Airflow Through Buses

June 2020
Nick Rorres
Equipment Engineer

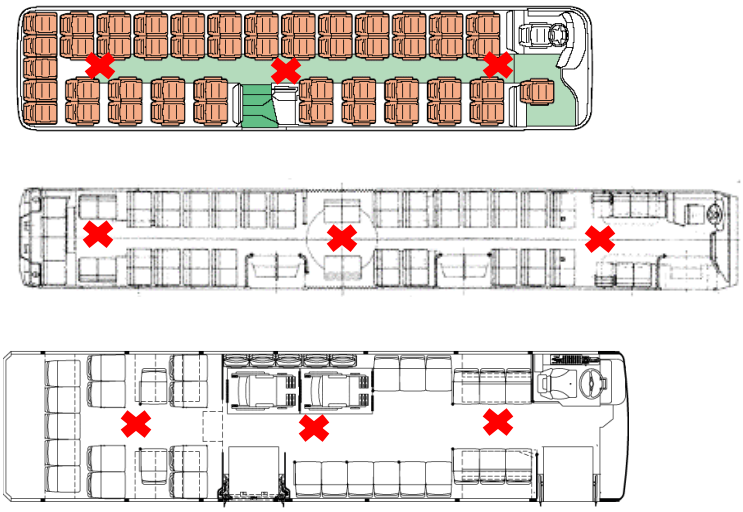
Introduction

This testing was completed to gain a better understanding of how airflow and temperature on buses are affected by having windows and roof hatches open to allow for fresh air exchange. In response to the COVID-19 pandemic, studies have been completed that support the theory that enclosed environments facilitate the transmission of coronaviruses and that a main reason for decrease in ridership is the public's unwillingness to subject themselves to enclosed areas. Keeping windows open could possibly give riders a feeling of security as well as reduce the possibility of transmission. The main issue with leaving windows open on buses is whether or not the open windows will render the HVAC systems so ineffective that passengers will be uncomfortable. This testing aims to measure both the differences in airflow and temperature on buses with windows open and closed. Based on previous knowledge, it is expected that opening windows and hatches will lead to more fresh air exchange but will also lead to an increase in internal temperature on the buses.

Methods

In this testing, a Mannix 8906 digital flow meter was used to measure both airflow and temperature at 3 different positions on the bus at different speeds. Intercity, transit, and articulated buses were all tested. Measurements were taken were taken at about five feet above floor level, along the centerline of the bus, at the front, in the middle and in the rear as seen in the diagrams below. Each bus was driven at 15, 30 and 50 mph for each condition of windows open and closed. Airspeed measurements were taken with the bus traveling both east and west at each speed, and measurements were averaged in order to account for natural windspeed and direction. Temperatures were taken on each bus before and after each testing condition.

The transit and articulated buses were tested with all windows closed, only hatches open, windows in the front half of the bus open with hatches, and all windows and hatches open. Intercity buses were tested with hatches closed and hatches open in a specific orientation. On intercitys, the front hatch must be angled so that the side of the hatch closer to the front of the bus is higher than the back half of the hatch. The back hatch should be angled in the opposite direction. For intercitys the fresh air vent was open in the front of the bus and the parcel rack blowers were off. Air conditioning remained on cool for all testing.



The red X's are the test locations on each type of bus. Measurements were taking about 5 feet above floor level.

Results

Transit Buses: *5/27/20*

Outside Temperature	79 °F
Average Wind Speed	6 mph
Average Wind Direction	East to West
Skies	Sunny

Temperatures	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open	All Open and Not Moving
Before Test	69 °F	69 °F	73 °F	73 °F	73 °F
After Test	69 °F	73 °F	73 °F	73 °F	78 °F

0 MPH	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	43 ft/min	15 ft/min	151 ft/min	82 ft/min
Middle	0 ft/min	0 ft/min	43 ft/min	31 ft/min
Rear	53 ft/min	80 ft/min	125 ft/min	118 ft/min

15 MPH - AVG	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	51 ft/min	13 ft/min	56 ft/min	66 ft/min
Middle	39 ft/min	28 ft/min	42 ft/min	8 ft/min
Rear	70 ft/min	192 ft/min	110 ft/min	155 ft/min

30 MPH - AVG	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	46 ft/min	10 ft/min	132 ft/min	69 ft/min
Middle	8 ft/min	3 ft/min	116 ft/min	16 ft/min
Rear	61 ft/min	273 ft/min	363 ft/min	316 ft/min

