Infiltration in Energy Modeling: A Simple Equation Made Better

Lisa Ng
Andrew Persily
Steven Emmerich

Engineering Laboratory, National Institute of Standards and Technology
100 Bureau Drive Gaithersburg, MD 20899

Content submitted to and published by:
ASHRAE Journal
Volume 56; Issue 7; pp.70-72

U.S. Department of Commerce
Penny Pritzker, Secretary of Commerce

National Institute of Standards and Technology
Willie E May, Acting Director

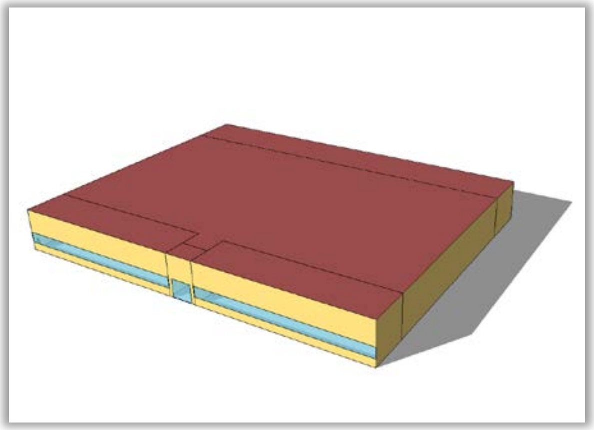
NIST National Institute of Standards and Technology • U.S. Department of Commerce

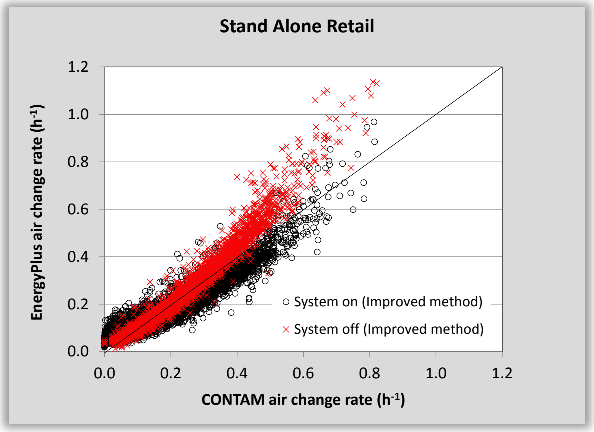
DISCLAIMERS

Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

Any link(s) to website(s) in this document have been provided because they may have information of interest to our readers. NIST does not necessarily endorse the views expressed or the facts presented on these sites. Further, NIST does not endorse any commercial products that may be advertised or available on these sites.

Infiltration in energy modeling: a simple equation made better





As building envelope performance and HVAC equipment efficiencies continue to be improved to reduce building energy use, a greater percentage of the total energy loss of a building can occur through envelope leakage. Although the energy impacts of unintended infiltration on a commercial building's energy use can be significant (Emmerich et al. 2005), current energy simulations and building designs generally do not accurately account for envelope infiltration and the impacts of improved airtightness. New strategies to incorporate airflow calculations into building energy calculations have been developed, which are more accurate than current approaches in energy simulation software and easier to apply than multizone airflow modeling (Ng et al. 2014). These new strategies are based on relationships between infiltration rates calculated using multizone airflow models, weather conditions, and building characteristics, including envelope airtightness and HVAC system operation.

INFILTRATION IN ENERGY MODELING NOW

Infiltration has long been recognized as a key component of heating and cooling loads. Various methods exist to account for infiltration in load calculations and more detailed energy analysis. EnergyPlus uses the following empirical equation to calculate infiltration:

$$\text{Infiltration} = I_{\text{design}} \bullet F_{\text{schedule}} \left[A + B|\Delta T| + C \bullet W_{\text{s}} + D \bullet W_{\text{s}}^{2}\right] \qquad (1)$$

where I_{design} is defined by EnergyPlus as the "design infiltration rate", which is the airflow through the building envelope under design conditions. Its units are selected by the user and can be h^{-1}, $m^3/s \bullet m^2$ or m^3/s. F_{schedule} is a factor between 0.0 and 1.0 that can be scheduled, typically to account for the impacts of fan operation on infiltration. $|\Delta T|$ is the absolute indoor-outdoor temperature difference in °C, and W_{s} is the wind speed in m/s. *A*, *B*, *C*, and *D* are constants, for which values are suggested in the EnergyPlus user manual (DOE 2013). However, those values are based on studies in low-rise residential buildings and may not be applicable to taller buildings and mechanically ventilated buildings. Given the challenges in determining valid coefficients for a given building, a common strategy used in EnergyPlus for incorporating infiltration is to assume fixed infiltration rates, sometimes using a different constant value depending on whether the HVAC system is on or off. However, this strategy does not reflect known dependencies of infiltration on outdoor weather and the complexities of HVAC system operation.

