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14. ABSTRACT

In all studies investigating temperature and humidity effects on COVID-19 and related coronaviruses, low air temperature (AT) and low relative humidity (RH) favored the survival of both SARS-CoV-2 and related coronaviruses; however, inactivation was more rapid at increasing RH levels and at high AT [1-8]. In each case, high temperature at high RH were found to have a synergistic effect on the inactivation of coronavirus viability while lower temperatures and low relative humidity support prolonged survival of viruses on contaminated surfaces [3]. The results of these studies suggest that RH has a greater effect on viral stability/inactivation that AT [2].

15. SUBJECT TERMS

Temperature, Humidity, COVID-19, SARS-CoV-2

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Temperature and Humidity Effects on SARS-CoV-2 and Related Coronaviruses

Last Updated: 11 May 2020

Purpose: This document was crafted in response to multiple inquiries regarding the **persistency of SARS-CoV-2 as it relates to changes in the temperature and humidity of the environment**. 711 HPW/RHM has developed this framework for operational/maintenance risk analysis based on the best known available information. Ultimately, the acceptance of risk rests solely with the commander who is best positioned to understand the complexities of the operational, maintenance, and mission requirements of their unit. It is impractical and ill-advised to attempt to develop a one-size-fits-all response for all scenarios. However, there are some heuristics that may be applied to inform the commander of the spectrum of risks and allow them to make an informed decision based on the available evidence and intelligence. Given that COVID-19 research is rapidly changing, please note when this document was last updated.

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1. Summary:

Numerous factors have been identified that influence the survival of SARS-CoV-2, which causes the COVID-19 disease and other related coronaviruses, to include: strain variation, titer, surface type, suspending medium, mode of deposition, air temperature (AT) and relative humidity (RH) along with the method used to determine the viability of the virus.[7] **This knowledge compellation will focus primarily on temperature and humidity effects on SARS-CoV-2 and related coronaviruses**.

Current literature describes coronaviruses as large, enveloped viruses containing a single-stranded RNA genome of positive polarity.[6] It possess an envelope spike glycoprotein that binds to cellular receptors allowing for membrane fusions with the host cell.[9] Coronaviruses can be classified into four genera: alpha, beta, gamma, or delta, but of these four only alpha- and beta- coronaviruses are known to infect humans.[9] SARS-CoV-1, SARS-CoV-2, and MERS-CoV are all beta- coronaviruses believed to originate in bats; however, SARS-CoV-1 and SARS-CoV-2 are found to be more genetically alike, with roughly 96% genomic similarity.[9,10] While previous studies give an idea of how SARS-CoV-2 will behave on different surfaces and in different environmental conditions, the studied viruses are different from SARS-CoV-2 in transmission rate, receptor binding affinity, severity, etc.[9] In humans, they have been reported to be responsible for 16-20% of common colds and have also been isolated from cases of gastroenteritis.[6]

In all studies investigating temperature and humidity effects on COVID-19 and related coronaviruses, low AT and low RH favored the survival of both SARS-CoV-2 and related coronaviruses; however, inactivation was more rapid at increasing RH levels and at high AT.[1-8] In each case, **high temperature at high RH were found to have a synergistic effect on the inactivation of coronavirus viability** while lower temperatures and low humidity support prolonged survival of viruses on contaminated surfaces.[3] The **results of these studies suggest that RH has a greater effect on viral stability/inactivation than AT.**[2]

2. **Operational Implications of Findings:** The findings of this literature review are intended to help provide a better understanding of current research on how AT and RH effects SARS-CoV-2 and other related coronaviruses. Given the numerous knowledge gaps, **the magnitude of the risk due to virally contaminated surfaces is uncertain and should be examined further**. Commanders should **continually reach out to their CBRN and medical experts for updates on SARS-CoV-2 research**, and to ensure that they are given the necessary context regarding the research findings in order to prevent unintended misinterpretation of the data.

3. Key Points from Literature:

3.1. At the time this document was composed, very few studies were available exploring temperature and humidity effects on SARS-CoV-2 stability. The vast majority of the studies observed known established coronaviruses such as SARS (Severe Acute Respiratory Syndrome), MERS (Middle East Respiratory Syndrome), Human Coronaviruses HCoV-NL63, HCoV-229E, or HCoV-OC43 as well as known surrogates such as TGEV (Transmissible Gastroenteritis Virus) and MHV (Mouse Hepatitis Virus).

- SARS-CoV and MERS-CoV can survive *in vitro* for 48 hours in a dry environment and up to 5 days under 20°C and 40%-50% humidity.[9]
- SARS-CoV-2 is believed to possess similar properties *in vitro*.[9]

3.2. In 2015, The World Health Organization (WHO) compiled laboratory data on resistance of the SARS-CoV-1 against different environmental factors (refer to Appendix A: Table 1).[5]

As suggested by a number of other studies, SARS-CoV-1 stability is favored in low temperatures.

- The labs involved in this study included: Chinese University Hong Kong; Government Virus Unit, Dept. of Health, Hong Kong, SAR China; Queen Mary Hospital, The University of Hong Kong, Hong Kong, SAR China; National Institute of infectious Diseases, Tokyo, Japan; and University Marburg, Germany

3.3. Ijaz et al. (1985) examined the survival of airborne human coronavirus 229E (HCV/229E) under different conditions of temperature (20 ± 1 °C and 6 ± 1 °C) and low (30 ± 5%), medium (50 ± 5%), and high (80 ± 5%) RH (refer to Appendix B for Tables 2 & 3).[6]

- At 20 ± 1 °C, HCV/229E recovery was better at 30 ± 5% RH and 50 ± 5% RH (87% and 91% respectively) but at high RH, only 55% of the original input HCV/229E was detected (initial loss = 45%).[6]
- On the other hand, at 6 ± 1 °C there was an overall enhancement of HCV/229E recovery at all three RH levels. This enhancement was most remarkable at high RH where, contrary to the results at 20°C, there was essentially no initial loss (100% recovery).[6]
- At both 6 ± 1 and 20 ± 1 °C, aerosolized HCV/229E was found to survive best at 50% RH with a half-life of 67.33 ± 8.24 hr and 102.53 ± 9.38 hr while at 30% RH the virus half-life was 26.76 ± 6.21 hr.[6]
- High RH at 20 ± 1 °C, on the other hand, was found to be the least favorable to the survival of aerosolized virus and under these conditions the virus half-life was only about 3 hr; no virus could be detected after 24 hr in aerosol.[6]

