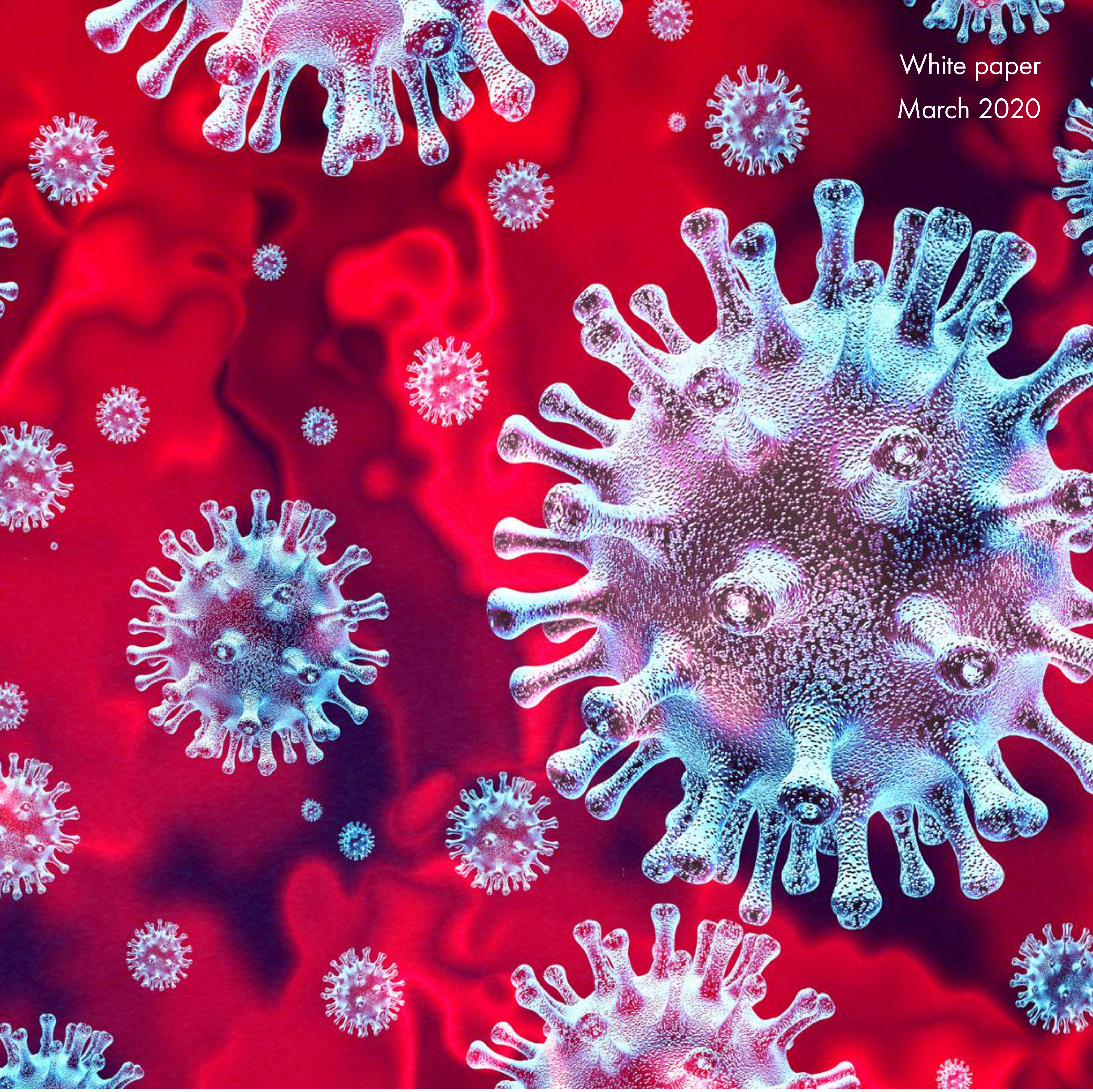

How humidity control can reduce viral infectivity and longevity

Munters

Executive summary

Based on gathered research, which will be presented in this paper, there is a demonstrable link between humidity and the infectivity and longevity of a variety of viruses. The research demonstrates that at Relative Humidity (RH) levels between 40 and 50%, many types of common and harmful viruses such as influenza and coronaviruses are rendered inert much more quickly than at RH levels of ≤ 20%.

This is particularly relevant in locations where winter tends to consist of low outdoor temperatures and low indoor humidity, as these conditions provide a favourable environment for viral transmission. By effectively controlling indoor climates in these locations, it is possible to limit the transmission of harmful viruses.