50 MPH - AVG	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	53 ft/min	48 ft/min	30 ft/min	48 ft/min
Middle	15 ft/min	0 ft/min	158 ft/min	153 ft/min
Rear	43 ft/min	282 ft/min	391 ft/min	472 ft/min

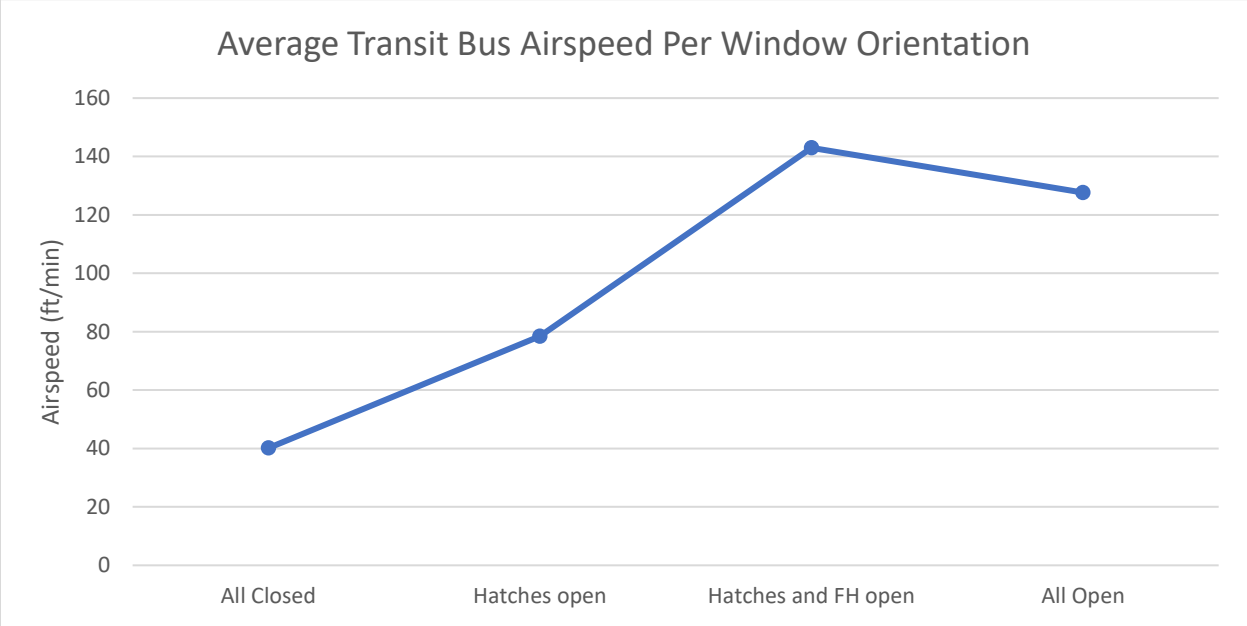


Figure 1. This graph plots the airflow averages at all tested locations on the bus at all tested speeds.

