Tool Evaluates Control Measures for Airborne Infectious Agents

W. Stuart Dols
Lisa Ng
Brian J. Polidoro
Dustin Poppendieck
Steven J. Emmerich
Andrew Persily

National Institute of Standards and Technology,
Gaithersburg, MD 20899, USA

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Introduction

The purpose of the new, on-line tool *Fate and Transport of Indoor Microbiological Aerosols* (FaTIMA) is to determine the fate of infectious aerosols, e.g., those associated with SARS-CoV2, that are 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, e.g., coughing. Larger emitted droplets fall rather quickly to the ground due to gravitational settling and can impact various surfaces or ballistically enter the respiratory tract of another, nearby occupant [2]. Smaller droplet nuclei can remain airborne for longer periods of time, and these aerosolized particles are the focus of FaTIMA.

FaTIMA models the fate of such indoor microbiological aerosols due to 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 determine the risk of infection.

The underlying model for FaTIMA, shown schematically in Figure 1, consists of a single zone characterized by a uniform aerosol concentration that is served by a mechanical ventilation system and incorporates source and removal mechanisms of an aerosol with a single, user-defined representative size. (Users who need to understand spatial variations in aerosol concentrations 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 are provided to enable 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.

FaTIMA employs the solver of the CONTAM program, which has been used for decades for multi-zone, 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.

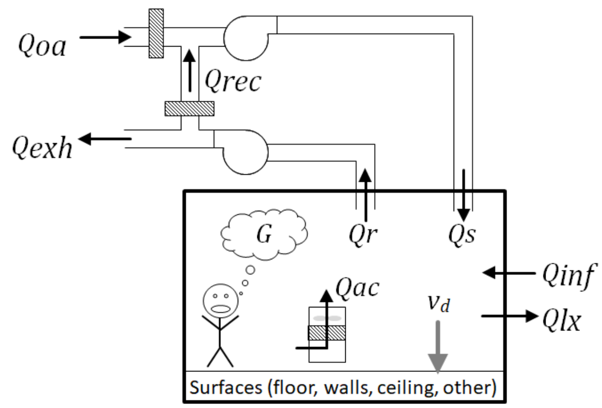

Figure 1 – Schematic of Single-zone Model

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 further 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*.

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 rate: Air leakage through unintentional openings in the exterior envelope of a building, driven by wind, indoor-outdoor temperature difference and equipment operation. CONTAM calculates infiltration from mass balance principles, but FaTIMA uses a constant value Q_{inf} entered by the user. While commercial buildings are often assumed to have no infiltration when heating, ventilation, and air-conditioning (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 FaTIMA from the other system airflows. The AHS model calculates the zone air balance, including the system outdoor air intake Q_{oa}. It also calculates Q_{rec}, 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_{rec}, are displayed as Calculated Airflows.

System Filters and Portable Air Cleaners: FaTIMA accounts for filtration of particles 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 that were correlated with specific filters and may not be representative of specific 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.

It is important to note that other factors can reduce the effective efficiency of a filtration system, such as airflow that bypasses the filter. 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 microbiological aerosols 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, are made up of a range or distribution of particles of varied sizes, shapes, and constituent materials. However, the current version of FaTIMA on considers a single particle size in each simulation. Therefore, it is important to understand that the simulation results will be specific to that size based on the input assumptions and the modeling strategies employed in the tool.

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 using FaTIMA as either 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 provides for the input of a half-life (deactivation rate) to enable tracking particles that contain 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 towards occupant exposure.

Particle Deposition Velocities: FaTIMA requires the input of deposition velocities for the modeled particle size. Particle deposition rates have been measured within various environments including occupied spaces and test chambers, and models of deposition velocity have also been developed. One such model is presented in the user guide [12], along with some empirically determined deposition rates for various particle sizes and types in residential buildings. FaTIMA provides 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 on this information.

