



Advanced Air Filtration Methods at San Francisco BART

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The BART System

- Three generations of around 800 cars.
- Accepting 775 “Fleet of the future” (FOTF) cars over 10 years for a 1,048 target fleet size.
- 80mph maximum speed, full ATO operation.
- 63,000lbs empty, 110,000lbs loaded.
- 5 ½ ft track gauge.
- 131 route miles, 262 mainline miles.
- 50 stations.



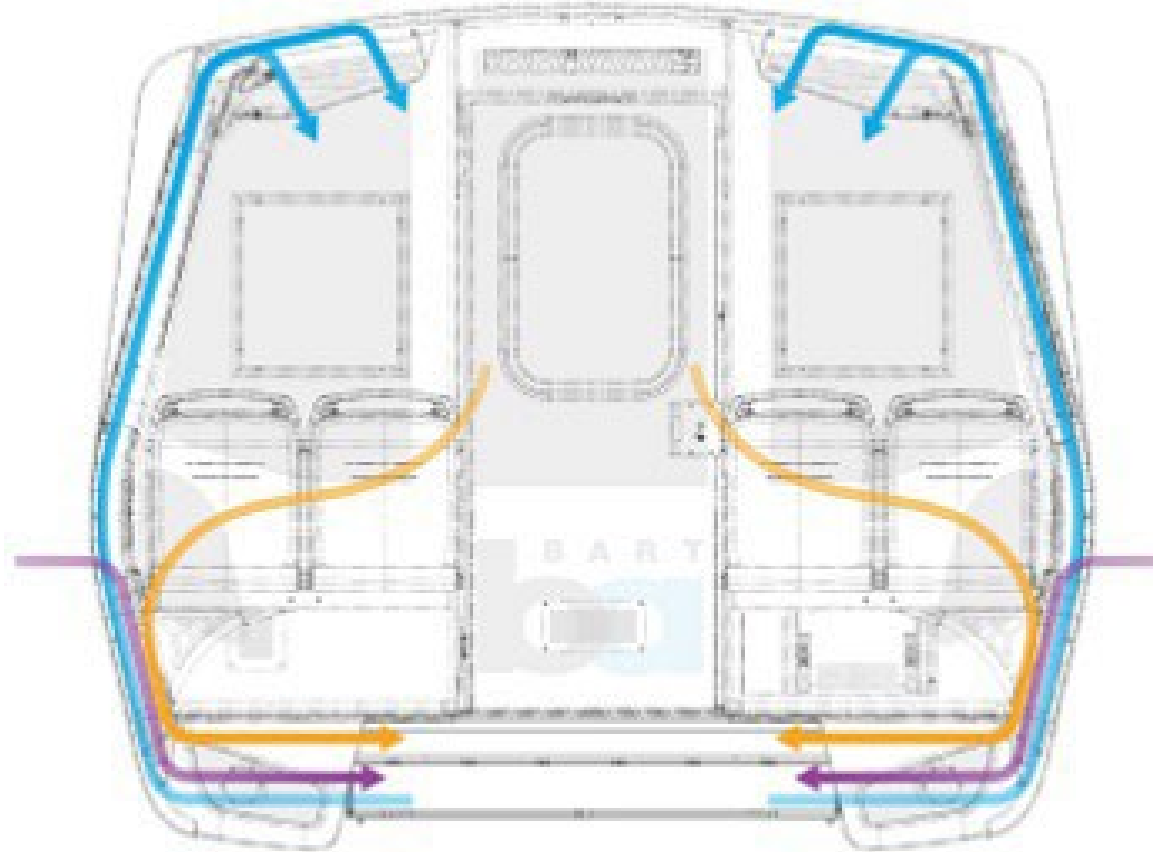
BART Car Ventilation

How air circulates through BART cars

Supply air is pulled through the HVAC units (located under the car floor), filtered and conditioned (cool/warm) before being sent up through the walls where it enters the cabin from above, or from the lower window masks.

Circulated air is then pulled back through the return ducts to the HVAC units. At the same time, 30% **fresh air** is pulled in through fresh air intakes on the sides of the car.

Fresh and circulated air are then mixed in the HVAC units where the process starts over.



Legacy Car HVAC Unit

- Legacy C-car HVAC unit on a shipping rack.
- Two HVAC units per C-car.
- Total cooling capacity per car 14 tons.
- Total air flow per car 4000 cfm.

Note:

Other legacy car type HVAC units not shown here.
Legacy cars are being replaced by the FOTF cars.



