

A Tool to Model Virus Particle Exposure in Residences (ViPER)

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< NIST

MULTIZONE MODELING

ViPER - Virus Particle Exposure in Residences Tool

For more simulation capabilities, visit [FaTIMA](#).

Results Format
Particle Concentration

Base Case	Comparison Case 1
Home Size Small	Home Size Small
Visit Duration 1/2 hour	Visit Duration 1/2 hour
Portable Air Cleaner None	Portable Air Cleaner None
HVAC Fan Operation AUTO/Intermittent	HVAC Fan Operation AUTO/Intermittent
HVAC Filter None/Don't Know	HVAC Filter None/Don't Know
Outdoor Air Ventilation None/Don't Know	Outdoor Air Ventilation None/Don't Know
Post-Visit Runtime None	Post-Visit Runtime None

Result change from base:

End of visit:
No change.

60 minutes after visit:
No change.

[Add Case](#)

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NIST Technical Note 2211

A Tool to Model Virus Particle Exposure in Residences (ViPER)

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National Institute of Standards and Technology

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Abstract

Virus Particle Exposure in Residences (ViPER) is a web-based, single zone indoor air quality and ventilation analysis tool developed by the National Institute of Standards and Technology (NIST) for evaluating an occupant's relative exposure to infectious aerosols exhaled by a temporary, contagious visitor inside a dwelling (i.e., subsequently referred to as the home). This tool is specifically designed for use in a residential environment. When an occupant (the home's resident) anticipates having a visitor (a potential, temporary and continuous source of infectious aerosols), this tool can be used to vary a set of input parameters and then compare the changes to either particle concentration or integrated exposure. Some such parameters include home size, visit duration, and portable air cleaner effectiveness, as well as mechanical ventilation rates and heating, ventilating and air-conditioning system operation strategies. This tool is based on a database of 1,296 CONTAM simulation results. CONTAM is a multizone indoor air quality and airflow analysis program developed by NIST. ViPER allows users to compare a "base" scenario meant to represent their home against multiple "what-if" scenarios meant to mitigate their exposure to infectious aerosols. ViPER is available, along with CONTAM and other NIST-developed software, on the NIST Multizone Modeling Website <https://www.nist.gov/el/energy-and-environment-division-73200/nist-multizone-modeling>.

Keywords

airflow, CONTAM, contaminants, infectious aerosols, occupant exposure, simulation, residential

Limitations and Disclaimers

The information provided by ViPER is based on the results of CONTAM simulations of the impacts of multiple exposure mitigation measures. The simulations were performed assuming a single contagious occupant within a zone and a uniform particle concentration throughout the zone. The predicted impact of the measures will be different for other homes, occupancies, HVAC systems, ventilation options, and other input parameters. Nevertheless, the information provided by ViPER could support decisions that would help reduce particle exposure generated by a contagious visitor. ViPER does not define levels of exposure considered to be safe or healthy, nor consider the impacts of these measures as part of broader risk reduction strategies that might be implemented by a resident.

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1. Introduction

In addition to close contact transmission, it is believed that SARS-COV-2 is also transmitted via airborne routes in buildings (ASHRAE 2021; Morawska and Milton 2020). Certain measures can be used to reduce airborne transmission, including changes to the operation of heating, ventilating and air-conditioning (HVAC) systems and the use of portable air cleaners. However, selecting the most effective measures for reducing exposure inside a home can be challenging. The National Institute of Standards and Technology (NIST) has developed a tool that provides a simple, easy-to-use web-based interface designed for homeowners and tenants to quickly evaluate the effects of user-selected measures to reduce their exposure to airborne particle concentrations.

The Virus Particle Exposure in Residences (ViPER) tool is a single zone indoor air quality and ventilation analysis tool for evaluating an occupant’s relative exposure to infectious aerosols resulting from a temporary, contagious visitor inside the home. This tool is specifically designed for use in a residential environment by homeowners and tenants that may not be familiar with the best ways to operate their home’s systems in order to reduce potentially harmful infectious aerosols. ViPER simplifies the analysis by providing users with a predetermined set of parameters, allowing them to make selections based on their home, then providing a result of “increase”, “decrease”, or “no change” in either particle concentration or integrated exposure. The tool utilizes a database of 1,296 CONTAM simulation results to allow users to evaluate multiple “Comparison Cases” to a “Base Case” that best represents their home. ViPER was developed in collaboration with the Centers for Disease Control and Prevention (CDC) and the CDC Foundation. ViPER is available, along with CONTAM (Dols and Polidoro 2020) and other NIST-developed software, on the NIST Multizone Modeling Website <https://www.nist.gov/el/energy-and-environment-division-73200/nist-multizone-modeling>. ViPER’s user interface is shown in **Figure 1**.