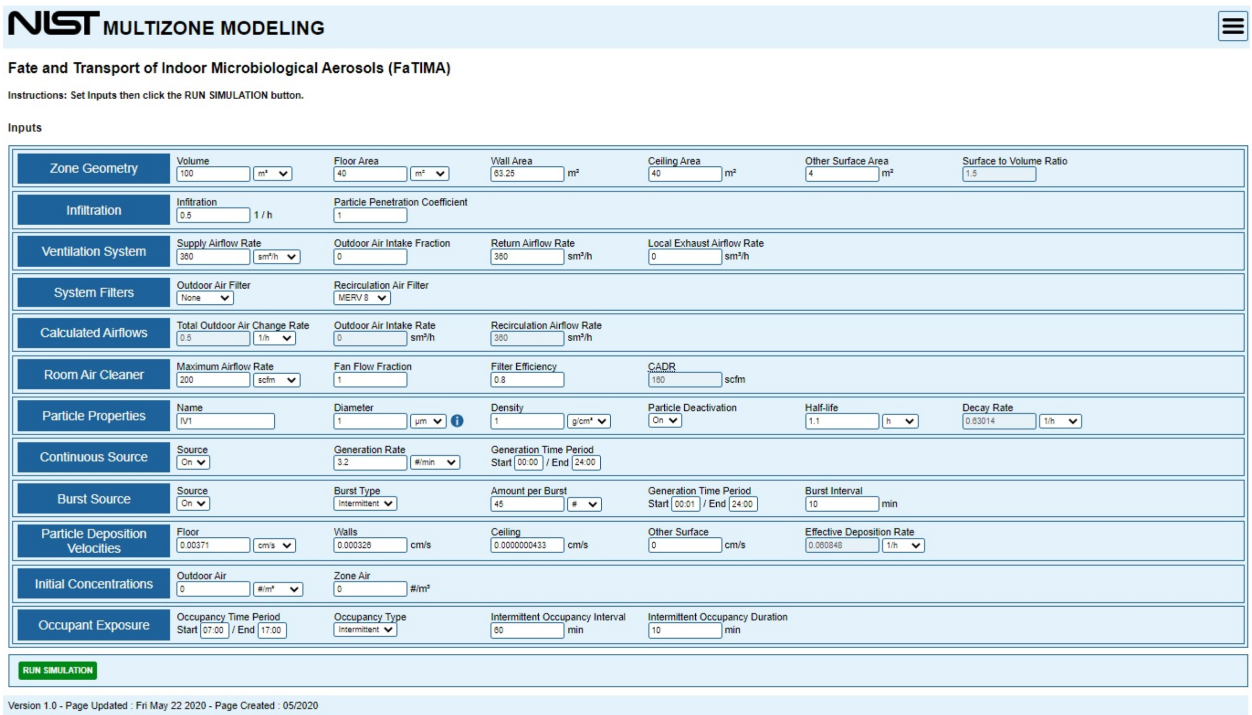

Figure 2 – FaTIMA web interface (Input section)

Outputs

Figure 3 shows FaTIMA's results web interface, which average and maximum aerosol 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 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 to show relative values related to fate, source, surface deposition and filtration.

After a simulation has been completed, the user can download a CONTAM project file and 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 for comparisons between different scenarios. For those familiar with CONTAM, the project file can be used directly in CONTAM for those familiar with its interface, which allows the exercise of CONTAM capabilities not implemented in FaTIMA.