FOTF Car HVAC Unit

- FOTF Car HVAC unit on a shipping rack.
- Two HVAC units per car.
- Total cooling capacity 16 tons per car.
- Total air flow per car 4300 cfm.



Advanced HVAC System of BART's New Cars

- BART's Fleet of The Future (FOTF) cars have a modernized HVAC system which includes:
- Increased air flow from 4000 cubic feet per minute to 4300 cu feet per minute.
- Supply air ducts on the ceiling for better air flow and more cooling for standees.
- Improved design against refrigerant leakage.
- Switched from an ozone-depleting refrigerant to an environmentally friendly one.
- On board HVAC Controller continually communicates the HVAC performance status to the train operator and can provide fault logs and diagnostic functions to help with troubleshooting.

BART Car's Ventilation System Characteristics

- AIR IS REPLACED EVERY 70 SECONDS INSIDE THE TRAIN CAR

The formula for calculating Air Changes per Hour (ACH) is as follows:

$$\text{ACH} = \frac{\text{Air flow in Cu ft/min (CFM)} \times 60}{\text{Volume of the room in cu ft}}$$

Total supply air in CFM from the HVAC system per BART train car = 4300

Total volume of the BART train car interior = 4631 cu ft (approx.)

Therefore,

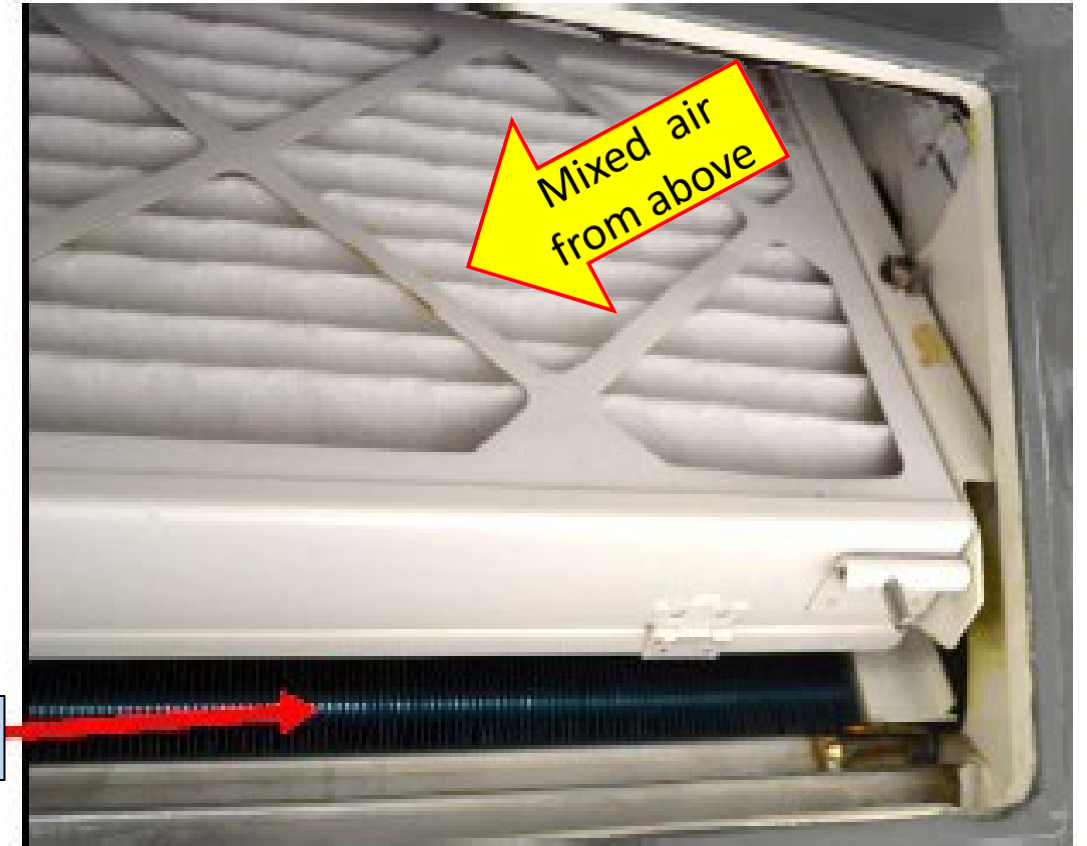
$$\text{ACH} = \frac{4300 \times 60}{4631} = 55.7 \text{ air changes/hour} = 55.7 \text{ air changes/60 min}$$

$$= 0.93 \text{ air change/min} = 1.08 \text{ air change/70 sec}$$

- Overall, the air in BART trains at a given moment is about 75% filtered and 25% fresh air drawn from outside the car (it's 80/20% on legacy trains and 70/30% on Fleet of the Future trains).

