenza and all respiratory viruses, which cause increased disease in winter seasons. Please see the publication referenced in the introduction [2].

The managing director of BTGA, Günther Merz, stated in an interview on March 18th on ARD TV channel that maintaining a RH of 45-50% in buildings is important for the prevention of viral transmissions. This clearly shows that REHVA’s guideline on SARS-CoV2 is not in agreement with the entire European sector of building technology

Infection risk, ventilation and RH

Building code standards for ventilation for infection control are based on the principles of dilution and removal of infectious droplets. High ACR of 12 and negative air pressure are mandated conditions in isolation rooms used for patients with highly contagious infections. The belief is that these settings reduce the risk of airborne transmission out of the isolation room, thereby protecting healthcare workers and other patients.

Distinct from room ventilation, humidity levels have a direct impact on has on:

- Disease resistance of infected and other susceptible persons [2]
- Inactivation of viruses on surfaces and in the air [2]

- Transmission risk through droplet dynamics [6]. See also graph with link below:
https://www.dropbox.com/s/0a3wru89m71wp24/Fig.%20Transmission%20of%20respiratory%20infections%20under%20different%20indoor%20humidity..pptx?dl=0

Impact of air changes and RH on the transmission risk

A study by Yang W modeled 2011 the dynamics of exhaled influenza droplets indoors and the impact of humidity and ACR [6]. They stated that, "settling is important for removal of large droplets", and, "ventilation and inactivation are relatively more important for removal of IAVs associated with droplets <5 µm". Both, ventilation and intermediate humidity help reduce the risk of infection from influenza. "Humidity is an important variable in aerosol transmission of IAVs because it both transforms droplet sizes and affects IAV inactivation rates".

In wintertime, the season of all respiratory viruses including Coronaviruses pathogenic to humans, elevated air change rates have the dangerous side effect of lowering indoor RH. As outdoor air with low absolute humidity is brought indoors and heated to comfort temperatures, the resulting indoor RH falls from a low of 20% to a maximum of 40% [7]. Low outdoor absolute humidity, converted to excessively low indoor RH with heating, triggers the winter seasonality of respiratory viruses. The resulting low indoor RH is the causative factor for human illness from these viruses [2]. We cannot change outdoor climate, however, indoor climates and RH are created by humans and can therefore be improved by humans. Building codes, building technology and facility management are key in creating indoor climates, which help human occupants resist seasonal infectious disease.

Since the importance of RH in regard to resistance of human airways against infections and the impacts of RH on microbes in the built environment was not considered in the past, the optimum balance between desirable AC and maintaining a minimal RH above 40-45%, is uncharted territory and needs intensive research.

Maintaining a minimal RH of 40 to 45% in buildings with high ACR such as hospitals would require intensive humidification efforts and substantially increased energy needs. An alternative approach is to maintain sensor controlled ACR of approximately 2 to 3 AC/hour, requiring less energy and permitting intermediate humidity levels to be reached. The moderate humidity range also serves to better inactivate respiratory pathogens in the air and on the surfaces. Ultimately, the optimal balance between ACR and RH depends on whether airborne or contact transmission is predominant. If contact transmission is dominant, the "time of viability" on surfaces becomes the greatest risk factor and the importance of RH increases. If airborne transmission is the dominant route of ongoing human exposure, the requirement for higher air change rates also comes into play. Science must address this uncharted territory.

Infection risk in mechanically ventilated buildings

The guidelines mention some risks associated with specific ventilation strategies, for example with recirculation (I thought this is a no-go in Europe?) and rotary heat exchangers. Not reviewed are the risks of commonly used overflow ventilation. If the fresh supply air in the initial room subsequently overflows into second and third rooms, potential transfer of airborne viruses from one room to the next puts more persons at risk. As we think about floating pathogens and social distancing, questions regarding optimal enclosure versus open space designs for offices and general use areas in our buildings, appear in a new light [9]. The article by Joseph G. Allen in the New York Times, March 4th, 2020 "Your Building Can Make You Sick or Keep You Well", called public's attention to this issue.

REHVA developed guidelines for "health-based ventilation". With our current perspective of needing to contain a highly infectious virus that may be added to room air by merely any infected occupant, single room ventilation is the only design without additional risk. Single room ventilation has several advantages. First, it is available with heat recovery. Second, it avoids hygiene risks associated with extensive ductwork. In an epidemic or pandemic, single room ventilation is the only appropriate, health-based ventilation design for residential and commercial buildings. In these challenging times, all hospital rooms capable of patient occupancy, essentially become isolation rooms. The need for anterooms for efficient air surge control [12] underlines the difficulty in maintaining a unidirectional airflow when rooms with temperature or pressure differences are connected and door openings happen.