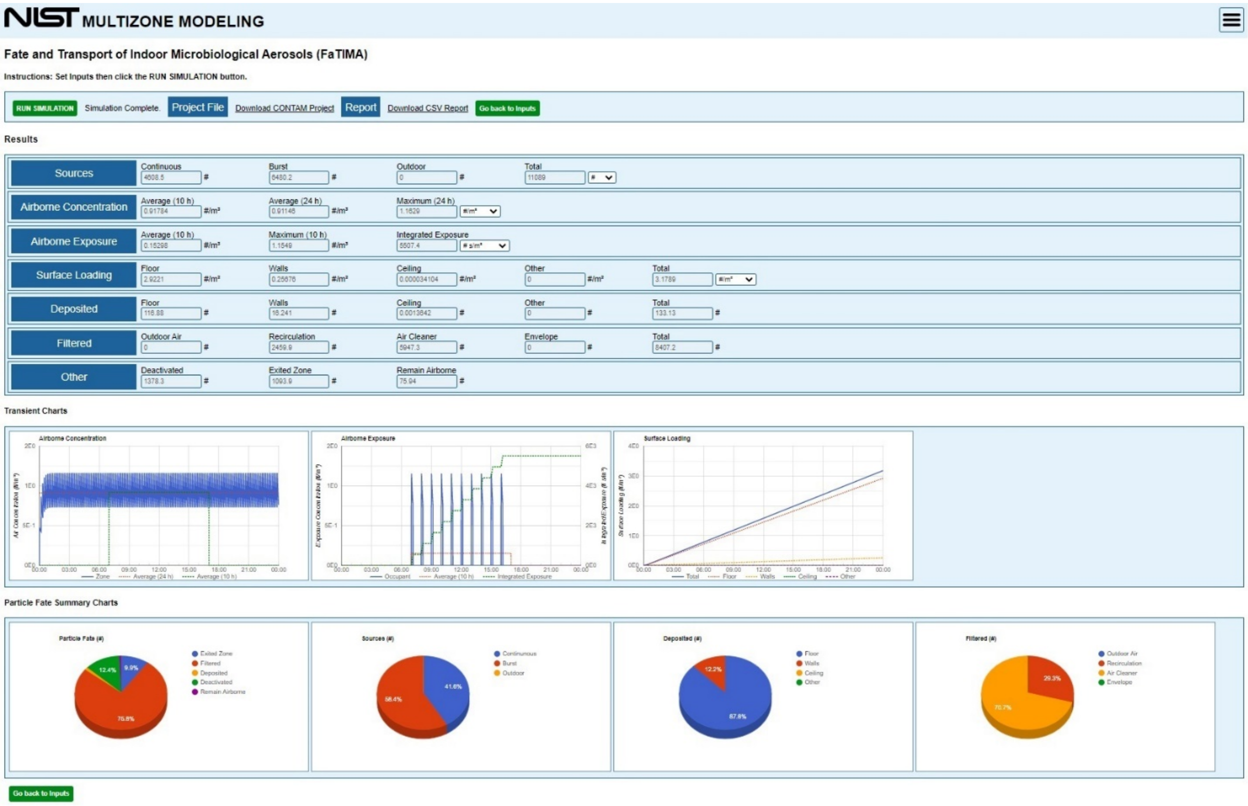

Figure 3 – FaTIMA web interface (Results section) shows numerical values (top); time histories of airborne concentration, exposure and surface loadings (middle); and summary pie charts (bottom)

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 determined for a single contagious occupant in a classroom ventilated according to ANSI/ASHRAE 62.1-2019, *Ventilation for Acceptable Indoor Air Quality*. The space was assumed to be served by a terminal unit with a 70 % recirculation rate and 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 which implemented these controls were compared to the baseline case by dividing their integrated exposure by that of the baseline case to determine a normalized integrated exposure (NIE) as shown in Figure 4. For example, face coverings result 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 50 %, and the PAC reduced exposure by 40 %. It should be noted that a larger capacity PAC unit could reduce exposure further. Each of the two filtration controls combined with face coverings reduced exposure over 70 %.

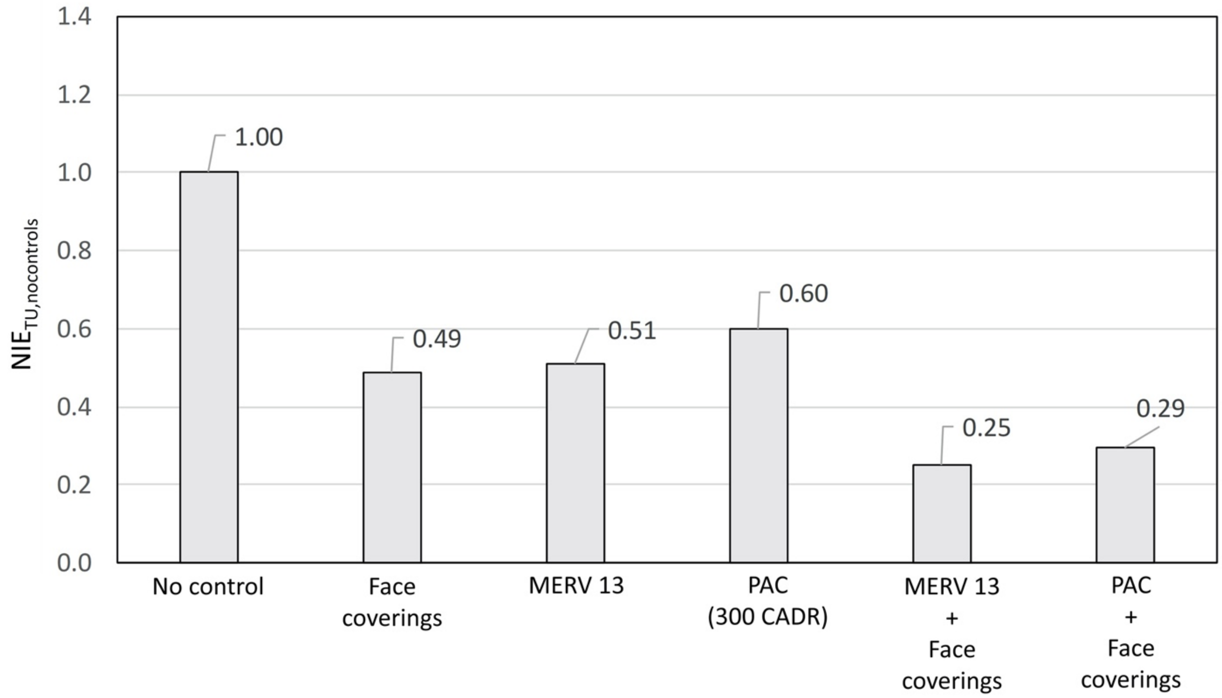

Figure 4 – NIE results for example case

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

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