- At low temperature (6 ± 1 °C) and high RH (80%), however, the survival pattern was completely reversed, with the HCV/229E half-life increasing to 86.01 ± 5.28 hr, nearly 30 times that found at 20 ± 1 °C and high RH.[6]
- At low temperature (6 ± 1 °C), virus survival at medium (50 ± 5%) and low (30 ± 5%) RH was markedly enhanced but, in addition, virus survival at high (80%) RH was the reverse of that seen at room temperature; under these conditions, HCV/229E was very stable.[6]
- Although optimal survival at 6 °C still occurred at 50% RH, the pronounced stabilizing effect of low temperature on the survival of HCV/229E at high RH indicates that the role of the environment on the survival of viruses in air may be more complex and significant than previously thought

3.4. Cassanove et al's. (2010) study substitutes TGEV and MVH as surrogates from SARS-CoV-1 confirm Ijaz et al. (1985) findings of coronavirus stabilization at low temperature and low humidity (refer to Appendix C for figures 1-3).

- At 4°C, infectious virus deposited on stainless steel surfaces at initial levels of 4 to 5 $\log_{10}$ most probable numbers (MPN) persisted for as long as 28 days, and the lowest level of inactivation over the 28-day experiment took place at 20% RH.
- The levels of both viruses declined by 0.5 $\log_{10}$ over 28 days at 20% RH. Greater reduction took place at 50% RH, at which the levels of both viruses declined by 3.5 $\log_{10}$ after 21 days.
- At 80% RH, the TGEV level declined by 3.2 $\log_{10}$ over 28 days, and the MHV level declined by 2.5 $\log_{10}$.
- Inactivation was more rapid at 20°C at all RH levels than at 4°C.
- The highest rate of inactivation was observed at 50% RH, at which the TGEV level declined by 2 $\log_{10}$ by day 3, and the level of MHV declined by 3 $\log_{10}$ by day 5.
- Unlike the results at 20°C, the loss of infectivity at 40°C was more rapid at 80% RH than at 50%RH.
- At 40°C and 80% RH, the infectious titers of MHV and TGEV were 4.1 and 2.8 $\log_{10}$ lower at 3 hr, respectively.
- The relationship between inactivation and RH was not monotonic, and survival was greater at low RH, a finding reflected in the results of previous studies of coronaviruses and other enveloped viruses in aerosols.
- Greater survival of other enveloped viruses, including vaccinia virus, Venezuelan equine encephalitis virus, and influenza virus, at low RH has been observed previously.
- Overall, virus survival was enhanced by a lower AT. Similar relationships between AT and virus inactivation have been observed for enveloped viruses in liquids and aerosols.
- At 40°C, the same protective effect of low RH was seen at 20% RH compared to that at 50% and 80% RH.
- Overall, however, inactivation was more rapid at all three RH levels at this high AT.
- The results of the statistical analysis suggest that RH has a greater effect on viral inactivation than AT, but there are interactions between AT and RH.

3.5. Chan et al. (2011), researching AT and RH effects on the viability of SARS-CoV-1 (strain HKU39849) also noticed a stabilizing effect of SARS coronavirus in low temperature and low humidity environments.

- This study evaluated how temperature affects titer reduction of SARS (strain HKU39849) at starting titer 10^5/10 µL and incubated with a relative humidity >95% at different temperatures (38°C, 33°C, and 28°C) and the viral titer was determined at varying incubation times (3, 7, 11, 13, and 24 hrs) (refer to Appendix D for figures 4-6).
- Virus dried on plastic retained viability for up to 5 days at 22~25°C at relative humidity of 40~50% with only 1 log loss of titer.
- High relative humidity (>95%) at comparatively low temperature (28°C and 33°C) did not affect the virus infectivity significantly.
- High temperature (38°C) at 80–90% relative humidity led to a 0.25~2 log loss of titer at 24 hr.
- However, if the dried virus was stored at high temperature (38°C) and high relative humidity (>95%), there was a further ~1.5 log loss of titer for each time point up to 24 hr (0.38~3.38 log) when compared with high temperature (38°C) at a lower relative humidity 80–90%.
- This study demonstrated that SARS CoV can survive at least two weeks after drying at temperature (22–25°C) and humidity (40–50%,) conditions found in an air-conditioned environment.
- The virus is stable for 3 weeks at room temperature in a liquid environment but it is easily killed by heat at 56°C for 15 minutes.
- Virus viability was rapidly lost (>3 log) at higher temperatures and higher relative humidity (e.g., 38°C, and relative humidity of >95%).
- The studies indicate that SARS-CoV is relatively more stable than the human coronaviruses 229E or OC43 and some other viral respiratory pathogens such as respiratory syncytial virus.

3.6. In their studies Van Doremalen & Munster (2013), showed that MERS-CoV was more stable at low temperature/ low humidity conditions and could still be recovered after 48 hours (refer to Appendix E for Figures 7 & 8 and Table 4).

- After four hours, no viable A/Mexico/4108/2009 (H1N1) virus was detected in comparison to 8, 24 or 48 hours for MERS-CoV depending on environmental conditions.
- This study shows that the relationship between temperature and humidity and the inactivation rate of this coronavirus is important when utilizing differing decontamination measures. The viability of the virus on a surface or aerosolized is the main avenue of possibly contaminating additional objects or infecting new individuals.
- By changing the environmental parameters, temperature and humidity, one would be able to dictate the length of viability of the virus, therefore potentially cutting down on the routes of transmission.
- MERS-CoV was very stable in aerosol form at 20°C – 40% RH. The decrease in viability at 20°C – 70% RH (89%) was comparable to that of A/Mexico/4108/2009 (H1N1) virus.
- Severe acute respiratory syndrome coronavirus (SARS-CoV) has been reported to stay viable for up to five days at 22 to 25°C and 40 to 50% RH and increase in temperature and humidity resulted in a rapid loss of viability.

- Although a comparison between different experimental studies should be approached cautiously, 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.
- Although the route of transmission for MERS-CoV is currently unknown, the spread of MERS-CoV between people in close contact settings suggest contact and fomite transmission routes are most likely involved.