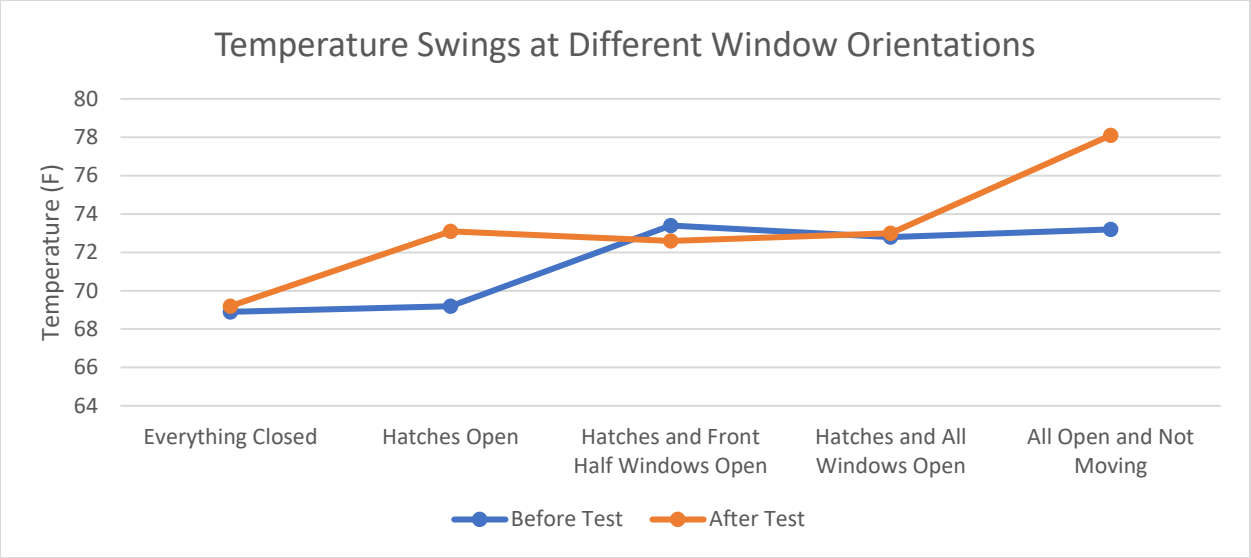


Figure 2. This graph plots the changes in temperature over the course of testing each window orientation.

Intercity Buses: *5/28/20*

Outside Temperature	70 °F
Average Wind Speed	5 mph
Average Wind Direction	North to South
Skies	Partly Sunny

Temperatures	Everything Closed	Hatches Open	All Open and Not Moving
Before Test	77 °F	77 °F	74 °F
After Test	70 °F	79 °F	77 °F

0 MPH	Everything Closed	Hatches Open
Front	0 ft/min	7 ft/min
Middle	0 ft/min	0 ft/min
Rear	0 ft/min	0 ft/min

15 MPH - AVG	Everything Closed	Hatches Open
Front	0 ft/min	48 ft/min
Middle	0 ft/min	8 ft/min
Rear	7 ft/min	0 ft/min

30 MPH - AVG	Everything Closed	Hatches Open
Front	7 ft/min	211 ft/min
Middle	0 ft/min	16 ft/min
Rear	0 ft/min	116 ft/min

50 MPH - AVG	Everything Closed	Hatches Open
Front	7 ft/min	216 ft/min
Middle	0 ft/min	146 ft/min
Rear	0 ft/min	79 ft/min

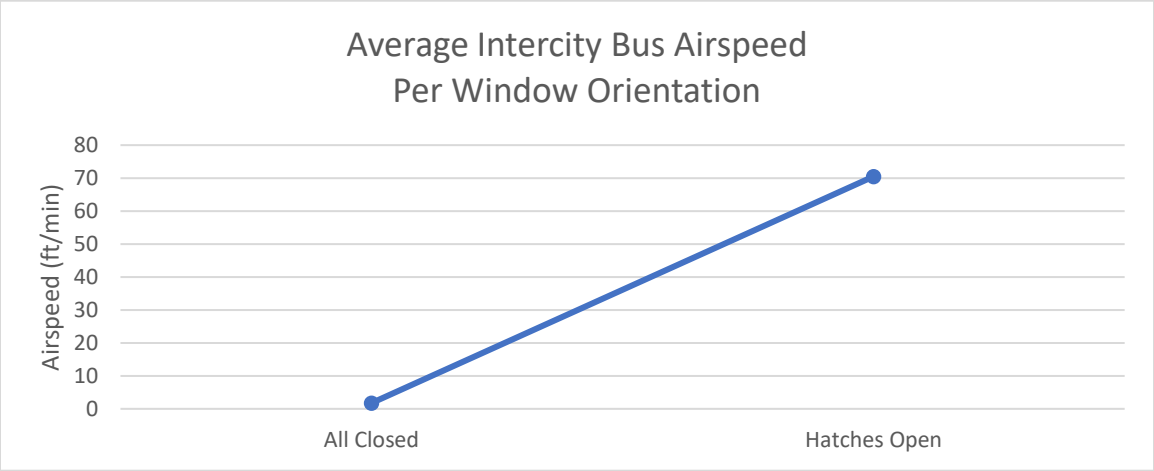


Figure 3. This graph plots the airflow averages at all tested locations on the bus at all tested speeds.