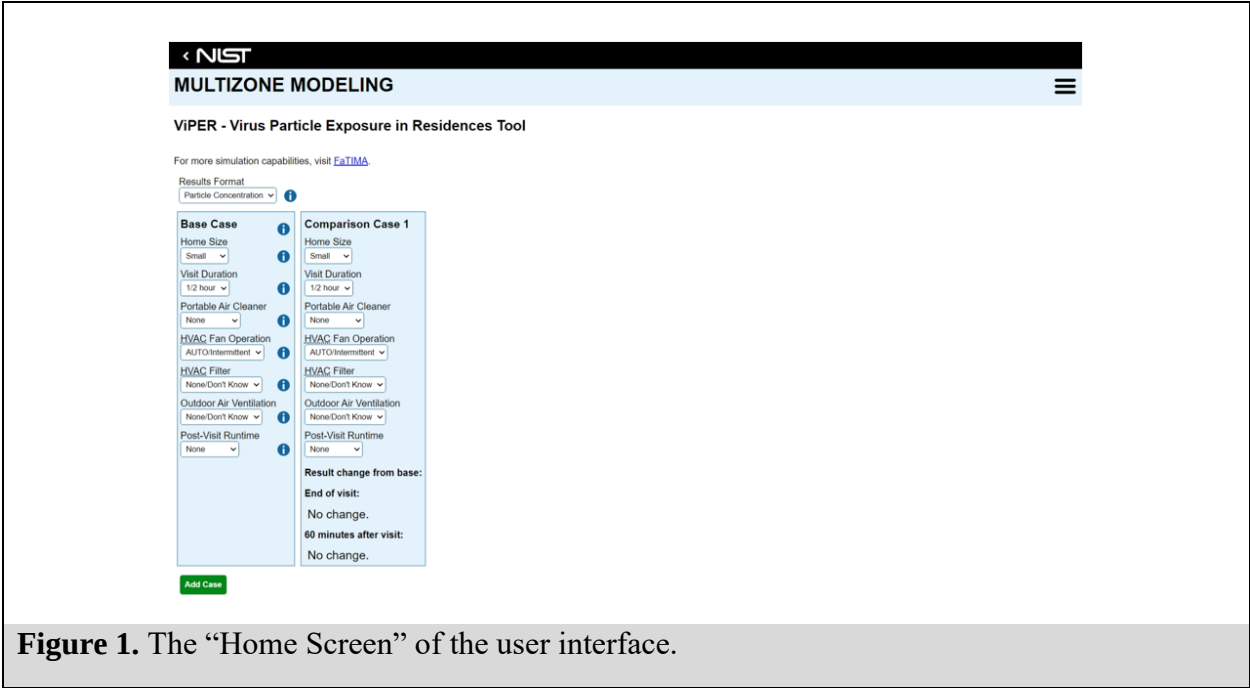


Figure 1. The “Home Screen” of the user interface.

1.1. Model Assumptions

While SARS-CoV-2 (the virus that causes COVID) itself ranges from 0.07 μm to 0.09 μm (Lee 2020), it typically is present in respiratory aerosols that also contain water, salts and proteins. According to Liu et al. (2020), the peak concentrations of SARS-CoV-2 occur in aerosols in two size ranges. One range was between 0.25 μm and 1.0 μm , and the other was larger than 2.5 μm . The particle concentration and exposure data in the ViPER tool were simulated using 1 μm particles, representing a typical respiratory aerosol that may contain SARS-CoV-2 based on the findings in Liu et al. (2020) as well as the limitation to simulate only one particle size in FaTIMA at the time of publication. The simulation data also does not account for the number of particles generated that are contagious or not contagious.

It has been shown that activities such as breathing, speaking, and singing may generate different amounts and sizes of aerosols (Alsved et al. 2020; Asadi et al. 2019). However, the results in ViPER are provided in percentage increase (or decrease), therefore, it was not important to state the particle generation rate or inhalation rate of the exposed resident.

Some studies have shown that increasing the relative humidity indoors can reduce the transmission of influenza (Kudo et al. 2019; Noti et al. 2013). While higher relative humidity outdoors was correlated to a reduction in the spread of COVID-19 indoors (Mecenas et al. 2020; Ward et al. 2020), there was limited evidence that low relative humidity indoors (< 40 %) increases the airborne transmissions of SARS-CoV-2 (Ahlawat et al. 2020). Nonetheless, the effects of humidity were not accounted for in the simulation data.