3.7. Otter et al's. (2015) review of MERS-CoV, SARS-CoV-1, TGEV, MVH, HCoV-NL63, Human metapneumovirus, HCoV-229E, Herpes simples virus, adenovirus, and HCoV-OC43 concluded that many factors influence survivability for these viruses on a given. These important factors include: strain variations, 'dose-response' relationship between the titre applied and survival time, the surface substrate (including the ability to survive on materials used to make PPE), the suspending medium (with the addition of mucus increasing substantially the survival time of influenza), the mode of deposition, temperature and RH, and the method used to determine the presence of the virus (specifically culture versus the use of PCR to detect viral RNA) (refer to Appendix F for Table 5).

- These results summarize what has already been previously mentioned concerning the coronavirus family (minus SARS-CoV-2), that low temperature and low RH are favored for the survival of those viruses.

3.8. From Chin et al's (2020) research on SARS-CoV-2, reported that the virus is highly stable at 4°C, but sensitive to heat (refer to Appendix G for Table 6).

- At 4°C, there was only around a 0.7 log-unit reduction of infectious titer on day 14. With the incubation temperature increased to 70°C, the time for virus inactivation was reduced to 5 minutes.

3.9. Lastly, Altamure et al. (2020) also showed similar results to Chin et al's (2020) results on SARS-CoV-2, but incorporated relative humidity in their study (refer to Appendix G for Table 7 and Figure 9 & 10).

- Emerging Results: Surface decay in saliva on stainless steel is accelerated by increased humidity and temperature.[1]
- As information and updates regarding SARS-CoV-2 stability outside of the human body are continually being released, this data is subject to change.

4. Limitations:

- It is important to note that many of these studies used surrogate viruses or studied SARS-CoV-1 or MERS-CoV. Thus, it can be dangerous to assume the viruses will act identically. This information should just be used as a tool to better understand and predict the behavior of SARS-CoV-2, not an established rule for behavior.

- Many of these studies compiled information from studies already conducted or studies completed in different labs. This can lead to ambiguous results due to different testing procedures, equipment, or interpretation of the raw data.
- All studies evaluated the effects of temperature and humidity on the reduction to the initial virus titer load. Different starting titer loads can impact the time required for a given temperature or humidity to effectively reduce the titer load to undetectable.
- Studies also simulated the virus titer, vector, and fomite which is not a perfect representation of contamination in the real world.
- The physicochemical properties of SARS-CoV-2 and other related coronaviruses are largely not yet known.

5. Conclusions by Topic:

5.1. *Lipid-containing enveloped viruses and temperature/humidity stability*

- Based on their study Ijaz et al. (1985) postulated that low humidity may aid viral stabilization at room temperature. Previous authors have proposed a tentative rule that lipid-containing viruses were generally more stable in aerosols than lipid-free viruses and that lipid-containing viruses are more labile in moist air (above 50% RH) than in dry air.[6] From Ijaz et al. (1985) study, this is also true of HCV/229E (when disregarding temperature), a lipid-containing virus, which at its optimal RH was considerably more stable in aerosol than poliovirus; however, its behavior at the different levels of RH and temperature did not follow this rule.[6]
- The role of temperature on the airborne survival of HCV/229E appears to be more complex than anticipated. It is suggested that under conditions of high humidity, the fluidity of the lipid-containing envelope is stabilized at low temperature, thus protecting the virion; however, further studies are needed to explain these phenomena.[6]
- According to the authors, it is premature at this stage to draw any conclusions regarding the epidemiological relevance of these findings.[6] However, it is tempting to speculate on the environmental role in the seasonal dissemination of this human respiratory virus.[6]
- Questions relating to interepidemic reservoirs as well as the transmission of infection needs to also be addressed.[6]
- Increased research into the protective/stabilization effect of low RH and AT on the coronavirus family.

5.2. The relationship between AT, RH, and virus inactivation on surfaces

- The relationship between AT, RH, and virus inactivation is still not entirely clear and may vary depending on the virus type.[2]
- Multiple mechanisms may contribute to viral inactivation on surfaces.[2]
- Some inactivation may take place when viral capsids accumulate at the air-water interface (AWI) of a solution, causing structural damage.[2]
- Virus inactivation on surfaces may involve both desiccation and interaction at the AWI, with the contribution of each depending on the RH.[2]
- However, this risk is still poorly understood, and more work is needed to quantify the risk of exposure and possible transmission associated with surfaces.[2]

- More data on the survival rates and inactivation kinetics of SARS-CoV itself are needed before these relationships with other coronaviruses can be definitively established.[2]

5.3. Dose-response

- Ample evidence of SARS-CoV-1 and -2 nucleic acids on surfaces and inanimate objects in hospitals has been reported.[2]
- However, there is no data on the occurrence of infectious coronavirus on these surfaces.[2]
- The dose-response relationship and minimal infectious doses for infection of humans by SARS-CoV and other coronaviruses have also not been defined.[2]
- Given these gaps in our knowledge, the magnitude of the risk due to virally contaminated surfaces is uncertain and should be examined further.[2]
- The dose-response relations is highly dependent upon AT and RH.

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7. Disclaimer:

This document was crafted in response to multiple inquiries regarding the persistence of SARS-CoV-2 as it relates to changes in the temperature and humidity of the environment. More specifically, this document reviews studies conducted by outside organizations and/or labs on other viruses that may not behave exactly like SARS-CoV-2, but have similar characteristics.

To assist those with a need for information on the persistency of SARS-CoV-2, we at AF 711 HPW/RHM are providing this standard response document to represent our interpretation of the state of the science and key considerations to keep in mind in when handling potentially contaminated AF assets.

We believe it is imperative that AF 711 HPW/RHM supports its customers and the broader Air Force during this unprecedented time caused by COVID-19 by providing balanced, thoughtful scientific data for discussion. We aim to provide the above data and discussion for the consideration of the medical teams and operational commanders making recommendations and guidelines.

This document was specifically crafted to assist in understanding the potential persistency of SARS-CoV-2 as an effect of temperature and relative humidity with the intent to provide information only, not to share opinions or recommendations. This document is intended, and should be used for, this purpose and no other. This documentation is not intended to be used as operational guidance on its own.

Finally, the information provided is not intended to address specific patient care or to provide advice about the transmission of contagious illness. Procedures and equipment required to reduce the risk of transmission of contagious illness to Air Force members are outside the scope of what has been provided. This document is for general informational purposes only, and not to provide specialized guidance.