Analysis of research

The survival of the following lipid enveloped viruses, which are mentioned in peer-reviewed research papers(1), is linked to RH and temperature:

- Influenza
- Coronaviruses (including severe acute respiratory syndrome-associated coronavirus)
- Respiratory syncytial virus
- Parainfluenza viruses
- Measles, rubella
- Varicella zoster virus

On the other hand, non-lipid enveloped viruses tend to survive longer in higher RHs (typically over 70%). These include:

- Respiratory adenoviruses
- Rhinoviruses

Relationship between temperature and humidity

For reference the following definitions have been adopted in this document:

- Absolute Humidity (AH) – The amount of grams of water vapour per kilogram of (dry) air (g/kg)
- Relative Humidity (RH) – The ratio (in %) between the actual quantity of water vapour in the air and the maximum quantity of water vapour that the air can contain at a certain temperature. At 100% RH, air is saturated and can hold no additional moisture. Condensation will then occur if the temperature is reduced.

AH is a useful measure for converting RH levels between environments at different temperatures, such as indoor and outdoor conditions. If there are no additional sources of moisture or humidity in an indoor environment with outdoor ventilation, then changes in outdoor RH will influence indoor RH levels.

The relationship between temperature and humidity is demonstrated in the following illustration. In all three cases, both absolute humidity (6 g of water) and air mass (1 kg of air) are constant.

As temperature increases the air volume expands, and so the relationship between the relative humidity and the occupied space changes.

When calculating indoor humidity levels, we need to take into account the prevailing outdoor levels of RH and AH. If we assume that outdoor air is admitted into an empty indoor space and heated with no significant moisture loads present (e.g. no moisture is introduced from ingression, building materials, combustion or occupants) then we can establish a direct relationship between indoor and outdoor humidity levels at different temperatures.

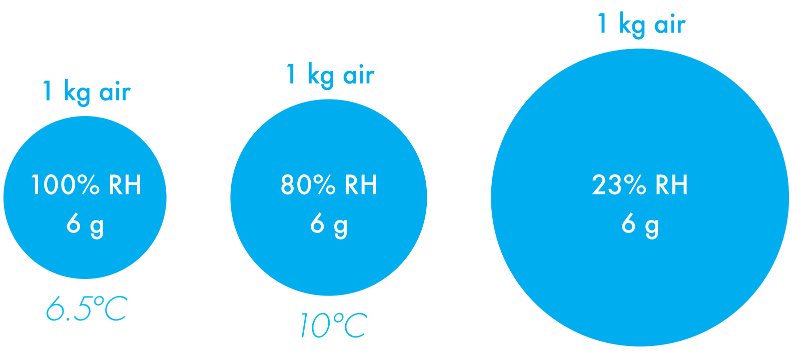

Figure 1: Visual representation of the relationship between air mass, temperature, AH and RH%

To demonstrate this, the table below shows indoor humidity levels that would occur in an indoor space described in the paragraph above, based on the outdoor levels reported in London on 12th–13th March 2020.

Time	9:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	09:00
Outdoor temp (C)	8°	9°	9°	7°	7°	6°	7°	6°	8°
Outdoor RH%	60	49	52	67	68	77	70	73	62
Air pressure (hPa)	1,011	1,011	1,010	1,011	1,011	1,013	1,014	1,016	1,017
Outdoor AH (g/kg)	4.00	3.50	3.71	4.18	4.24	4.47	4.35	4.23	4.11
Indoor RH% @ 20°C	28	24	26	29	29	31	30	30	28
Indoor RH% @ 24°C	22	19	20	23	23	24	24	23	22

Table 1: Climate conditions for London, UK on 12th–13th March 2020. Source: Met Office, UK

Based upon the outdoor conditions shown in Table 1, at an indoor temperature of 20°C the indoor RH% level varies between 24 to 31% RH. If the indoor temperature increases to 24°C, the indoor RH% level varies between 19 to 24% RH.

By using a psychrometric chart, we can easily visualise the effect on RH% levels when altering air temperature at specific AH levels. By using the measurement value in Table 1 for AH at 09:00 on March 12th (4 g/kg), the connection between RH levels at 4 and 20°C becomes apparent.

