Tool Evaluates Control Measures for Airborne Infectious Agents

BY W. STUART DOLS, MEMBER ASHRAE; LISA NG, PH.D., MEMBER ASHRAE; BRIAN J. POLIDORO; DUSTIN POPPENDIECK; STEVEN J. EMMERICH, FELLOW ASHRAE; ANDREW PERSILY, PH.D., FELLOW/LIFE MEMBER ASHRAE

The purpose of the new online tool Fate and Transport of Indoor Microbiological Aerosols (FaTIMA) is to model the fate of infectious aerosols (e.g., those associated with SARS-CoV-2) generated within the built environment and the potential impact of various control measures.[1] Pathogen-containing aerosols can be generated by an infected person through breathing and other activities involving the respiratory system, such as coughing. Larger emitted droplets fall rather quickly to the ground due to gravitational settling; these can impact various surfaces or ballistically enter the respiratory tract of another, nearby occupant.[2] Smaller droplet nuclei can remain airborne for longer periods, and these aerosolized particles are the focus of FaTIMA.

FaTIMA models the fate of such indoor microbiological aerosols based on the effects of ventilation, filtration, deposition and inactivation. FaTIMA can be used to evaluate relative effects of control measures on airborne infectious agents but does not model the risk of infection.

The underlying model (*Figure 1*) consists of a single zone, served by a mechanical ventilation system, that incorporates source and removal mechanisms of an aerosol having a single, user-defined representative size and a uniform concentration. (Users who need to understand spatial variations in airborne concentration should consider using computational fluid dynamics instead.) The mechanical ventilation system model allows specification of supply, return, exhaust and outdoor air intake rates. Aerosol sources may be specified as any combination of continuous (e.g., breathing) or intermittent (e.g., coughing) emissions. Aerosol removal mechanisms include filtration (within the ventilation system and via a room air cleaner), deactivation and deposition onto floors, walls, ceilings and other surfaces. Simulations run for 24-hours, with results provided as a time history of the airborne concentration and surface loading and the integrated exposure of an occupant.

W. Stuart Dols and Lisa Ng, Ph.D., are mechanical engineers, Brian J. Polidoro is an IT Specialist, Dustin Poppendieck is an environmental engineer, Steven J. Emmerich is a group leader, and Andrew Persily, Ph.D., is a division chief in the Engineering Laboratory at the National Institute of Standards and Technology, Gaithersburg, Md. Dols and Ng are members of and Persily is a consultant to SSPC 62.1. Emmerich is chair of GPC 44 and a member of SSPC 62.2.

This peer-reviewed column does not represent official ASHRAE guidance. For more information on ASHRAE resources on COVID-19, visit ashrae.org/COVID19.

FaTIMA uses the equation solver of the CONTAM program, which has been used for decades for multizone, whole-building airflow and contaminant transport analysis. Details regarding CONTAM's underlying theory and capabilities are provided in the CONTAM user guide.[3] While CONTAM provides a generalized modeling tool that allows users to address a broad range of problems related to contaminant transport within the built environment, FaTIMA targets a specific class of problems related to bioaerosols using a simplified building representation. The FaTIMA documentation provides information TO help users select inputs based on published information, but these input values are not meant to be recommendations for applying the tool.

The web interface of FaTIMA is divided into two sections: inputs and results, as shown in *Figure 2* and *Figure 3*, respectively. The inputs are subdivided into zone geometry, infiltration, ventilation system, system filters, calculated airflows, room air cleaner, particle properties, continuous source, burst source, particle deposition velocities, initial concentrations, and occupant exposure.

FIGURE 1 Schematic of single-zone model.

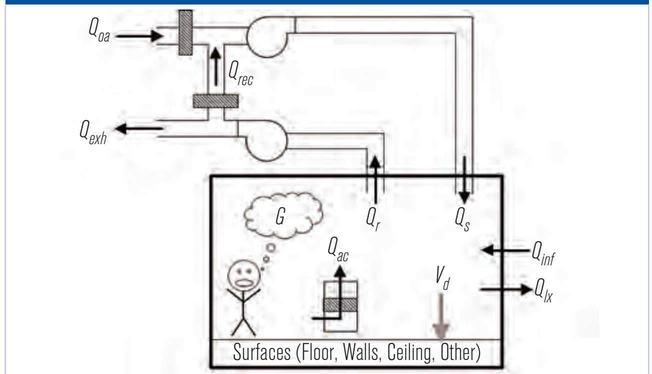


FIGURE 2 FaTIMA web interface (input section).