Content in this document is intended to provide guidance on this specific topic and does not represent a position on policy or endorse a specific direction in policy. These are the scientific opinions and literature reviews constructed by 711 HPW scientists. If there are any questions related to what is contained in the document please direct them towards the 711 HPW/RHM COVID-19 Medical Response & Integration Cell: 711HPW.RHM.MedSTCOVID-19Cell@us.af.mil.

8. Appendix

A.

Table 1. Stability and resistance of SARS-CoV-1 against different environmental factors.[5]

Substrate	Initial Viral Count Log_{10}(PFU)	Condition	Survival Time	Method of Testing Viability
Stool	1.00E+03	Room Temperature	At least 2 days	Virus isolation in cell culture
Urine	1.00E+03	Room Temperature	At least 24 hr	Virus isolation in cell culture
Virus culture medium+1% bovine serum	1.00E+03	On plastic surface in room temperature	At least 2 days	Virus isolation in cell culture
Virus culture medium+1% bovine serum	1.00E+04	-37°C	At least 1 hr	Virus isolation in cell culture
Virus culture medium+1% fetal calf serum	1.00E+04	56°C	Degradation of titer over time (10,000 infectious virus units in 15 min)	Virus isolation in cell culture
Virus in acetone, 10% formaldehyde and paraformaldehyde, 10% Clorox, 75% ethanol, 2% phenol	1.00E+06	Room Temperature	Less than 5 min	Virus isolation in cell culture
Virus culture+2% bovine serum	1.00E+06	-80°C	At least 4 days	Virus isolation in cell culture and RT-PCR
Virus culture+2% fetal calf serum	1.00E+06	4°C	At least 4 days	Virus isolation in cell culture and RT-PCR
Virus culture+2% fetal calf serum	1.00E+05	37°C	Less than 4 days	Virus isolation in cell culture and RT-PCR
Virus culture+2% fetal calf serum	1.00E+06	56°C	Less than 30 min	Virus isolation in cell culture
Virus culture	1.00E+06	4°C	At least 21 days	Virus isolation
Virus culture	1.00E+06	-80°C	At least 21 days	Virus isolation
Virus in phosphate buffer saline	9.00E+04	Room Temperature		
		Plastered wall	24 hr	Virus isolation in cell culture
		Plastic surface	36 hr	Virus isolation in cell culture
Virus in phosphate buffered saline (PBS)	9.00E+04	Room Temperature		
		Formica surface	36 hr	Virus isolation in cell culture
		Stainless steel	36 hr	Virus isolation in cell culture
		Wood	12 hr	Virus isolation in cell culture
		Cotton cloth	12 hr	Virus isolation in cell culture
		Pig skin	≥24 hr	Virus isolation in cell culture
		Glass slide	72 hr	Virus isolation in cell culture
		Paper file cover	24 hr	Virus isolation in cell culture
Virus in sterilized stool	9.00E+04	Room Temperature		

Substrate	Initial Viral Count Log_{10}(PFU)	Condition	Survival Time	Method of Testing Viability
		Plastered wall	36 hr	Virus isolation in cell culture
		Plastic surface	72 hr	Virus isolation in cell culture
		Formica surface	36 hr	Virus isolation in cell culture
		Stainless steel	72 hr	Virus isolation in cell culture
		Wood	24 hr	Virus isolation in cell culture
		Cotton cloth	24 hr	Virus isolation in cell culture
		Pig skin	≥24 hr	Virus isolation in cell culture
		Glass slide	96 hr	Virus isolation in cell culture
		Paper file cover	36 hr	Virus isolation in cell culture

B.

Table 2. Recovered coronavirus after aerosolization and equilibration of the aerosol cloud.[6]

	Recovered Coronavirus 229E (%)	
Relative Humidity (%)	**20 ± 1ºC**	**6 ± 1ºC**
30 ± 5	87.0 ± 2.5	91.0 ± 2.6
50 ± 5	90.9 ± 1.6	96.5 ± 3.0
80 ± 5	55.0 ± 3.5	104.8 ± 5.1

Table 3. Half-life of aerosolized coronavirus under different conditions of relative humidity and temperature.[6]

Virus	Temperature (°C)	Half Life (hr)		
		High Relative Humidity (80 ± 5%)	Mid Relative Humidity (50 ± 5%)	Low Relative Humidity (30 ± 5%)
Coronavirus 229E (prepared in continuous line of L132 human lung cells)	20 ± 1	3.34 ± 0.16	67.33 ± 8.24	26.76 ± 6.21
	6 ± 1*	86.01 ± 5.28	102.53 ± 9.38	34.46 ± 3.21
* Half-life values were predicted by regression analysis of the 24 hr results shown in Fig 2 of the document				

C.

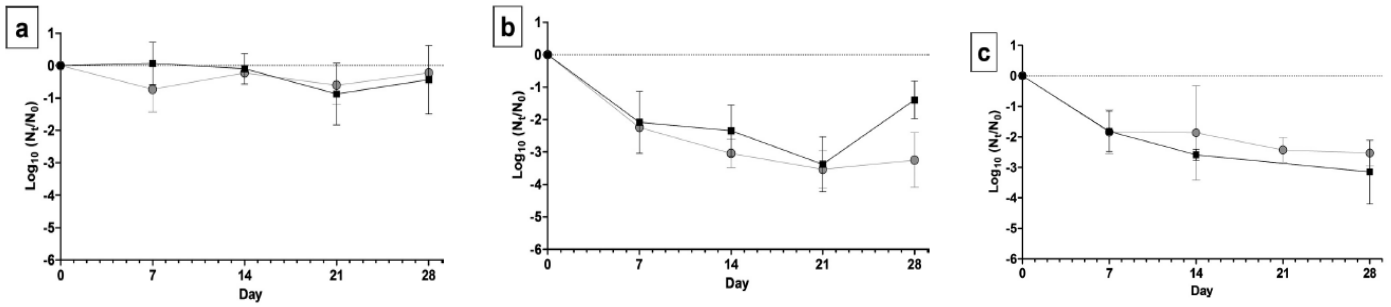

Figure 1. Survival of TGEV and MHV at 4°C and (a) 20% RH, (b) 50% RH, and (c) 80% RH. Squares, TGEV; circles, MHV.[2]