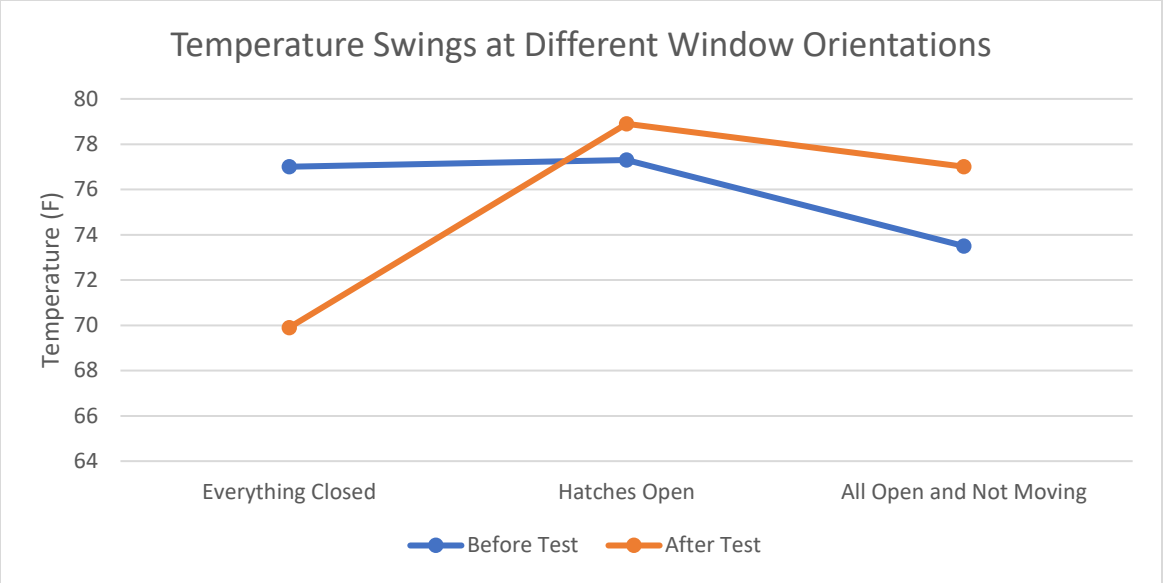


Figure 4. This graph plots the changes in temperature over the course of testing each window orientation.

Articulated Buses: *5/29/20*

Outside Temperature	80 °F
Average Wind Speed	5 mph
Average Wind Direction	East to West
Skies	Sunny

Temperatures	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open	All Open and Not Moving
Before Test	71 °F	70 °F	71 °F	72 °F	73 °F
After Test	69 °F	71 °F	72 °F	77 °F	78 °F

0 MPH	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	210 ft/min	202 ft/min	181 ft/min	261 ft/min
Middle	32 ft/min	37 ft/min	43 ft/min	85 ft/min
Rear	120 ft/min	118 ft/min	153 ft/min	202 ft/min

15 MPH - AVG	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	127 ft/min	192 ft/min	66 ft/min	129 ft/min
Middle	53 ft/min	81 ft/min	172 ft/min	78 ft/min
Rear	138 ft/min	183 ft/min	78 ft/min	157 ft/min

30 MPH - AVG	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	177 ft/min	223 ft/min	71 ft/min	112 ft/min
Middle	43 ft/min	129 ft/min	340 ft/min	201 ft/min
Rear	184 ft/min	190 ft/min	168 ft/min	224 ft/min

50 MPH - AVG	Everything Closed	Hatches Open	Hatches and Front Half Windows Open	Hatches and All Windows Open
Front	194 ft/min	201 ft/min	138 ft/min	172 ft/min
Middle	118 ft/min	245 ft/min	451 ft/min	482 ft/min
Rear	165 ft/min	194 ft/min	210 ft/min	373 ft/min