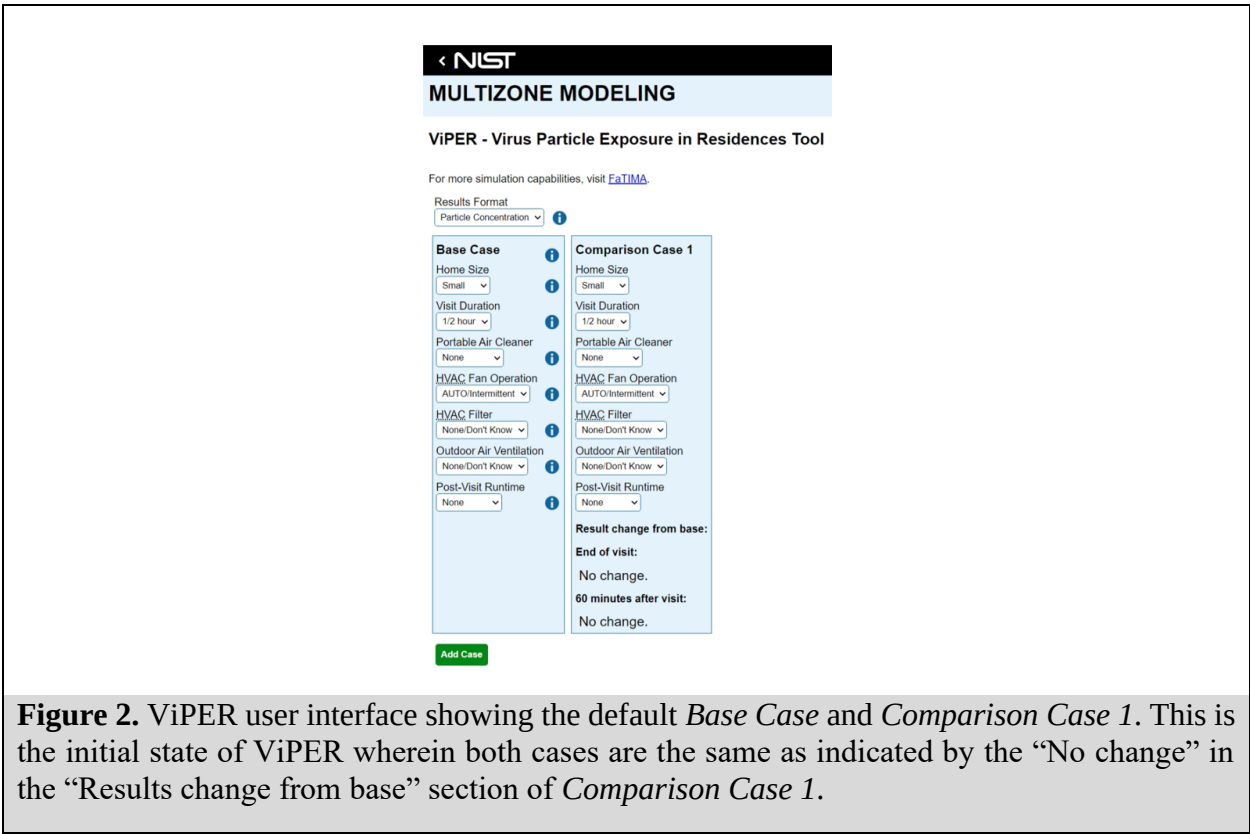
The simulation data assumed one resident and one visitor. If the user wants to account for more visitors, they are advised to use other NIST tools including FaTIMA and CONTAM (Dols and Polidoro 2020). CONTAM is available for free here: <https://www.nist.gov/el/energy-and-environment-division-73200/nist-multizone-modeling/software/contam>. FaTIMA is available for free here: <https://www.nist.gov/services-resources/software/fatima>.

2. User Interface

This section provides a brief overview of the ViPER interface. Details will be provided in the sections that follow. ViPER is a web-based tool, so it can be used within most browsers on a computer or mobile device. The user interface provides at least two cases with which to work as shown in **Figure 2**. The first case displayed will always be the *Base Case* and those that follow will be labeled *Comparison Case* and numbered consecutively. The figures shown in this document depict the tool as displayed on a computer screen; however, the interface may appear differently on a smaller, mobile device. You can reset ViPER to its default conditions by refreshing the webpage via the (↻) button on the browser or clicking the F5 key on the keyboard.

2.1. Defining Cases

To use ViPER, one would first define the *Base Case* that best represents their home. Once the base case is defined, the user can then define one or more *Comparison Cases*. Note that two default cases (the *Base Case* and *Comparison Case 1*) are initially displayed when visiting the website as shown in **Figure 2**; however, the user should be sure to modify the *Base Case* to match their specific circumstances, e.g., the size of their home. Regardless, the *Base Case* will always appear first, and multiple *Comparison Cases* can be created using the “Add Case” button shown at the bottom of **Figure 2**.



2.2. Viewing Results

Results are either based on the total particle concentration or integrated exposure as selected by the user via the Results Format input (described in the next section). Results for each *Comparison Case* are provided relative to the *Base Case* for two different times: at the end of the visit, i.e., immediately after the contagious visitor has left the home, and 60 minutes after the contagious visitor has left the home. For example, the “End of visit” result will be the total particle concentration at the end of the visit of the *Comparison Case* divided by the total particle concentration at the end of the visit for the *Base Case*. The “60 minutes after visit” result would be the ratio of the total concentrations 60 minutes after the contagious visitor left the home. In this manner, a ratio less than one will be indicated as a decrease in concentration and a ratio greater than one as an increase in concentration. Note that ViPER does not provide absolute values of the total concentration or integrated exposure.

Results for each *Comparison Case* are immediately updated for the selected inputs. Changing inputs for a specific *Comparison Case* will immediately update the results for that specific case and changing inputs of the *Base Case* will immediately update the result of all *Comparison Cases*.