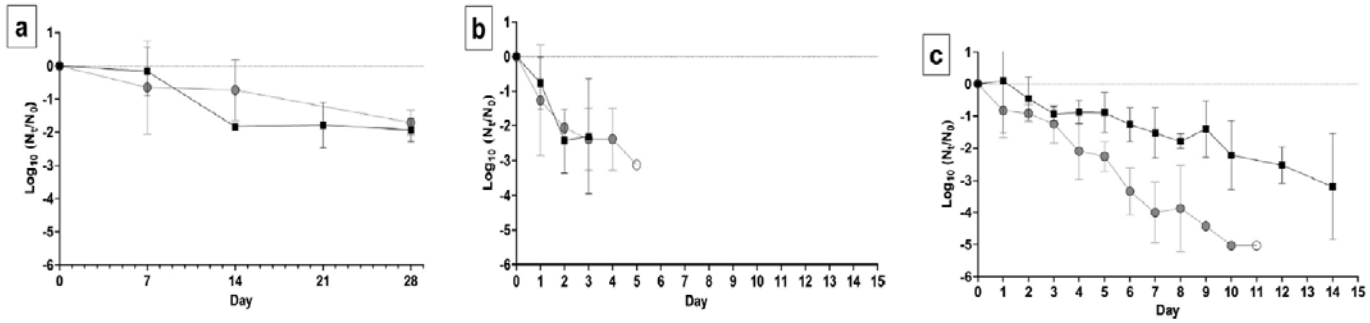

Figure 2. Survival of TGEV and MHV at 20°C and (a) 20% RH, (b) 50% RH, and (c) 80% RH. Filled squares, TGEV; filled circles, MHV; open circles, value for the sample was below the detection limit of the assay (5 log_{10} MPN).[2]

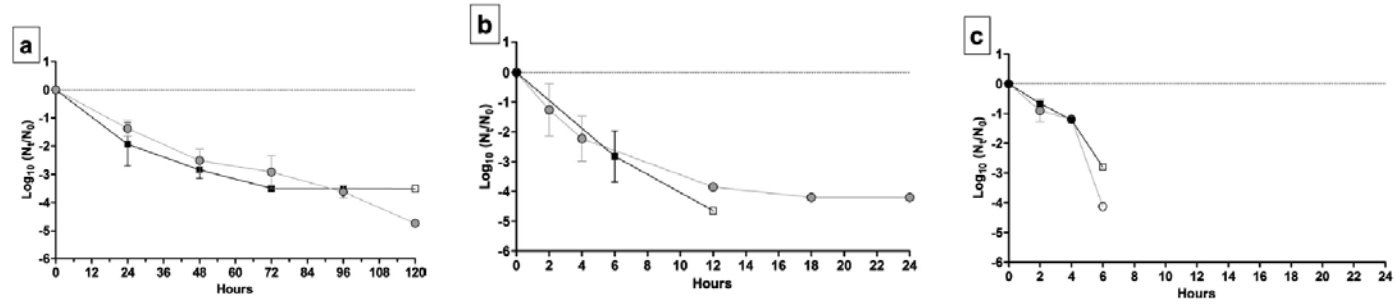

Figure 3. Survival of TGEV and MHV at 40°C and (a) 20% RH, (b) 50% RH, and (c) 80% RH. Filled squares, TGEV; filled circles, MHV; open squares, value for the TGEV sample was below the detection limit of the assay (4 log_{10} MPN); open circle, value for the MHV sample was below the detection limit of the assay (4 log10 MPN).[2]

D.

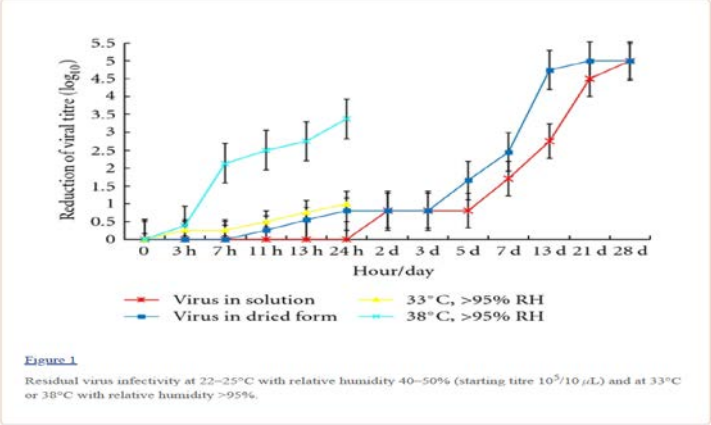

Figure 4. Residual virus infectivity at 22–25°C with relative humidity 40–50% (starting titre 10 /10 μL) and at 33°C or 38°C with relative humidity >95%.[3]

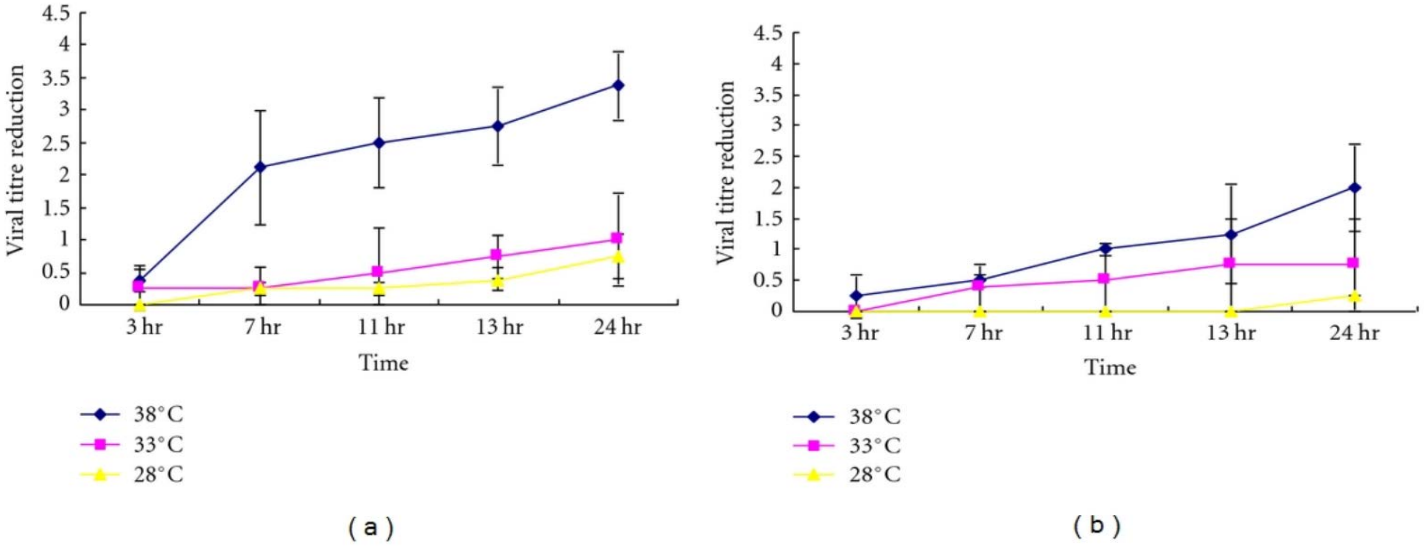

Figure 5. Infectivity of SARS Coronavirus (10 /10 μL) to different temperatures at (a) >95% relative humidity, (b) >80–89%.[3]