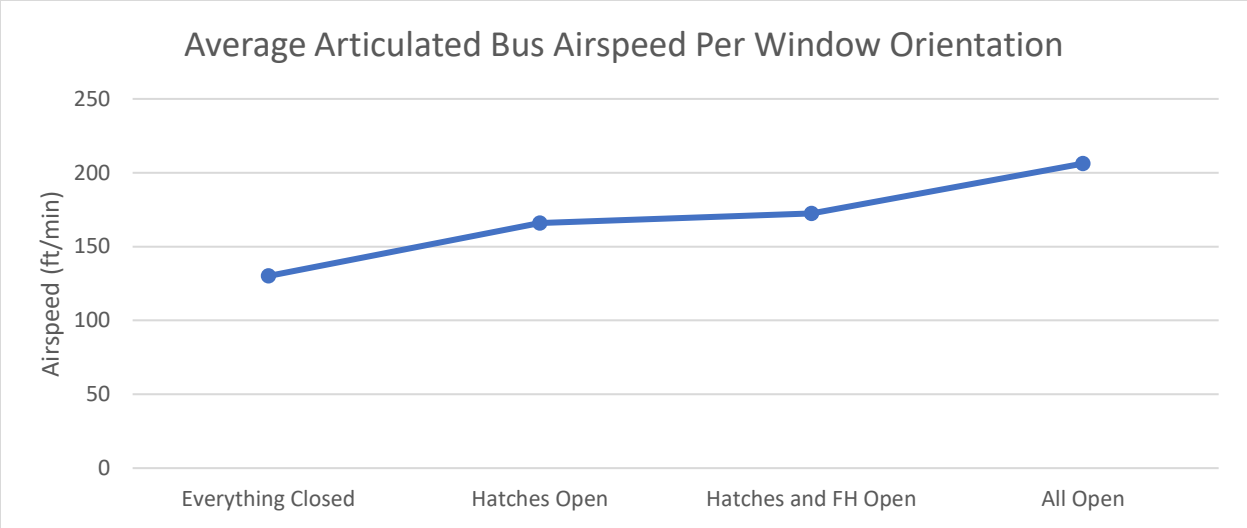


Figure 5. This graph plots the airflow averages at all tested locations on the bus at all tested speeds.

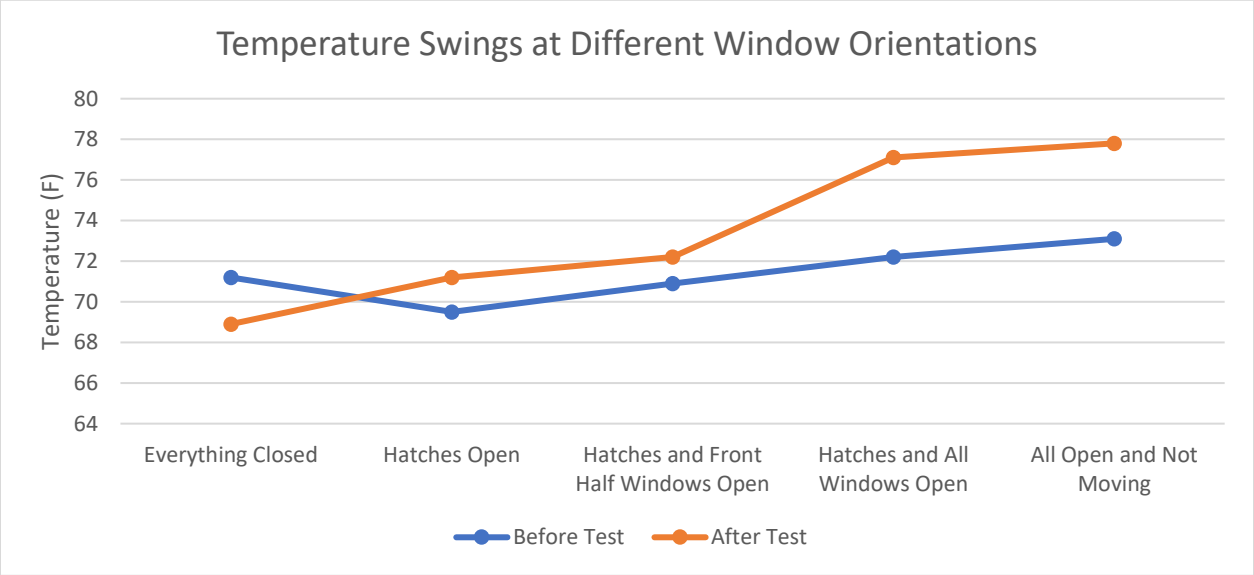


Figure 6. This graph plots the changes in temperature over the course of testing each window orientation.