3. Inputs

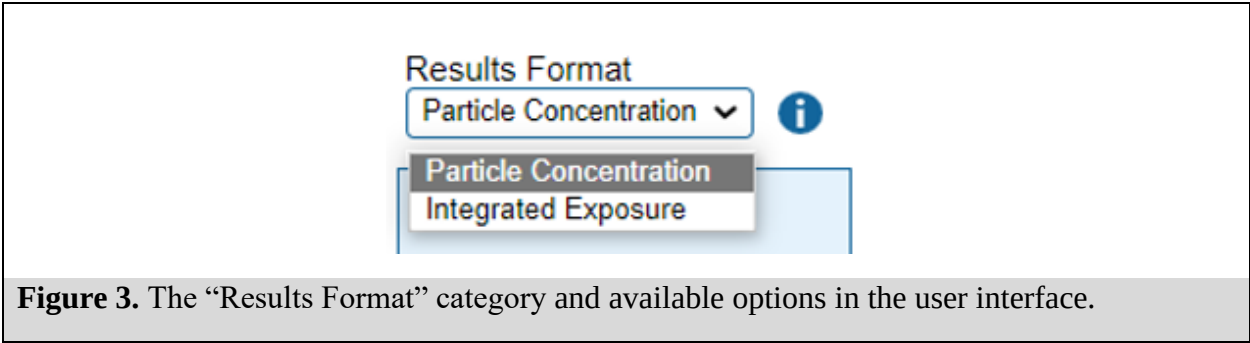
ViPER has eight inputs as shown in **Table 1** along with their associated options. Short descriptions for each input are provided below and more detailed descriptions are provided in the remainder of this section. The available options will not match every user’s home; therefore, the user may need to select the option that most closely reflects their conditions.

1. **Results Format:** Select the desired format of the results.
2. **Home Size:** Select the option that most closely reflects the size of the home where the visit will take place.
3. **Visit Duration:** Select the length of time the contagious visitor will continuously be in the home.
4. **Portable Air Cleaner:** Select the clean air delivery rate (CADR) of the unit operating inside the home during the visit.
5. **HVAC Fan Operation:** Select how the HVAC system will be operated during the visit.
6. **HVAC Filter:** Select what type of filter is within the HVAC system.
7. **Outdoor Air Ventilation:** Select how outdoor ventilation is delivered to the home.
8. **Post-Visit Runtime:** Select how long selected inputs will continue to operate once the contagious visitor has left the home.

Table 1. ViPER’s eight inputs and associated options.	
INPUTS	OPTIONS
Results Format	Particle Concentration Integrated Exposure
Home Size	Small Medium Large
Visit Duration	½ hour 2 hours 4 hours
Portable Air Cleaner	None Low Speed High Speed
HVAC Fan Operation	AUTO/Intermittent ON/Continuous
HVAC Filter	None/Don’t Know MERV 6 MERV 13
Outdoor Air Ventilation	None/Don’t Know Low High Window(s) Only
Post-Visit Runtime	None 60 Minutes

3.1. Results Format

This input has two options for designating how the results are expressed: ‘Particle Concentration’ and ‘Integrated Exposure’ as shown in **Figure 3**. The ‘Particle Concentration’ option corresponds to results being expressed as the number of particles within the home at the end of the visit and 60 minutes after the visit. The ‘Integrated Exposure’ option corresponds to results being expressed as the cumulative occupant exposure to particles within the home through the end of the visit and 60 minutes after the visit.



3.2. Home Size

This input has three options for designating the size of the home, or even a section of the home (a room or floor), where a visit will occur: ‘Small’, ‘Medium’, and ‘Large’ as shown in **Figure 4**. The dimensions for each home size are provided in **Table 2**, where zone volumes are based on a height of 2.74 m (9.0 ft). The home sizes were taken from the American Housing Survey (AHS 2017), where the small home was the low-end of the 25th percentile of home sizes reported (the average size of a one-bedroom apartment), the medium home was the median of the 50th percentile of homes sizes reported, and the large home was the upper-end of the 75th percentile of home sizes reported (the average size of a single-family home).



Table 2. Dimensions associated with Home Sizes based on a zone height of 2.74 m (9.0 ft).		
HOME SIZE	FLOOR AREA, m² (ft²)	VOLUME, m³ (ft³)
Small	93 (1,000)	255 (9,000)
Medium	163 (1,750)	446 (15,759)
Large	232 (2,500)	637 (22,500)

3.3. Visit Duration

This input has three options for the duration of the contagious visitor's stay within the home: '1/2 hour', '2 Hours', and '4 Hours' as shown in **Figure 5**. Each option corresponds to a contagious visitor staying inside the home continuously for the indicated amount of time.

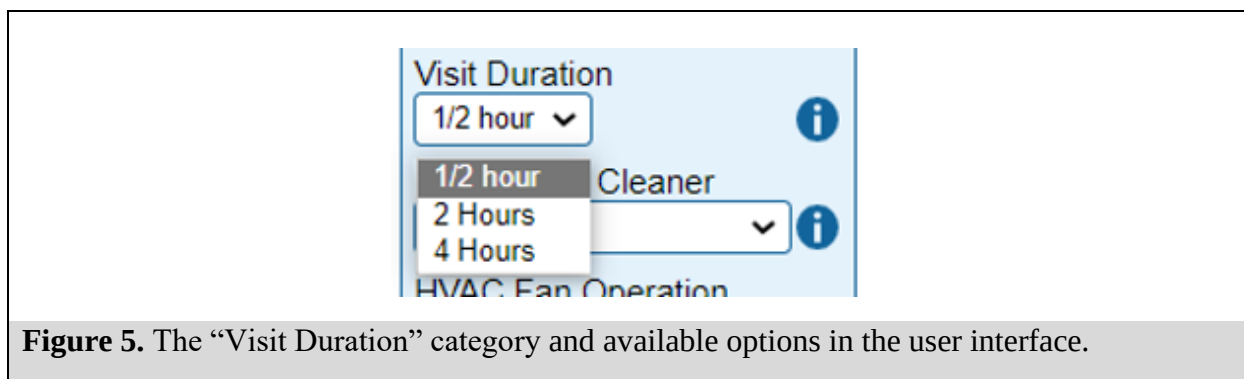


Figure 5. The “Visit Duration” category and available options in the user interface.