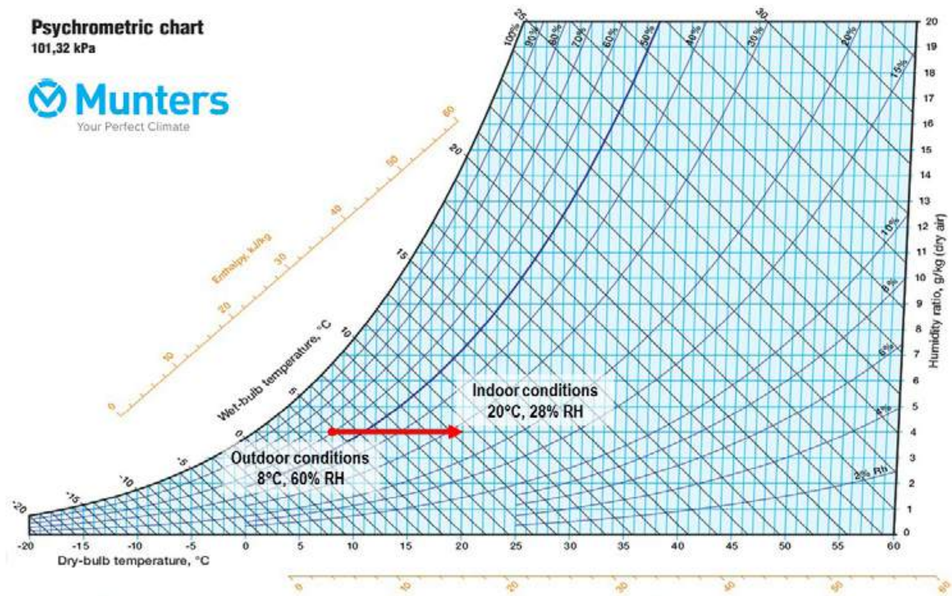

Figure 2: Psychrometric chart showing 8 and 20°C RH% conditions along the AH 4 g/kg line.

Humidity's role in influenza virus transmission

If relative humidity is controlled within the 45 to 50% range, infectivity drops rapidly

Viruses that cause respiratory illnesses are usually transmitted by viral particles which tend to be emitted by coughing, sneezing, talking, and breathing[8]. These activities generate a cloud of airborne water particles with diameters ranging from a few millimetres to <1 μm. Large droplets (>50 μm in diameter) settle on the ground almost immediately, and particles in the 10–50 μm range settle within several minutes. Small particles (<10 μm), including droplet nuclei from evaporated larger particles, can remain airborne for hours and are easily inhaled deep into the respiratory tract. If not inhaled, these will also settle on surfaces[9] over time. Aside from particle size, airflow and climate also affect the amount of time these particles remain airborne.

The climate conditions presented in Table 1 can be cross-referenced with Figures 3 and 4 to extrapolate the infectivity and transmission efficiency of aerosolised influenza particles.

Figure 3 below shows the effect of influenza infectivity with respect to RH, based on the size of the aerosolised particles.

Based on the data in Table A, infectivity over the RH range of 24 to 31% is over 70% for all particle sizes at a constant indoor air temperature of 20°C. If RH is controlled within the 45 to 50% range, infectivity drops rapidly to below 20% at the same air temperature.