A SIMPLE EQUATION MADE BETTER

A new strategy has been developed that can more accurately estimate infiltration in EnergyPlus and other energy simulation tools. In this method, A, B, and D values in Equation (1) are determined based on key building characteristics. (Note that C is assumed to be equal to zero since the infiltration rates were not highly impacted by that term as demonstrated in Ng et al. (2014).) The building characteristics considered are: building height (H in m), exterior surface area to volume ratio (SV in m^2/m^3), and net system flow (i.e., design supply air minus design return air minus mechanical exhaust air) normalized by exterior surface area (F_n in $m^3/s{\bullet}m^2$). Note that the exterior surface area was calculated considering the building surfaces subject to infiltration, which are the above-grade walls and roof. This is different than the approach taken in Appendix G of ASHRAE 90.1-2013, but the two values can easily be converted to one another (ASHRAE 2013). The following relationships between these constants and the building characteristics (H, SV, and F_n) were considered:

$$A = M_A \cdot H + N_A \cdot SV + P_A \cdot F_n \tag{2}$$
$$B = M_B \cdot H + N_B \cdot SV + P_B \cdot F_n \tag{3}$$
$$D = M_D \cdot H + N_D \cdot SV + P_D \cdot F_n \tag{4}$$

where M, N, and P are constants, and their subscripts distinguish them between A, B, and D.

Seven commercial reference buildings (DOE 2011) were selected for testing this method: Full Service Restaurant, Hospital, Large Office, Medium Office, Primary School, Stand Alone Retail, and Small Hotel. Building-specific A, B and D values were calculated by conducting annual simulations using the multizone airflow model CONTAM (Walton and Dols 2013). Details of the CONTAM and EnergyPlus simulations can be found in Ng et al. (2014), which includes system flow rates. These simulations were performed on an hourly basis over one year using Chicago weather and assuming an above-grade envelope leakage of 0.00137 $m^3/s{\bullet}m^2$ at 4 Pa (Ng et al. 2014). The building-specific A, B and D values and the building characteristics of the seven buildings were fit to Equations (2) through (4) to calculate M, N, and P. Equations (5) through (10) show the results for system-on and system-off conditions, assuming that $A = 0$ and the net system flow is zero ($F_n = 0$) when the system is off.

$$A_{on} = 0.0001 \cdot H + 0.0933 \cdot SV + -47 \cdot F_n \tag{5}$$
$$B_{on} = 0.0002 \cdot H + 0.0245 \cdot SV + -5 \cdot F_n \tag{6}$$
$$D_{on} = 0.0008 \cdot H + 0.1312 \cdot SV + -28 \cdot F_n \tag{7}$$

$$A_{off} = 0 \tag{8}$$
$$B_{off} = 0.0002 \cdot H + 0.0430 \cdot SV \tag{9}$$
$$D_{off} = -0.00002 \cdot H + 0.2110 \cdot SV \tag{10}$$

The following is an example of the proper use of these equations. The Stand Alone Retail Reference Building is 6.1 m in height, has a surface-to-volume ratio of 0.24 m^2/m^3, and a normalized net system flow of 0.00021 $m^3/s \bullet m^2$. Plugging these values into Equations (5) through (10) yields

$$A_{on} = 0.0137 \qquad A_{off} = 0$$
$$B_{on} = 0.0059 \qquad B_{off} = 0.0119$$
$$D_{on} = 0.0311 \qquad D_{off} = 0.0515$$

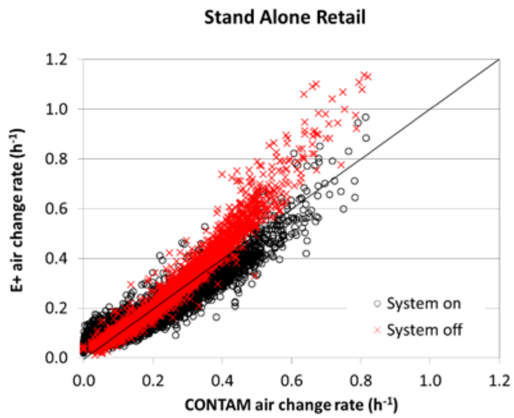
A, *B*, and *D* were calculated for each of the seven reference buildings using these equations and are listed in Table 1. They were then input into the EnergyPlus ZoneInfiltration:DesignFlowRate object. A_{on}, B_{on}, and D_{on} were used with $F_{\text{schedule}} = 1.0$ during system-on hours and $F_{\text{schedule}} = 0.0$ during system-off hours. A_{off}, B_{off}, and D_{off} were used with $F_{\text{schedule}} = 1.0$ during system-off hours and $F_{\text{schedule}} = 0.0$ during system-on hours.