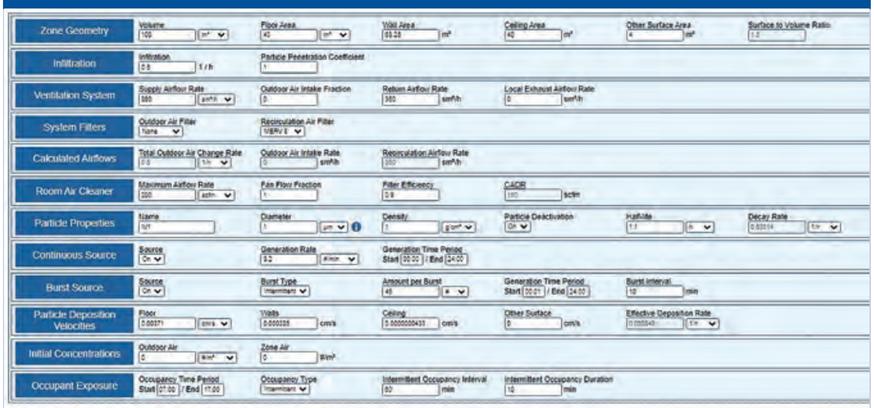


FIGURE 3 FaTIMA web interface (results section) shows numerical values (top); time histories of airborne concentration, exposure and surface loadings (middle); and summary pie charts (bottom).

Inputs

Inputs to FaTIMA (*Figure 2*) are described briefly here; more details are in the user guide (https://doi.org/10.6028/NIST.TN.2095).

Zone Geometry. Inputs include zone volume and floor, wall, ceiling and other surface areas to account for removal of airborne particles by deposition to these surfaces.

Infiltration. Air leakage through unintentional openings in the exterior envelope of a building is driven by wind, indoor-outdoor temperature difference and equipment operation. While CONTAM calculates infiltration from mass balance principles, FaTIMA uses a constant infiltration airflow rate Q_{inf} entered by the user. Although commercial buildings are often assumed to have no infiltration when HVAC systems are operating, studies have long shown that infiltration in commercial buildings can be of the same order of magnitude as system outdoor air intake rates.[4–6]

Ventilation System. The model implements a simple air-handling system (AHS) that provides supply air to and removes return air from the zone. The supply and return airflow rates, Q_s and $Q_{r,}$ respectively, the outdoor air fraction of the AHS and the local exhaust Q_{lx} are user inputs. Q_{exh} in *Figure 1* is the air leaving the system, which is calculated by FaTiIMA from the other systems airflows. The AHS model calculates the zone air balance, including the system outdoor air intake Q_{oa} and the infiltration rate Q_{inf}. It also calculates Q_{rc}, which is the return air from the space that is recirculated and mixed with the outdoor air. These three flows, Q_{oa}, Q_{inf} and Q_{rc}, are displayed as Calculated Airflows.

System Filters and Portable Air Cleaners. FaTIMA accounts for filtration of particles both within the ventilation system and by a room air cleaner. Ventilation system filters (outdoor air and recirculation) can be selected from a predefined set of filters specified according to the minimum efficiency reporting value (MERV) (per ANSI/ASHRAE Standard 52.2-2017). These filters are based on filter models correlated with specific filters and may not be representative of different filters of a given rating or account for variations in installation that affect actual efficiency.[7] Details of the MERV filter models are provided in the FaTIMA documentation.[1]

Other factors, such as airflow that bypasses the filter, can reduce the effective efficiency of a filtration system. FaTIMA can also account for the impact of a portable room air cleaner, requiring the user to define room air filter efficiencies and the airflow rate through the air cleaner, Q_{ac}, as shown in *Figure 1*.