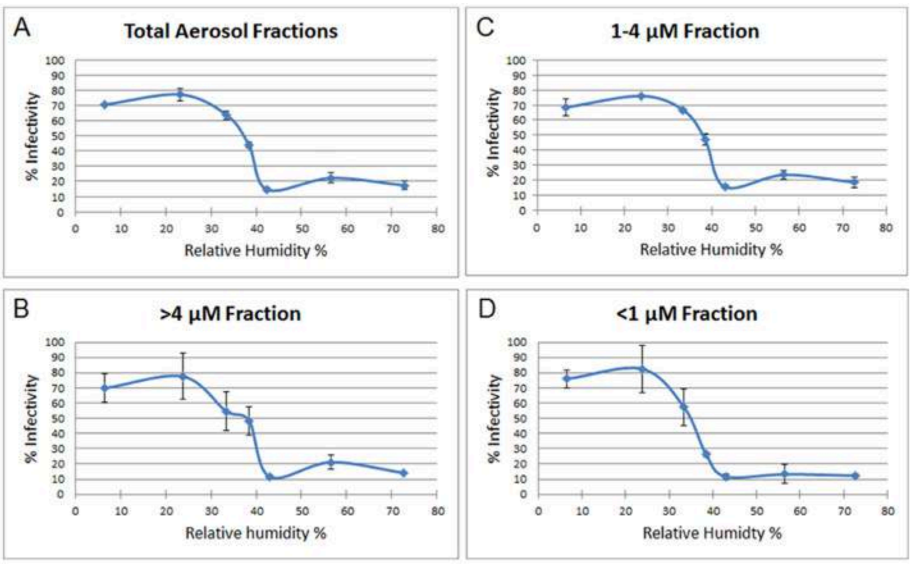

Figure 3: High humidity reduces the infectivity of influenza. Influenza virus was coughed into the examination room and NIOSH samplers collected aerosol samples for 60 minutes from the mannequin's mouth, 10 cm to the right and left of the mouth, and at positions P1 and P2 within the room. At constant temperature (20°C), the RH was set at various points between 7% and 73%. The percentage of virus that retained infectivity relative to that prior to coughing is shown. Table A: The percentage of infectious virus from all fractions (>4 μm, 1-4 μm, <1 μm) was determined by the viral plaque assay (VPA) and is shown. Tables B–D: The percentage of infectious virus within each aerosol fraction is shown. Data are means 6 standard error (n = 5). doi:10.1371/journal.pone.0057485.g003(8)

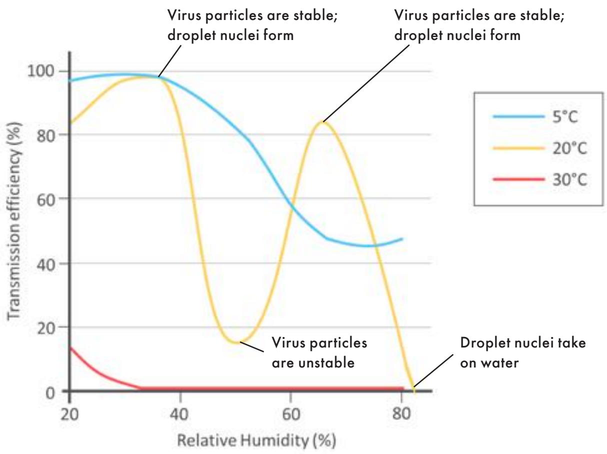

Figure 4: Based on a live test, the efficiency of respiratory droplet transmission varies with humidity and temperature. Transmission efficiency, calculated as the percentage of exposed subjects that contracted infection, is plotted against relative humidity[2][3].

The relationship between particle stability and transmission efficiency is shown in Figure 4, and again the influence of RH plays a major role, showing a significant drop in transmission efficiency at around 50% RH. Using the data from Table 1, based on indoor air at 20°C over the RH range of 24 to 31%, transmission efficiency lies between 80 to 90%, which represents a significant increase.

Other research[4] shows a strong link between AH and the survival, transmission and basic reproductive number (R_0) of influenza. For reference, R_0 represents the number of secondary infections the average infectious person would produce in a fully susceptible population. The figure below demonstrates the relationship between AH and R_0.

Again, the data presented in Figure 5 shows a direct link between AH and viral transmission, and by extension indoor RH levels that are directly linked to low outdoor AH levels will lead to the same level of viral transmission.

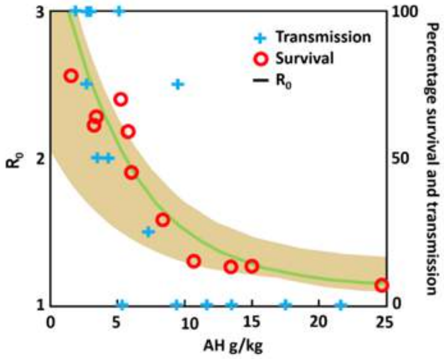

Figure 5: Virus survival, transmission, and the basic reproductive number, R_0, plotted as a function of absolute humidity. Influenza virus survival data are from Harper[5], influenza virus transmission data is from Lowen et al.[2,3], and R_0 is based on best-fitting, absolute humidity-forced, susceptible-infected-recovered susceptible simulations from Shaman et al.[6]. The solid line is R_0 for the best-fitting simulation; the tan coloured region shows the range of R_0 values as a function of absolute humidity for the 10 best-fitting simulations. The measure of absolute humidity is 2 m above-ground AH in g/kg and is taken from National Center for Environmental Prediction–National Center for Atmospheric Research (NCEP-NCAR) reanalysis[7].

Humidity's role in coronavirus transmission

Inactivation was more rapid at 20°C than at 4°C

Coronaviruses have a lipid envelope and are similiarly affected by humidity changes. However, due to the inherent risks of working with SARS-CoV and related viruses, research requires specially trained personnel working under biosafety level 3 (BSL-3) laboratory containment conditions. This means there are significant challenges in studying this virus, and only limited data on its survival and response to environmental stressors is available.