3.4. Portable Air Cleaner

This input has three options for designating the clean air delivery rate (CADR) of a portable air cleaner located within the home: 'None', 'Low speed', and 'High speed' as shown in **Figure 6**. The CADR is defined by ANSI/AHAM AC-1: Method for Measuring the Performance of Portable Household Electric Room Air Cleaners for smoke particles (AHAM 2019). It was assumed that the simulated PAC contained a high-efficiency particulate air (HEPA) filter with a filter efficiency of 99 % for 1 μm particles. The 'None' option corresponds to the absence of a portable air cleaner or the portable air cleaner being off. The 'Low Speed' option corresponds to the operation of a portable air cleaner at the maximum airflow rate of 47 L·s⁻¹ (100 cfm) and filter efficiency of 0.99, resulting in a CADR of 99 in units of cfm. The 'High Speed' option corresponds to the operation of a portable air cleaner at the maximum airflow rate of 142 L·s⁻¹ (300 cfm) and filter efficiency of 0.99, resulting in a CADR of 297 in units of cfm. If either 'Low Speed' or 'High Speed' are selected, portable air cleaner operation will occur for the entire “Visit Duration” (see Sec. 3.3) plus the “Post-Visit Runtime”, if selected (see Sec. 3.8).

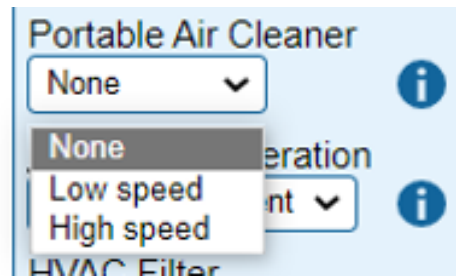


Figure 6. The “Portable Air Cleaner” category and available options in the user interface.

3.5. HVAC Fan Operation

This input has two options for designating the operation of the HVAC fan: ‘AUTO/Intermittent’ and ‘ON/Continuous’ as shown in **Figure 7**. HVAC fan refers to the fan located in a central, forced-air HVAC system, such as a heat pump or air-conditioner/furnace, if one exists in the home of interest. These forced-air systems only recirculate air and do not bring in any outdoor air. The ‘AUTO/Intermittent’ option corresponds to a forced-air fan that operates automatically according to a thermostat. This option assumes the HVAC system operates 20 % of the time, i.e., on for the first three minutes of every 15-minute interval starting at the beginning of the simulation. Note that the operation time of the actual system within a home may be more or less than the time assumed in this tool and will vary with outdoor air temperature and other factors. The ‘ON/Continuous’ option corresponds to a forced-air fan that operates continuously. To represent a home where the HVAC system is off or a dwelling without a forced-air system, select the ‘AUTO/Intermittent’ option for “HVAC Fan Operation” input and the ‘None/Don’t Know’ option for the “HVAC Filter” input (see Sec. 3.6). Whether ‘AUTO/Intermittent’ or ‘ON/Continuous’ is selected, “HVAC Fan Operation” will occur for the entire “Visit Duration” (see Sec. 3.3), plus the “Post-Visit Runtime”, if selected (see Sec. 3.8).



Figure 7. The “HVAC Fan Operation” category and available options in the user interface.

3.6. HVAC Filter

This input has three options for designating the type of HVAC filter: ‘None/Don’t Know’, ‘MERV 6’, and ‘MERV 13’ as shown in **Figure 8**. The minimum efficiency reporting value, or MERV, is defined by ANSI/ASHRAE Standard 52.2-2017: Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size (ASHRAE 2017). The filters in the model were based on the work of Kowalski et al. (1999), who developed models of MERV filters as recreated in **Figure 9**. The HVAC filter refers to the filter located within a central HVAC system, such as a heat pump or air-conditioner/furnace, if one exists in the home of interest. The ‘None/Don’t Know’ option corresponds to a home where the HVAC system only recirculates air and does not include a filter (split-system, window air conditioner, baseboard heating, etc.) or if the HVAC system includes a 30-day disposable filter. The ‘MERV 6’ option corresponds to a MERV 6 rated filter or a filter with an efficiency of 0.16 for 1.0 μm particles shown in **Figure 9**. The ‘MERV 13’ option corresponds to a MERV 13 rated filter or a filter with an efficiency of 0.90 for 1.0 μm particles as shown in **Figure 9**. To represent a home where the HVAC system is off or a home without a forced-air system, select the ‘None/Don’t Know’ option for the “HVAC Filter” input and the ‘AUTO/Intermittent’ option for the “HVAC Fan Operation” input (see Sec. 3.5).