Particle Properties. The fate of a microbiological aerosol within the built environment depends on the aerosol properties, which must be input by the user, including diameter, density, generation rate, deposition rate and deactivation rate. Aerosols generated by building occupants and other sources consist of a range or distribution of particles of varied sizes, shapes and constituent materials. However, the current version of FaTIMA only considers a single particle size in each simulation. Therefore, the simulation results will be specific to that size based on the input assumptions and the modeling strategies used.

Sources. FaTIMA accounts for two types of sources to generate particles within the zone: continuous and burst. Tidal breathing is an example of a continuous source of aerosols from a human occupant. Burst sources such as coughs or sneezes can be modeled either as a single event or as intermittent events. FaTIMA assumes all particles generated are instantly distributed throughout the entire zone volume. For FaTIMA to model particles emitted, the user must input the rate of particle generation (depicted in *Figure 1* as *G*) of the specified aerosol size. For assistance in estimating this input, users are referred to studies that have quantified the generation of pathogen-containing aerosols emitted by people infected with various illnesses when breathing, coughing and sneezing.[8–11]

If the modeling effort involves simulating viable virus-laden aerosols, then the generation rate of the aerosol containing viable viruses must be input. In addition, one may also choose to account for deactivation of viable viruses. FaTIMA allows input of a half-life (deactivation rate) to enable tracking of particles containing viable viruses that have been deactivated during the simulation period. In FaTIMA, deactivated particles are modeled as if they are removed from the air; therefore, they do not accumulate on surfaces, get removed by filters or count toward occupant exposure.

Particle Deposition Velocities. FaTIMA requires the input of deposition velocities (shown as v_d in *Figure 1*) for the particle size to be modeled. Particle deposition velocities have been measured within various environments, including occupied spaces and test chambers, and models of deposition velocity have also been developed. One such model[12] is presented in the user guide, along with some empirically estimated deposition rates for various particle sizes and types in residential buildings. FaTIMA calculates an "effective deposition rate" based on the combination of all the deposition velocities and surface areas entered for a given simulation.

Occupant Exposure. The user inputs the time during which the exposed occupant occupies the space, which can be continuous or intermittent at regular intervals. FaTIMA bases the integrated occupant exposure based on this information.

Outputs

Figure 3 shows FaTIMA's results web interface, which displays average and maximum airborne concentration for the exposure period and for the full 24-hour simulation, as well as the integrated exposure during occupancy. Time histories of the zone airborne concentration, exposure concentration and surface loading are also provided. These concentration plots also show the average concentrations associated with both the exposure period and the full 24-hour simulation period. A set of summary pie charts presents the numerical results visually to show relative values related to fate, source, surface deposition and filtration.

After a simulation is complete, the user can download a CONTAM project file and a comma-separated value (CSV) file containing the inputs and simulation results. A spreadsheet is provided into which the CSV file can be imported to allow comparisons between different scenarios. For those familiar with CONTAM, the project file can be used directly in CONTAM, which allows the exercise of CONTAM capabilities not implemented in FaTIMA.

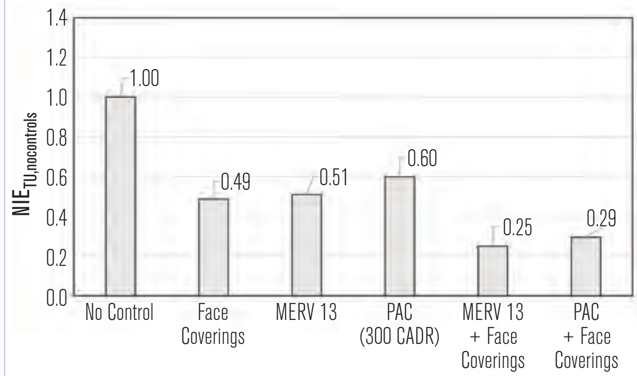
Example Application of FaTIMA

FaTIMA was used to evaluate the effect of face coverings (masks) and HVAC-related controls in a classroom for children ages 5 to 8 years.[13] In this example, the integrated exposure was modeled for a single contagious occupant (modeled as a continuous source from 9 a.m. to 3 p.m.) in a classroom ventilated according to ANSI/ASHRAE Standard 62.1-2019, *Ventilation and Acceptable Indoor Air Quality*. The space was assumed to be served by a terminal unit with a 70% recirculation rate and a MERV 6 filter. Simulations were performed for 1 µm aerosols to evaluate the following control methods separately and in combination: face coverings with a 30% filter efficiency, MERV 13 filtration, and a portable air cleaner (PAC) with a clean air delivery rate (CADR) of 142 L/s (300 cfm).

