Framework and case study for understanding factors impacting outdoor contaminant entry into commercial buildings

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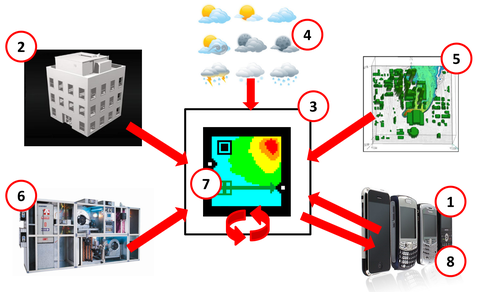
Introduction

Recent research and surveys have shown the negative impacts of outdoor pollutants on indoor air quality (IAQ), particularly ozone and fine particles. Building design and operation strategies can help reduce these impacts but many questions remain about the factors affecting their entry rates. The ability to accurately assess indoor exposure associated with outdoor contaminant entry is therefore important in building design standards and practice, as well as the regulation of ambient air pollutants.

Framework

The end result of this work could be a user-friendly tool that quickly and easily evaluates levels of building contamination and outputs a metric to aid in decision-making. The tool would rely on three main components:

- Simulation engine wrapped in a GUI
- Database of building models to populate engine
- Weather, contamination and pertinent building factors

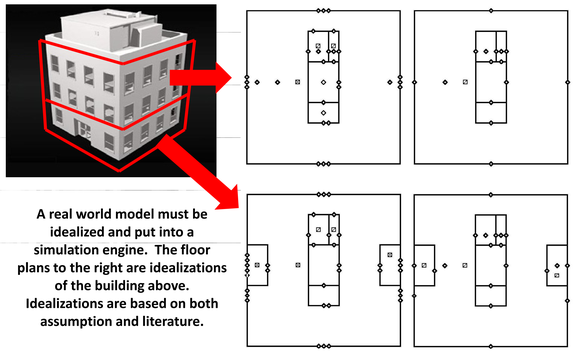


1) User operates smart device or computer pre-loaded with tool
2) User selects building configuration based on database of existing models
3) Tool opens guided user interface (GUI) which populates the CONTAM engine
4) User interacts with GUI to define weather patterns
5) User interacts with GUI to define probable contamination delivery and pattern
6) User interacts with GUI to update pertinent building factors
7) CONTAM engine runs based on existing building model and user input
8) Metric is delivered to discern degree of probable contamination

Medium Office Case Study

Contaminants are known to come in many shapes and sizes. For this study, a one micron particle is used based on the characteristics of many biological contaminants of concern. Additionally, preliminary simulations assume an outdoor plume of contamination persisting for ten minutes. The levels of contamination of the cloud are approximately one hundred times the typical urban levels for a one micron particle (Riley, 2002).

For the development of the building model database, preliminary simulation studies for a medium office building have been conducted to understand the various factors and their interactions affecting outdoor contaminant entry, including building configuration and airtightness, system design and operation, and weather conditions.



A real world model must be idealized and put into a simulation engine. The floor plans to the right are idealizations of the building above. Idealizations are based on both assumption and literature.

The figure above shows the idealized model of a medium office building in CONTAM, the multizone airflow and contaminant transport simulation engine used for this study (Walton and Dols, 2005). The physical characteristics of the building are based on reference buildings defined by Deru et al., a collection of buildlings that compiles the physical characteristics of more than 60% of the U.S. commercial building stock covering 16 types and 16 U.S. locations. Other assumptions have been tabulated below.

Table 1. Default Medium Office Building Characteristics

Value	Units	Comments	Source
3	-	Number of floors	Deru et al., 2010
1675	m^2	Gross floor area	Deru et al., 2010
2.74	m	Deck to plenum height	Deru et al., 2010
40.90	m	Building length	Deru et al., 2010
1	-	Aspect ratio	Deru et al., 2010
1.22	m	Plenum to deck height	Deru et al., 2010
13.94	m^2	Elevator shaft floor area	Industry standard
13.94	m^2	Stairwell shaft floor area	Industry standard
37.16	m^2	Loading dock floor area	Assumed
18.58	m^2	Lobby floor area	Assumed
9.29	m^2	Bathroom floor area (each)	Industry standard
2	-	Toilets per bathroom	Industry standard
2	-	Bathrooms per floor	Industry standard
50	CFM/toilet	Bathroom exhaust rate	Industry standard
1	CFM/SF	Design supply air flowrate	Assumed

Aside from the physical definition of the model, pertinent building characteristics are assumed to share a direct relationship with indoor contamination levels. Pertinent characteristics must be easily defined and obtainable, yet specific enough to accurately calculate indoor contaminant levels. The current metrics for understanding contaminant levels include:

1) **Entrained contaminant mass relative to the baseline**
2) **Entrained contaminant location**

The pertinent building factors for this simulation include:

1) **Air-Handler Unit (AHU) Operation** – Defines the amount of outdoor air (OA) entering the building through mechanical means.
2) **Air-Handler Unit (AHU) Filtration** – Defines the level of particulate filtration installed in the mechanical systems.
3) **Envelope Tightness** –A "leakier" envelope will allow more contaminant entry via infiltration, while a "tighter" envelope will allow less infiltration entry.
4) **Envelope Penetration Factor** – Defines the percentage of contamination that is lost upon passing through the building envelope based on crack characteristics.
5) **Weather Conditions** - Outdoor temperature, wind speed, and wind direction all building infiltration rate and the associated contaminant entry.
6) **Particle Deposition** - Defines the mass of contaminant that deposits on indoor surfaces based on particle size deposition surface area.

Factorial simulation of these factors allows one to draw conclusions about the synergistic effects that these factors may have on one another. Since AHU operation (either on or off) are directly related to the values of some variables, two sets of factorial simulations have been designed, with their values tabulated below.

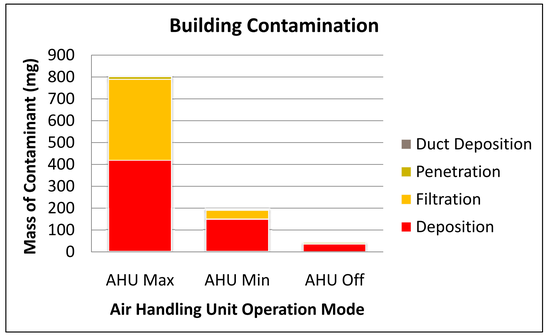
Table 2. Pertinent Characteristics when AHU is On

Low	Base	High	Variable	Description	Source or Assumptions
-	12	100	%	Air handler operation OA percentage	Typical operating range
0.5	0.9	1	ratio	Micron envelope penetration factor	Liu, 2001
-	6	11	MERV	AHS supply-side filter efficiency	Industry standard
2	5	8	cm2/m2	Envelope leakage (@ 4 Pa)	Emmerich, 2005
7.5E-5	3.0E-4	4.0E-4	m/s	Micron deposition velocity (fan on)	Howard-Reed et al., 2003
2.0E-5	6.0E-5	3.0E-4	m/s	Micron deposition velocity (fan off)	Howard-Reed et al., 2003
2.0E-5	2.0E-4	2.0E-4	ratio	Equivalent duct/filter efficiency	Sippola, 2002

Table 3. Pertinent Characteristics when AHU is Off

Low	Base	High	Variable	Description	Source or Assumptions
-	0	-	%	Air handler operation OA percentage	Typical setting
0.5	0.9	1	ratio	Micron envelope penetration factor	Liu, 2001
2	5	8	cm2/m2	Envelope leakage (@ 4 Pa)	Emmerich, 2005
2.0E-5	6.0E-5	3.0E-4	m/s	Micron deposition velocity (fan off)	Howard-Reed et al., 2003
2.0E-5	2.0E-4	2.0E-4	ratio	Equivalent duct/filter efficiency	Sippola, 2002

A total of six weather configurations are used for these simulations, based on combinations of outdoor temperature and directions. The weather profiles were based on weather from a mixed-humid climate, more specifically Baltimore, MD.



As an example of the kinds of outputs generated by these simulations, the figure above compares the base case to alterations in the AHU operation modes.

Analysis and Conclusions

In order to understand all of the results of this case study, approximately 800 simulation scenarios will need to be analyzed. However, the results of simply altering AHU operating procedures yields interesting results. For all three cases, penetration and duct deposition seem to play relatively no role in contamination, while deposition and filtration play more distinct roles. Additionally, a building is most to contamination vulnerable when operating in a mode where there is 100 % OA, since it is introducing such a large amount of contaminated outdoor air into the building. Alternatively, a building operating with the AHU shut off encounters the lowest levels of contamination. It will still be contaminated because the AHU no longer pressurizes the building and may allow higher levels of contamination through infiltration.

The information presented from this case study would suggest that if the infrastructure for a tool of this nature were to exist, an end user would simply need to define one variable to delineate between more severe and less severe cases of contamination. Further case studies intend to explore which variables are pertinent to evaluate contamination levels, which variables are missing from considering, and if one variable can be utilized in isolation to deliver similar results to the ones shown here.

Sources

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Acknowledgements

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For Further Information

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