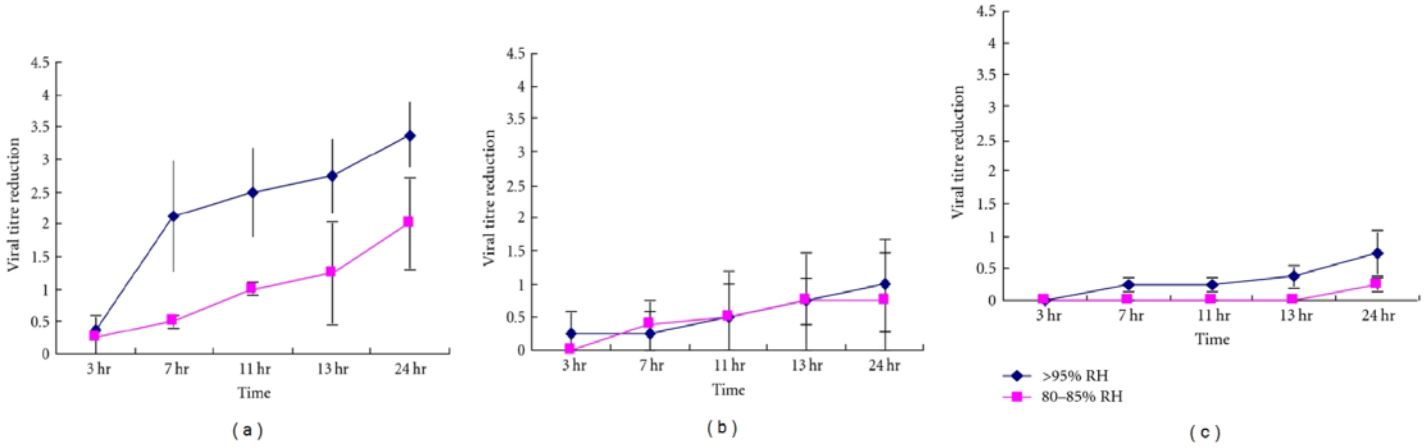

Figure 6. Infectivity of SARS Coronavirus (starting titer 10 /10 µL) at different relative humidity at (a) 38°C, (b) 33°C, and (c) 28°C.[2]

E.

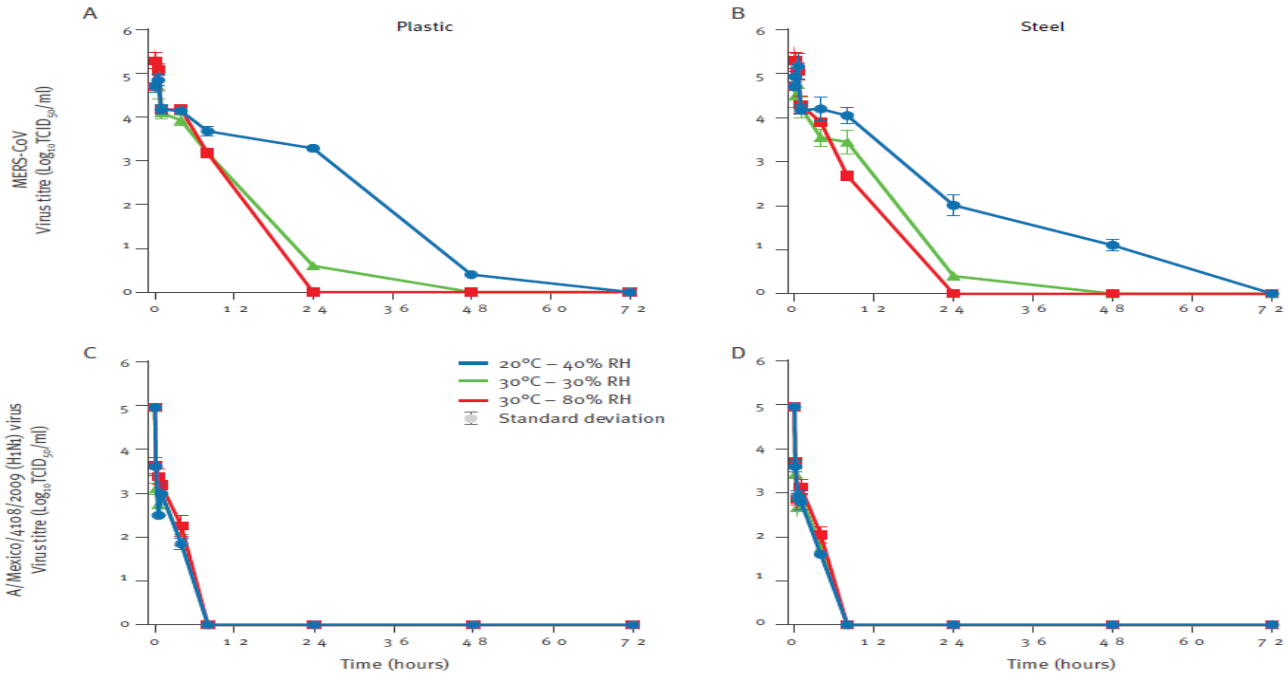

Figure 7. Viability over time of Middle East respiratory syndrome coronavirus (MERS-CoV) and A/Mexico/4108/2009 (H1N1) virus under different environmental conditions.[8]