Scenarios implementing these controls were compared to the baseline case by dividing their integrated exposure by that of the baseline case to calculate a normalized integrated exposure (NIE) as shown in *Figure 4*. For example, face coverings resulted in an NIE of 0.49, meaning the exposure over the 6 hour period was reduced by approximately 50%. *Figure 4* shows that increasing to MERV 13 filtration also reduced exposure by approximately 50% and that the PAC reduced exposure by 40%. A larger capacity PAC unit could reduce exposure further. When combined with face coverings, each of the two filtration controls reduced exposure by over 70%.

FaTIMA can be accessed here: https://pages.nist.gov/CONTAM-apps/webapps/FaTIMA/index.html. A report providing more detail on the tool,[1] including a user guide, is here: https://doi.org/10.6028/NIST.TN.2095. Readers are encouraged to explore the tool and use it to study the relative effectiveness of control measures for microbiological aerosols in indoor spaces. Plans exist to further develop the tool; suggestions are welcome and can be sent to the authors at NIST.

FIGURE 4 NIE results for example case.



References

1. Dols, W.S., B.J. Polidoro, D. Poppendieck, S.J. Emmerich. 2020. *A Tool to Model the Fate and Transport of Indoor Microbiological Aerosols (FaTIMA)*. National Institute of Standards and Technology.
2. Zhu, S., S. Kato, J.-H. Yang. 2006. "Study on transport characteristics of saliva droplets produced by coughing in a calm indoor environment." *Building and Environment* 41(12): 1691–1702.
3. Dols, W.S., B.J. Polidoro. 2015. *CONTAM User Guide and Program Documentation*. National Institute of Standards and Technology.
4. Grot, R.A., A.K. Persily. 1986. "Measured air infiltration and ventilation rates in eight large office buildings." In *Measured Air Leakage of Buildings*, ed. H. Trechsel and P. Lagus. ASTM International.
5. Persily, A.K., L.K. Norford. 1987. "Simultaneous measurements of infiltration and intake in an office building." *ASHRAE Transactions* 93(2):942–56.
6. Ng, L.C., N.O. Quiles, W.S. Dols, S.J. Emmerich. 2018. "Weather correlations to calculate infiltration rates for U.S. commercial building energy models." *Building and Environment* 127:47–57.
7. Kowalski, W.J., W.P. Bahnfleth, T.S. Whittam. 1999. "Filtration of airborne microorganisms: modeling and prediction." *ASHRAE Transactions* 105(2):4–17.
8. Duguid, J.P. 1946. "The size and the duration of air-carriage of respiratory droplets and droplet-nuclei." *Epidemiology and Infection* 44(6):471–79.
9. Milton, D.K., M.P. Fabian, B.J. Cowling, M. L. Grantham, et al. 2013. "Influenza virus aerosols in human exhaled breath: particle size, culturability, and effect of surgical masks." *PLoS Pathogens* 9(3):e1003205.
10. Leconte, S., G. Liistro, P. Lebecque, J.-M. Degryse. 2011. "The objective assessment of cough frequency: accuracy of the LR102 device." *Cough* 7(1):11.
11. Lindsley, W.G., et al. 2010. "Measurements of airborne influenza virus in aerosol particles from human coughs." *PLoS One* 5(11):e15100.
12. Lai, A.C.K., W.W. Nazaroff. 2000. "Modeling indoor particle deposition from turbulent flow onto smooth surfaces." *Journal of Aerosol Science* 31(4):463–76.
13. Ng, L.C., D.G. Poppendieck, B.J. Polidoro, W.S. Dols, et al. 2020. "Simulation of controls for reducing aerosol exposure in educational spaces using FaTIMA." National Institute of Standards and Technology. ■

https://bit.ly/3khhdC5
Rate this Column