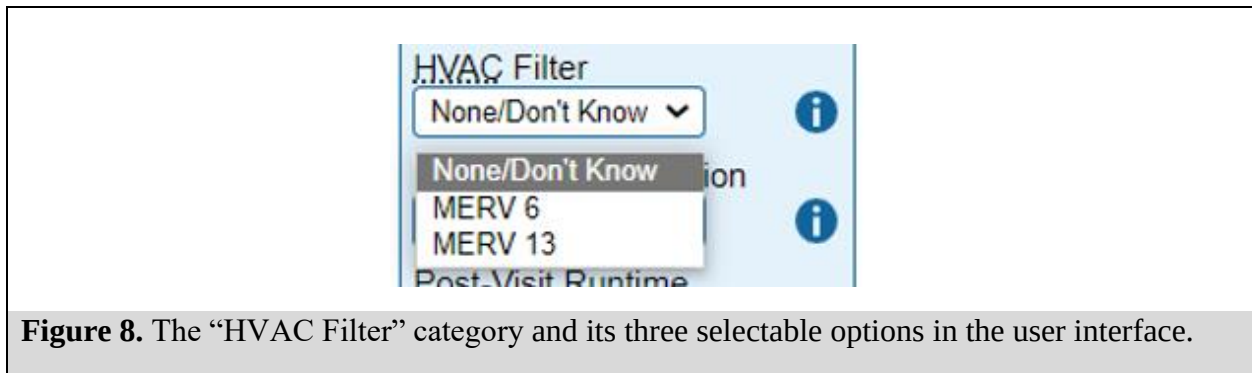


Figure 8. The “HVAC Filter” category and its three selectable options in the user interface.

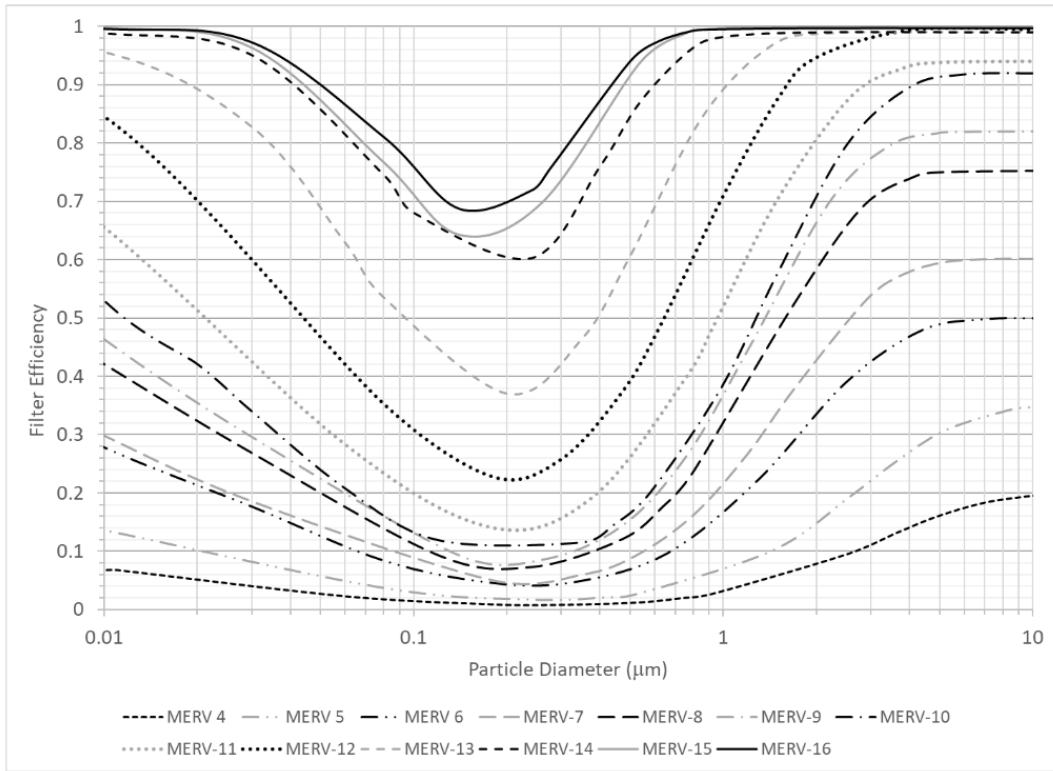


Figure 9. Filter efficiencies of different MERV filters at different particle diameters. Recreated by Dols et al. (2020) based on work by Kowalski et al. (1999)

3.7. Outdoor Air Ventilation

This input has four options for designating the type of outdoor air ventilation: ‘None/Don’t Know’, ‘Low’, ‘High’, and ‘Window Only’ as shown in **Figure 10**. Mechanical ventilation refers to outdoor air that is brought into the building (or drawn in) using a mechanical fan, such as an outdoor air intake attached to a central HVAC system, or air that is removed from the building by an exhaust fan. The ventilation rates for each home size are provided in **Table 3**.