The use of surrogate coronaviruses has the potential to overcome these challenges and expand the available data on coronavirus survival on surfaces. A study using transmissible gastroenteritis virus (TGEV) and mouse hepatitis virus (MHV) has been used to help determine effects of AT and RH on the survival of coronaviruses on stainless steel.

At 4°C, infectious virus persisted for as long as 28 days, and the lowest level of inactivation occurred at 20% RH. Inactivation was more rapid at 20°C than at 4°C at all humidity levels; the viruses persisted for 5 to 28 days, and the slowest inactivation occurred at low RH. Both viruses were inactivated more rapidly at 40°C than at 20°C. The relationship between inactivation and RH was not monotonic, and there was greater survival or a greater protective effect at low RH (20%) and high RH (80%) than at moderate RH (50%)[10].

If we again apply the climate data from Table 1 (based on indoor air at 20°C over the RH range of 24 to 31%), there is again a strong case for maintaining indoor RH at around 50% in order to reduce the longevity of these types of coronaviruses on hard surfaces.

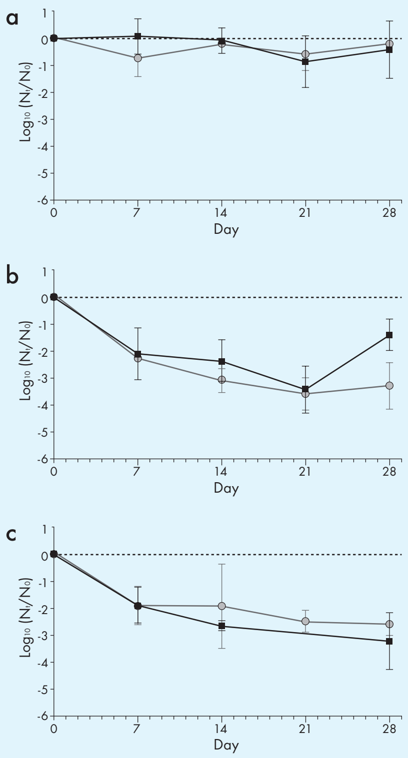

Figure 6: Survival of TGEV and MHV at 4°C and (a) 20% RH, (b) 50% RH, and (c) 80% RH. Squares, TGEV; circles, MHV. The error bars indicate 95% confidence intervals[10].

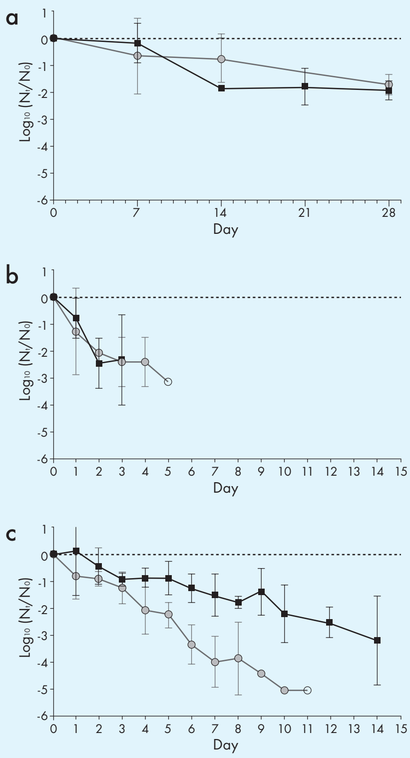

Figure 7: Survival of TGEV and MHV at 20°C and (a) 20% RH, (b) 50% RH, and (c) 80% RH. Filled squares, TGEV; filled circles, MHV; open circles, value for the sample was below the detection limit of the assay (5 log10 MPN). The error bars indicate 95% confidence intervals[10].

Conclusion

It is possible to reduce the transmission and longevity of harmful viruses by controlling indoor RH levels. This can be done by using humidity control solutions which facilitate precise RH control for indoor environments. This humidity control is useful at all times, but particularly in typical 'flu season', where outdoor temperatures and absolute humidity tend to be lower.

Research referenced in this document suggests that maintaining an indoor RH% level between 40 to 50% yields the maximum protective effect from aerosolised and settled virus particles. By maintaining these levels, it is possible to contribute to a healthier, safer environment.

About Munters

Munters has more than 60 years of experience in humidity control, with scalable solutions for all types of industrial, commercial and public service environments. We offer consultation, engineering support, installation and life cycle management for our flexible range of products, with a global presence that keeps us close to our customers.

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