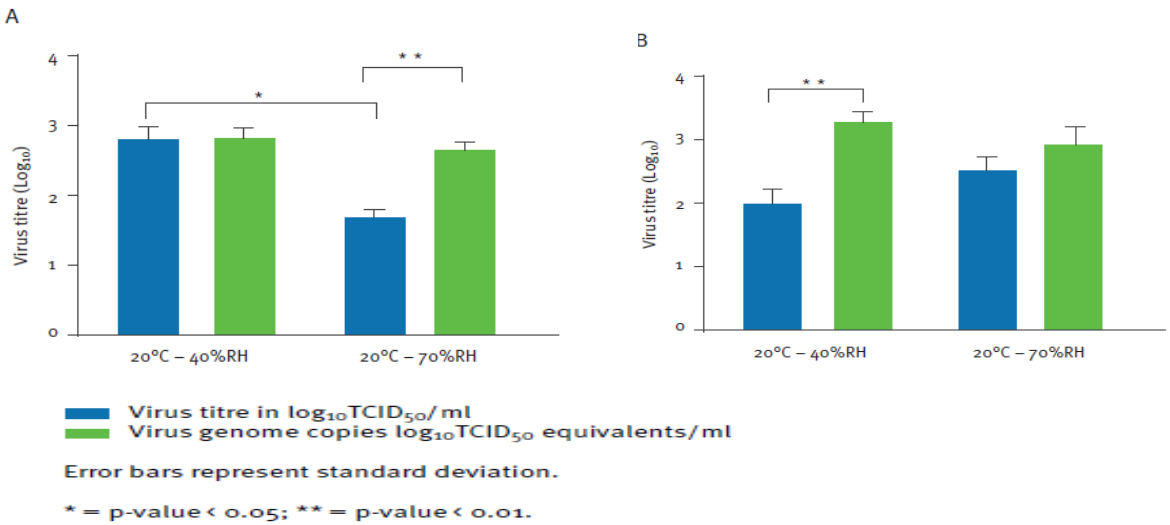

Figure 8. Aerosol stability of Middle East respiratory syndrome coronavirus (MERS-CoV) and A/Mexico/4108/2009 (H1N1) virus under different relative humidity conditions.[8]

Table 4. Decay of Middle East respiratory syndrome coronavirus (MERS-CoV) on plastic and steel surfaces at different temperatures and percent humidity.[8]

Surface type; temperature, relative humidity	Mean half-life time of MERS-CoV (hours)[a]	Standard deviation
Plastic; 20°C, 40%	0.954523	1.110443
Plastic; 30°C, 30%	0.441822	0.345291
Plastic; 30°C, 80%	0.904005	4.6838
Steel; 20°C, 40%	0.940139	1.837771
Steel; 30°C, 30%	0.973656	0.31109
Steel; 30°C, 80%	0.641163	0.825395

[a] Mean half-life was determined from three independent experiments.

F.

Table 5. Survival of SARS-CoV, MERS-CoV and surrogates on dry surfaces.[7]

Virus	Starting Titer	Dry Surface	Results
MERS-CoV	10^5	Steel and plastic	20°C/40% RH - 48h survival time 30°C/30% RH - 24h survival time 30°C/80% RH - greatly reduced (unspecified)
SARS-CoV-1	10^5	Plastic	Survives for 5 days, is viable for >20 days. Greater stability occurred at lower temperatures and lower humidity
SARS-CoV-1	Dilution (10^2 - 10^4)	Paper, disposable gowns, cotton gowns	Cotton gown 10^2 load - 5 min survival time; Disposable gown 10^4 load - 2 day survival time

Virus	Starting Titer	Dry Surface	Results
SARS-CoV-1	10^6	Wood board, glass, mosaic, metal, cloth, paper, filter paper, plastic	Survival time >72h (with reduced infectivity) on all surfaces and >120h on metal, cloth, and filter paper. No temp or humidity mentioned
TGEV	$>10^3$	Latex/nitrile gloves, N95 respirator, hospital scrubs, isolation gowns	Reduced amount after 4h, some was still detected after 24h. No temp or humidity mentioned
TGEV, MVH	10^5	Stainless steel discs	>28 day survival at low temp and relative humidity
HCoV-NL63, human metapneumovirus	No specified	Latex gloves, thermometer caps, stethoscopes, plastic table	Viable virus undetectable, RNA detected up to 7 days. Temp and humidity not mentioned.
SARS-CoV-1, HCoV-229E, herpes simplex virus, adenovirus	10^6-10^7	Polystyrene Petri dish	SARS-CoV - survives >6 days, HCoV-229E survived < 72h. Temp and humidity not mentioned
HCoV-229E, HCoV-OC43	10^3	Aluminum, cotton gauze, latex gloves	Viability fell to below detectable levels after 6h for 229E and 2h for HCoV-OC43.

G.

Table 6. Temperature stability of SARS-CoV-2.[4]

Time	Virus Titer (log $TCID_{50}$/mL)				
	4°C	22°C	37°C	56°C	70°C
1 min	NT	6.51 ± 0.27	NT	6.55 ± 0.1	5.34 ± 0.17
5 mins	NT	6.7 ± 0.15	NT	4.62 ± 0.44	U
10 mins	NT	6.63 ± 0.07	NT	3.84 ± 0.32	U
30 mins	6.51 ± 0.27	6.52 ± 0.28	6.57 ± 0.17	U	U
1 hr	6.57 ± 0.32	6.33 ± 0.21	6.76 ± 0.05	U	U
3 hrs	6.66 ± 0.16	6.68 ± 0.46	6.36 ± 0.19	U	U
6 hrs	6.67 ± 0.04	6.54 ± 0.32	5.99 ± 0.26	U	U
12 hrs	6.58 ± 0.21	6.23 ± 0.05	5.28 ± 0.23	U	U
1 day	6.72 ± 0.13	6.26 ± 0.05	3.23 ± 0.05	U	U
2 days	6.42 ± 0.37	6.83 ± 0.28	U	U	U
4 days	6.32 ± 0.27	4.99 ± 0.18	U	U	U
7 days	6.65 ± 0.05	3.48 ± 0.24	U	U	U
14 days	6.04 ± 0.18	U	U	U	U
NT = Not tested U = Undetectable					

H.