The ‘None/Don’t Know’ option corresponds to a home where no mechanical ventilation system is present. For this option, it is assumed that outdoor air is provided to the home only through infiltration, which is unintended leakage through the exterior walls, roof, and other surfaces. The infiltration rates assumed for the homes in this tool were: 16 L/s (0.23 h^{-1}) for a ‘Small’ home, 26 L/s (0.21 h^{-1}) for a ‘Medium’ home, and 35 L/s (0.20 h^{-1}) for a ‘Large’ home. These infiltration rates correspond to the maximum infiltration credit allowed by ASHRAE 62.2-2016 (ASHRAE 2016) which is two-thirds of the total required outdoor air ventilation rate. These infiltration rates were calculated using the mean leakiness of homes in the Residential Diagnostics Database (Chan et al. 2013). The infiltration rates assumed in this tool also represent an annual average infiltration rate and do not reflect real-time variation in weather, HVAC operation, and other factors that influence the infiltration rate.

The ‘Low’ option corresponds to a home where the mechanical ventilation operation meets ASHRAE Standard 62.2-2019 (ASHRAE 2019) (24 L/s (0.35 h⁻¹) for a ‘Small’ home, 38 L/s (0.31 h⁻¹) for a ‘Medium’ home, and 52 L/s (0.30 h⁻¹) for a ‘Large’ home).

The ‘High’ option corresponds to a home where the mechanical ventilation operation meets ASHRAE Standard 62.2, plus additional fan(s), i.e., window fans, supply fans, exhaust fans, and other fans that move outdoor air into or remove air from a home (not a ceiling or recirculating fan) (119 L/s (1.7 h⁻¹) for a ‘Small’ home, 133 L/s (1.1 h⁻¹) for a ‘Medium’ home, and 147 L/s (0.8 h⁻¹) for a ‘Large’ home). For both the ‘Low’ and ‘High’ options, infiltration is included.

The ‘Window Only’ option corresponds to a home where no mechanical ventilation system is present, but with windows open, corresponding to 33 L/s (0.46 h⁻¹) for a ‘Small’ home, 51 L/s (0.41 h⁻¹) for a ‘Medium’ home, and 70 L/s (0.39 h⁻¹) for a ‘Large’ home. Because airflow through windows is dependent on outdoor weather, indoor conditions, and the operation of HVAC equipment, it was assumed that the ‘Window Only’ option provides twice the assumed infiltration rate. For any selection, that “Outdoor Air Ventilation” operation will occur for the entire “Visit Duration” (see Sec. 3.3), plus any “Post-Visit Runtime” selected (see section 3.8).

For any selection, the “Outdoor Air Ventilation” operation will occur for the entire “Visit Duration” (see Sec. 3.3), plus the “Post-Visit Runtime”, if selected (see Sec. 3.8).

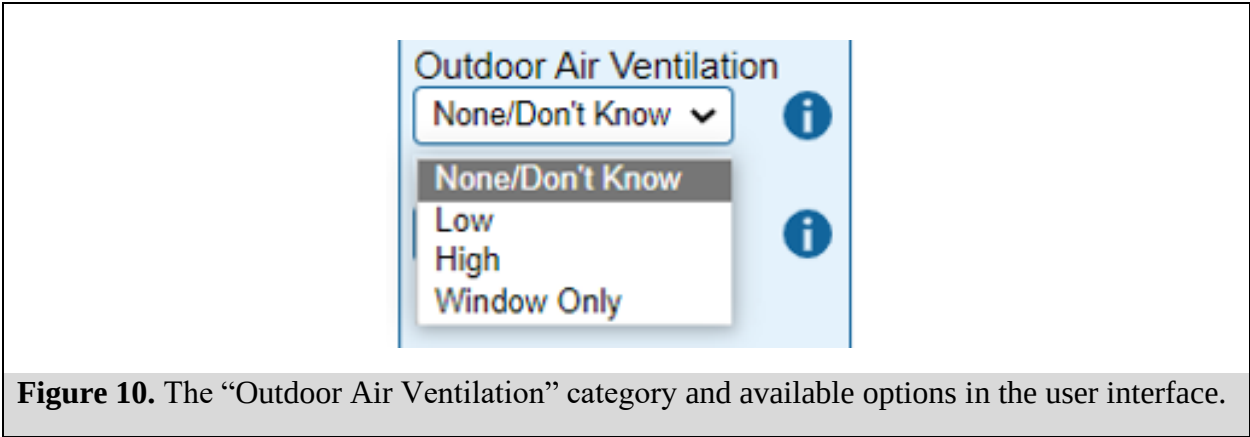


Table 3. Assumed ventilation rates for the three home sizes.				
HOME SIZE	OUTDOOR AIR VENTILATION RATES (L/S)			
	NONE/DON'T KNOW	LOW	HIGH	WINDOW ONLY
Small	16	24	119	33
Medium	26	38	133	51
Large	35	52	147	70

3.8. *Post-Visit Runtime*

This input has two options for designating the post-visit runtime duration for certain systems: ‘None’ and ‘60 Minutes’ as shown in **Figure 11**. The post-visit runtime refers to whether the portable air cleaner, outdoor air ventilation, and HVAC fan will operate at their selected levels after the contagious visitor has left the home. The ‘None’ option corresponds to a home where the three systems, if on during the visit, are turned off (the “Outdoor Air Ventilation” will revert to ‘None/Don’t Know’, which corresponds to infiltration only (see Sec. 3.7)) once the contagious visitor has left the home. The ‘60 minutes’ option corresponds to the three systems, if on during the visit, continuing to operate at their selected level for 60 minutes after the contagious visitor has left the home.