Discussion

From the results of this testing, transit buses experienced significantly more airflow with their hatches open, and more airflow by another magnitude when the windows in the front half of the bus were opened as well. They experienced the largest increase in airspeed due to open windows, compared to other bus styles. Opening the windows in the back half of the bus did not seem to make much a difference at all, compared to only having windows open on the front half. The faster the bus was moving, the more airflow. Factors in the environment outside, such as traffic or high winds can cause large increases of airflow as well. For example, a semi-truck passing the transit bus on the highway created increases in airspeed on the bus larger than 200 ft/min. Transit buses do not often drive at high speeds, so we will most likely receive airflow closer to the 30mph and 15 mph data, which is still a significant improvement over having

everything closed. It is important to consider that the transit bus HVAC systems are very powerful and move air much faster than the intercity buses.

The downside is a significant rise in temperature on the bus with windows and hatches open. While the bus was moving during our test, convective cooling kept the temperature at about 75 degrees, however, when the bus was not moving, the temperatures reached almost 80 degrees, even with the HVAC system running. Between runs or in heavy traffic, when buses are mostly stationary, temperatures will become quite uncomfortable. The time between temperature readings for all conditions was about 10-15 minutes. The temperatures gradually increased over the course of the tests and may have continued increasing if the conditions were not changed. It was only 79 degrees when we tested the transit bus, but average high temperatures in July and August are around 88 degrees in Denver.

Intercity buses only have hatches to open up, no windows. The airspeeds increased by an average of about 70 ft/min when the hatches were open on these buses. This is a significant increase; however, it is a lesser increase that what you would experience on a transit bus. The intercity buses also showed a significant increase in airspeeds through the bus when they were travelling at over 30 mph. These buses regularly travel on the highway, so they will experience these conditions often. When everything was closed on the intercity buses, there was almost no airflow at all, which would be a reason to keep the hatches open.

While the temperature did rise on the intercitys, it was not as big of a temperature swing as was observed on transit buses. This was most likely due to two factors: The hatches not letting out as much air-conditioned air, and the weather outside was partly cloudy and 70 degrees. If it was sunny and 90 degrees outside, the temperature inside the bus would’ve been much hotter with the hatches open.

The articulated buses have superior airflow to both transit and intercity buses simply due to their powerful HVAC systems. With all of their windows and hatches closed, they still produce airspeeds much higher than the intercity with hatches open, and a transit with windows open. With hatches and windows on the front side of the bus open, there is even more airflow. Temperatures rose from 72 to almost 78 degrees in about 20 minutes on these buses. On a hot day, the internal temperature could easily surpass 80 degrees. The HVAC alone seems to provide quite a bit flow on these buses, and it will keep the bus cool, however, it is not providing the fresh air change that is desired due to the HVAC system simply recirculating the air in the cabin.

Both transit buses and articulated buses had occasionally higher airflow rates with hatches closed than with hatches open. This is most likely due to air from the HVAC system being redirected from the main cabin of the bus to the hatches, which contributes to higher temperatures in the bus.

Conclusion

Overall, leaving windows and hatches open on buses will significantly increase airflow through the bus, however this also leads to much warmer interior temperatures. This means it is possible, if not likely, that leaving windows and hatches open will reduce the risk of virus infection for passengers and drivers on some level. Various studies have shown that it seems plausible that sufficient airflow can cause viruses to become diluted below the point where they can cause infections. In addition to this, moving air leads to evaporation of moisture and studies have shown that viruses have trouble surviving in warm dry environments. While these positive

factors may have the ability to make passengers feel safer riding on public transit, other problems arise with this method fresh air exchange.

Leaving the windows open on buses will cause passengers to become to particularly uncomfortable on hot days on all bus styles. On top of the excess heat, the afternoon thunderstorms experienced during Colorado summers will almost certainly lead to passengers and bus interiors getting wet. If these factors are present on a daily basis on RTD's buses, it could lead to passengers complaining and becoming less inclined to ride.

References

Bromage, Erin. "The Risks - Know Them - Avoid Them." *Erin Bromage PhD:* 20 May 2020, www.erinbromage.com/post/the-risks-know-them-avoid-them?fbclid=IwAR0FUGEZpVLbIeLd6wGclCIwYyQ6Pnob4fZx7bcEgUBj-pWC5DxcHMH__0E.

Chan, KH. "The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus." *Hindawi,* 1 Oct. 2011, www.hindawi.com/journals/av/2011/734690/.

Nishiura, Hiroshi. "Closed Environments Facilitate Secondary Transmission of Coronavirus Disease 2019 (COVID-19) PREPRINT." *MedRxiv,* 16 Apr. 2020, www.medrxiv.org/content/10.1101/2020.02.28.20029272v2.