Table 7. Estimation of SARS-CoV-2 surface decay at different temperatures and relative humidities.[1]

Condition	Half-Life (dry*)
20% RH / 73-74°F	18.6
20% RH / 95°F	7.5
40% RH / 73-74°F	7.0
40% RH / 83°F	2.7
40% RH / 95°F	7.2
60% RH / 73-74°F	6.6
60% RH / 95°F	1.0
80% RH / 73-74°F	10.5
*Half-lives based on linear regression of time points after droplet drying	

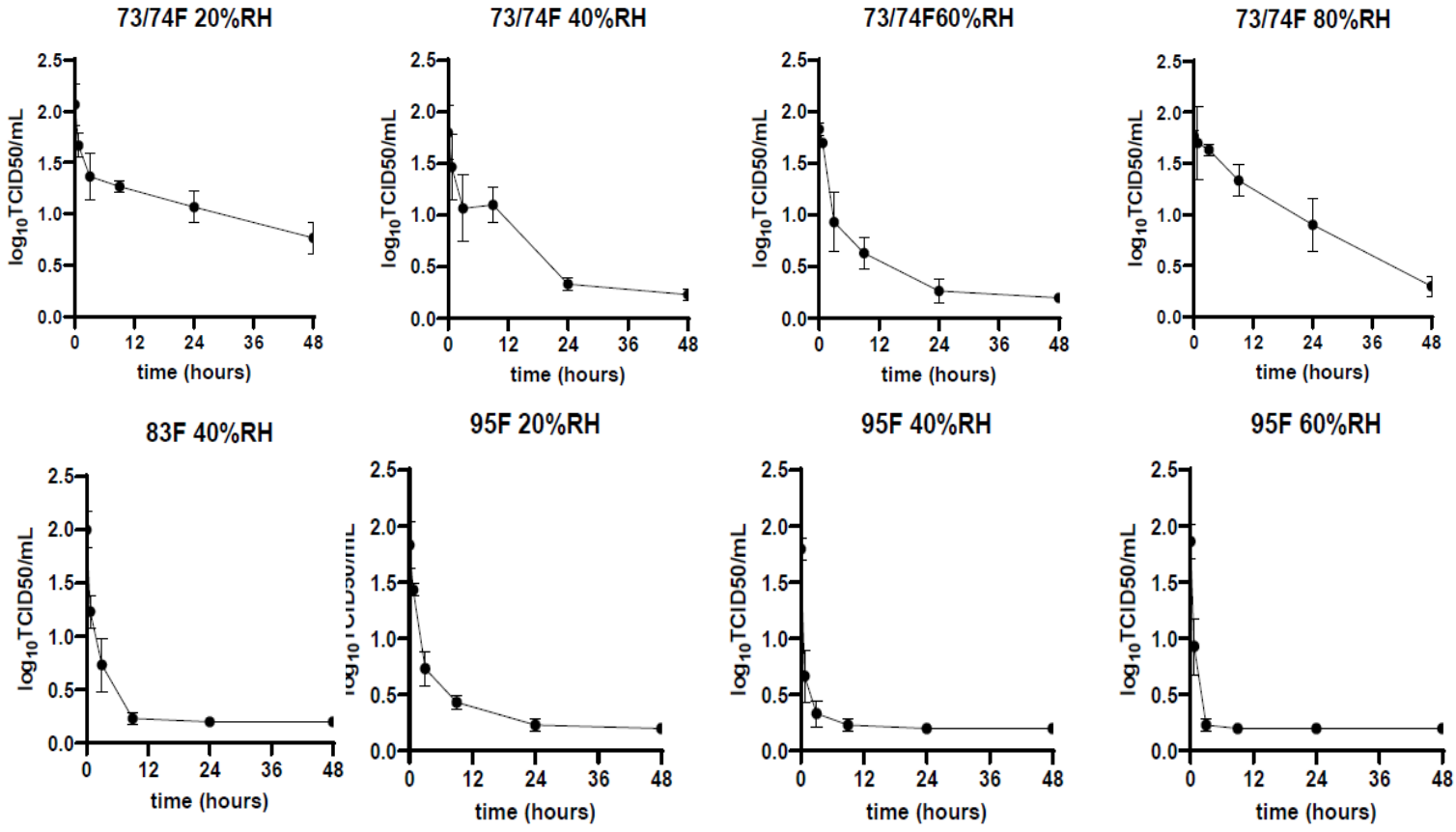

Figure 9. Estimation of SARS-CoV-2 Surface Decay at different temperatures and relative humidities.[1]

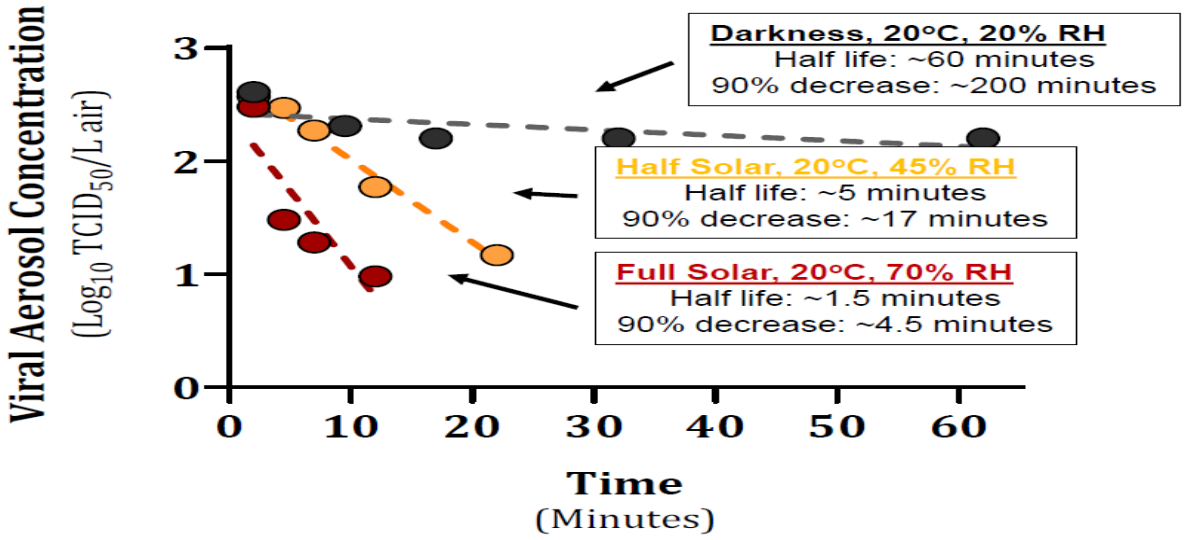

Figure 10. SARS-CoV-2 aerosol persistence.[1]