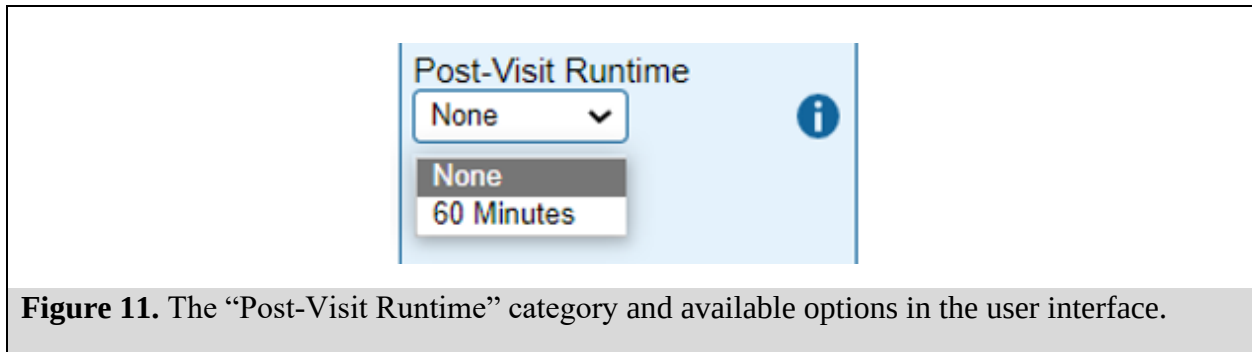
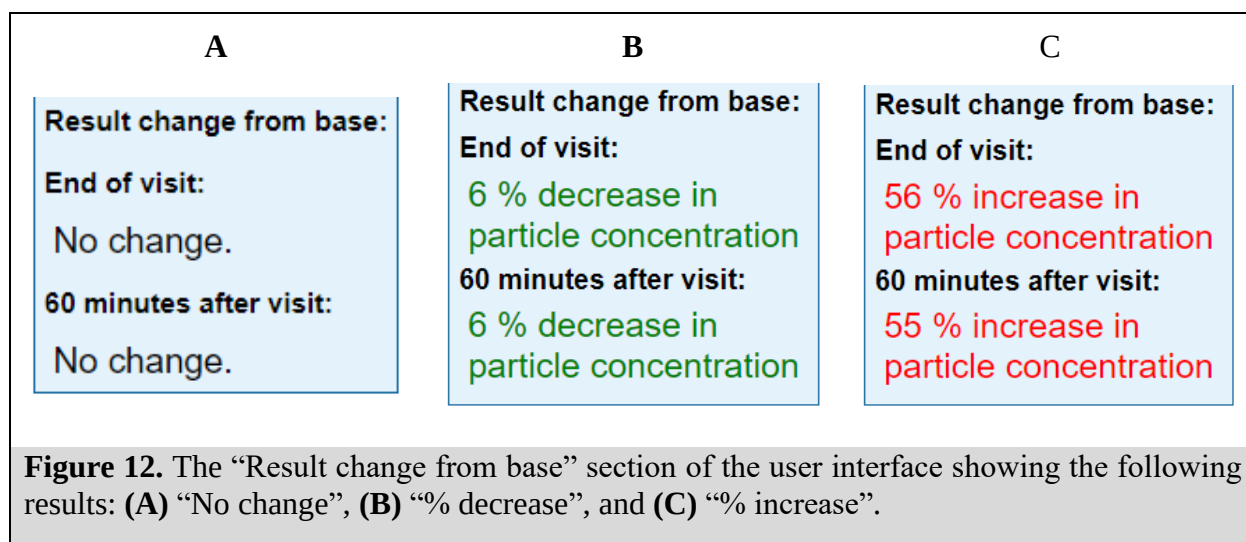


Figure 11. The “Post-Visit Runtime” category and available options in the user interface.

4. Result Change From Base

Results for each *Comparison Case* are displayed under “Result change from base” according to the previously selected option for the “Results Format” input (section 3.1). Results are displayed for two different time frames: “End of visit” and “60 minutes after visit”. Each result will display as either a “% increase”, “% decrease”, or “No change” in either particle concentration or integrated exposure to reflect the inputs of each *Comparison Case* relative to those of the Base Case (**Figure 12**).



5. Conclusion

ViPER is a web-based tool that presents data generated by CONTAM simulations of airborne particles for multiple home sizes, visit durations, portable air cleaner levels, outdoor ventilation rates, and HVAC filtration rates and operating strategies. Based on a database of 1 296 simulations, users can compare multiple *Comparison Cases* against an individual *Base Case* to perform “what-if” analysis related to particle exposure associated with contagious visitors in a home.

6. Acknowledgements

This tool was developed in collaboration with the Centers for Disease Control and Prevention (CDC) and the CDC Foundation under Agreement #1085. The authors would like to thank their colleagues at the CDC for their technical contributions to the selection of parameters for the simulations: Ginger Chew and Stephen Martin.

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