An ASHRAE Position Document on Airborne Infectious Diseases (approved by ASHREA board of directors 2014) claims that hospitals should have the ability, quote "…. to increase ventilation even as high as 100% outdoor air; the ability to humidify air; and receptacles at the upper room and ceiling heights of at least 2.4 m (8 ft.) to enable effective upper-room UVGI".

In view of Coronavirus transmission, building and ventilation design may increase the infection risk. This virus, with high stability on surfaces and in the air, teaches us that the built environment and shared air environments serve as vectors for SARS-CoV2 [9]. The contagiousness of SARS-CoV2 expressed as basic reproductive number R_0 is estimated as 1.5-3. On cruise ships, where extremely high occupant density and extensive ventilation needs intersect, the reproductive number increased up to 5-14 [10, 11]. This corresponds to the contagiousness of measles (R_0 of roughly 12-18). Without airborne transmission, such a high reproductive numbers is not possible, even in the occupant density of a cruise ship. More than 50% of the total energy consumption on cruise ships is from HAVAC systems. The design of a HAVAC system on these ships without recirculation of air or with HEPA filters would sharply increase energy consumption and costs. Several cruise ships were examples of the fact that the built environments and current technology may sharply increase infection risks.

Air Filters: do we filter the right microbes?

Air filters should not give as a false impression of being protect from all viruses. HEPA filters are rated to remove at least 99.97% of particles down to 0.3 microns. They will remove even small "droplet nuclei" of fractions of a micrometer quite efficiently and are therefore used in airplanes, hospitals, operating rooms and labs.

Low efficiency filters as used in residential and commercial buildings do not retain a significant portion of droplet nuclei with Coronaviruses unless they are aggregated or adherent to carriers like house dust. This is particularly worrisome in situation where air is re-circulated. It applies to air that is re-circulated to the same room ("Sekundärluft" in German) and to air that is re-circulated to a different room or building sector (called "Umluft" in German). Furthermore, the efficiency and risk profile of any filter depends on quality of maintenance and timely replacement.

Preliminary studies that compare the bacterial microbiome in filtered versus non-filtered air show worrisome results. Low efficiency filters retain a certain number of bacteria, fungi and some viruses from the supply air. Analysis of the bacterial microbiome of filtered and non-filtered air reveal that the bacteria in filtered air are closer to known pathogens than in non-filtered air (Kembel 2012/2014). In addition, mechanically ventilated rooms had lower bacterial diversity and more human-associated bacteria compared to window-ventilated rooms. To our knowledge no studies exist that compared the viral microbiome in filtered and non-filtered air.

We cannot be certain that filtration removes the harmful microbes, and consequently we do not know the outcome on the health of occupants. The need for scientific research on the impact of filtration on the indoor microbiome is immediate.

What has priority in view of the current pandemic with SARS-CoV2?

The current bottleneck of our health care system in this pandemic is the availability of well-equiped intensive care units, in particular the number of ventilators and functioning healthcare workers. Building technology has an important role in

- Decreasing the infection risk for healthcare workers
- Decreasing the number of severely ill patients and therefore the overwhelming demand for protective equipment
- Improving airborne and contact precaution for health care worker and patients

We know that during the SARS pandemic, 58% of cases were nosocomial, and in the recurrent MERS epidemics up to 70% of infections are hospital associated. (Munster, 2020). Now that studies show that dry indoor air increases the risk of transmission of respiratory infections and simultaneously harms the protective human airway resistance against respiratory pathogens, we should reconsider our strategies for creating a protective indoor environment. Trying to dilute airborne Coronaviruses by extremely high ACR has the unintended consequence of extreme air dryness. Indoor humidification controlled through sensors to maintain the range of 40 to 60%, in combination with demand-controlled ventilation (CO_2 sensors) might improve the protection of health care workers and patients from Coronavirus disease. This strategy deserves immediate and intensive research commitments

Public authorities of all levels, Public Health, builders and contractors, building outfitters and facility management have not yet fully acknowledged and recognized that the management of the built environment is in the very center of disease control [9]. Maintaining a favorable, health supportive indoor climate is costly and energy demanding. What humanity goes through right now, measured by human losses and economic costs, should motivate us to invest substantially more in the built environment. From a holistic view, this involves not only building technology, but also fundamentally the way we build houses, the materials we us and includes all sustainability aspects.

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