Table 1. *A*, *B*, and *D* values of simulated buildings using Equations (5) through (10)

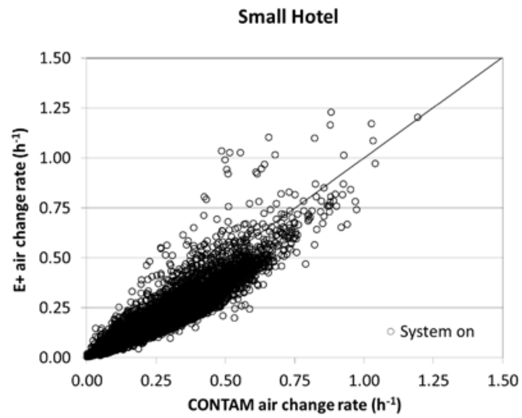
	Full Service Restaurant	Hospital (always on)	Large Office	Medium Office	Primary School	Small Hotel (always on)	Stand Alone Retail
***A* on**	0.1424	-0.0349	-0.0466	-0.0082	0.0310	-0.0008	0.0137
***B* on**	0.0186	0.0014	0.0040	0.0036	0.0088	0.0050	0.0059
***D* on**	0.1004	0.0049	0.0160	0.0177	0.0468	0.0256	0.0311
***A* off**	0	NA	0	0	0	NA	0
***B* off**	0.0086	NA	0.0155	0.0106	0.0154	NA	0.0119
***D* off**	0.0427	NA	0.0175	0.0437	0.0710	NA	0.0515

COMPARING RESULTS USING NEW EQUATIONS TO CONTAM

The Stand Alone Retail and Small Hotel generally have the lowest relative standard errors and highest R^2 of the buildings when comparing the EnergyPlus infiltration rates (calculated using the new method) with the CONTAM rates. Figure 1 shows two buildings for which the EnergyPlus results (using the new equations) matched particularly well with the CONTAM results: the Stand Alone Retail and Small Hotel. Each point corresponds to a single hour in the year. Results for the other buildings can be found in Ng et al. (2014). The average system-on error, excluding the Hospital and Large Office, is 25 % and the average system-off error is 17 %. The Hospital and Large Office had the lowest infiltration rates, making their relative standard errors (in percentages) higher than the other buildings.



(a)



(b)

Figure 1: EnergyPlus vs. CONTAM infiltration rates

The results of using the new method are promising given that it was developed using only seven buildings. Tests of the method were also performed on other buildings and for two other building envelope leakage values; the results of these tests can be found in Ng et al. (2014).

POTENTIAL CHANGES TO ENERGYPLUS

In developing this method, limitations in the infiltration models currently in energy simulation tool were identified, which could be addressed through minimal modifications. For example, Equation (1) assumes that infiltration is symmetrical about $|\Delta T|$. However, based on the physics of airflow in mechanically ventilated buildings, as reflected in the CONTAM simulation results, infiltration rates are not necessarily symmetrical around an indoor-outdoor temperature difference of zero when fans are on. In such cases, the absolute value of indoor-outdoor temperature difference ($|\Delta T=0|$) in Equation (1) will not accurately account for infiltration at negative indoor-outdoor temperature differences. This limitation could be overcome by allowing for negative indoor-outdoor temperature differences in the calculation of infiltration in EnergyPlus.

CONCLUSIONS

Due to an increased emphasis on energy consumption and greenhouse gas emissions, the potential savings from energy efficiency measures are often analyzed using energy simulation software. However, the impact of implementing some efficiency measures is oftentimes incomplete because building envelope infiltration is not properly accounted for within energy simulation models. Many of the airflow estimation approaches implemented in current energy software tools are inappropriate for large buildings or are otherwise limited. Based on the relationship between building envelope airtightness, building characteristics, weather, and system operation, methods have been developed to calculate infiltration rates that are comparable to performing multizone calculations. These methods show better accuracy when compared with existing approaches to estimating infiltration in commercial building energy calculations. However, more testing is needed in additional buildings and climates.

REFERENCES

ASHRAE (2013). ANSI/ASHRAE/IES Standard 90.1-2013: Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

DOE (2011). Commercial Reference Buildings from http://energy.gov/eere/buildings/commercial-reference-buildings.

DOE (2013). EnergyPlus 8.1. Washington, D. C., U. S. Department of Energy.

Emmerich, S. J., T. P. McDowell and W. Anis (2005). Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use. NISTIR 7238. Gaithersburg, MD: National Institute of Standards and Technology.

Ng, L. C., S. J. Emmerich and A. K. Persily (2014). An Improved Method of Modeling Infiltration in Commercial Building Energy Models. Technical Note 1829. Gaithersburg, MD: National Institute of Standards and Technology. http://dx.doi.org/10.6028/NIST.TN.1829

Walton, G. N. and W. S. Dols (2013). CONTAM User Guide and Program Documentation. NISTIR 7251. Gaithersburg, MD: National Institute of Standards and Technology.