Mechanism of Air Filtration in HVAC system

- Outside fresh air and returned air from the passenger compartment are drawn into the HVAC unit by the evaporator fan.
- The mixed air then passes through an air filter (See Fig. on right) to filter off airborne particles before entering an evaporator and a heater assembly.
- The air, which is now filtered and conditioned, is then supplied to the passenger compartment through the air ducts.



Response to Pandemic

With the outbreak of COVID-19, BART has taken immediate steps to:

1. Upgrade air filter in the HVAC systems to improve the air filtration in train cars.
2. Explore the possibility of installing UV-C lamps in the HVAC unit of the train cars to kill pathogens.

HVAC System Air Filter Upgrade

- Prior to the COVID-19 pandemic, air filters of a Minimum Efficiency Reporting Value (MERV) of 8 were used in the HVAC unit of BART train cars.
- In response to the pandemic, American Society of Heating and Air-Conditioning Engineers (ASHRAE) recommends to use a filter with of MERV 13, or better to filter off virus containing particles.
- Generally, increasing filter efficiency will increase pressure drop which can reduce air flow through the HVAC system.
- A high pressure drop can overload the HVAC system and can lead to equipment failure.

MERV Rating & Air Particles Filtering Efficiency

- MERV 8: about 20% efficiency at capturing particles at 1 to 3 microns (micrometer).
- MERV 13: about 85% efficiency
- MERV 14: at least 90% efficiency.

	Minimum % of particles trapped		
	"PM 2.5 Zone"		
MERV Rating	0.3 - 1.0 Microns	1.0 - 3.0 Microns	3.0 - 10.0 Microns
MERV-14	>75%	>90%	>95%
MERV-13	>50%	>85%	>90%

NOTE: Studies have shown that COVID virus trapped itself in respiratory droplets which are 1 micron or larger when transmitted through air. For comparison purposes, a human hair diameter is about 70 microns.

MERV 8 & MERV 14 Filter Physical Comparison

- MERV 14 at left has denser fold (called mini-pleat) than MERV 8 at right.
- The increased surface area of the denser fold reduces accumulation of particles at any one spot, resulting in a lower pressure drop than filters with large pleats.
- At BART air filters are changed out about every 3 months during car maintenance.



MERV 14 Air Filter Evaluation

- For trial purposes, a small quantity of MERV 14 filters were installed in the HVAC units of various car types of the BART fleet in 2020.
- Pressure drop test data of the trial MERV 14 filters were collected at interval of 6 weeks and 12 weeks (about one PM cycle).

Filter Type	Test Results: Pressure drop at 500 fpm face velocity	Comment
MERV 8 - New	0.25" wg	
MERV 8 - Used after one PM	0.35" to 0.38" wg	Tested on legacy cars
MERV 14 - New	0.41" wg	
MERV 14 - Used - after half a PM (6 weeks)	0.425" wg	Tested on legacy cars
MERV 14 - Used - after one PM (12 weeks)	0.53" wg	Tested on legacy cars

Pressure Drop Test - Test Set Up



MERV 14 Air Filter Trial Results

- No impact on the HVAC system of the cars under trial could be observed during the trial period.
- No significant reduction of supply air flow from the HVAC units in the passenger compartment of the train car could be noticed.
- BART continues to monitor its ridership condition to adjust the air filter replacement frequency as necessary.

Photo Comparison - New & Used MERV 14 Filters

- New MERV 14 filter at left and MERV 14 filter after 12 weeks of use at right, showing huge amount of tiny airborne particles trapped by the filter.
- Supply air to the passenger compartment is much cleaner.



UV-C light to kill Pathogens

- The use of ultraviolet light to kill microorganisms has been around for over 50 years.
- BART conducted a pilot program in 2020 to install a UV lamp in an HVAC unit of one of the legacy train car to evaluate if the lamp could survive in a dynamic environment. The result was successful.
- BART is now working on extending the pilot program on the new Fleet of the Future (FOTF) train cars.



Conclusion

- BART has determined the use of MERV 14 filters is the best approach to purify the supply air in train cars.
- BART has completed the replacement of all MERV 8 filters with the upgraded MERV 14 filters in the HVAC units of all train cars in service.
- The used MERV 14 filters will be replaced about every 3 months during the car's preventive maintenance.
- Upon successful completion of the pilot program, BART is planning to install UV-C lamp in the HVAC units of all Fleet of the Future (FOTF) cars.

Q&A



Thank you!

