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NIST Technical Note 2221

Implementing NIST Infiltration Correlations

Jyrteanna Teo
Lisa C. Ng

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NIST Technical Note 2221

Implementing NIST Infiltration Correlations

Jyrteanna Teo

Lisa C. Ng

Building Environment and Energy Division

Engineering Laboratory

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Abstract

This tutorial is a guide on how to implement the NIST infiltration correlations (Ng et al., 2021) into EnergyPlus building energy simulation software for the US Department of Energy prototype commercial buildings. The implementation can also be generalized to other building energy simulation software and other building models.

Key words

Infiltration; energy modeling; airflow modeling; DOE prototype commercial buildings; tutorial.



Implementing NIST infiltration correlations

PREPARED BY JYRTEANNA TEO & LISA NG
ACCOMPANYING VIDEO TUTORIAL BY ETHAN YEN

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1. Introduction

The Department of Energy (DOE) estimates that air leakage (or “infiltration”) through building envelopes accounted for 6 % of the total energy consumed by commercial buildings in 2010 (DOE 2014). Air barrier requirements are now included in the versions of ASHRAE Standards 90.1-2010 and 189.1-2017 and newer.

The potential building energy savings of air barriers is often evaluated using building energy simulation software, such as EnergyPlus (DOE 2020). In EnergyPlus, one of the approaches to accounting for air leakage into a building is the `ZoneInfiltration:DesignFlowRate` object. This object provides zone air leakage rates based on user inputs of a “design flow (leakage) rate” and empirically based coefficients (A , B , C and D in Equation (1)). This was based on the work by Coblenz and Achenbach (1963).

$$\text{Leakage rate} = I_{\text{design}} \cdot F_{\text{schedule}} [A + B|\Delta T| + C \cdot W_s + D \cdot W_s^2] \quad (1)$$

where I_{design} is the leakage rate under design conditions in units of $\text{m}^3 \cdot \text{s}^{-1} \cdot \text{m}^{-2}$ ^a of envelope surface area (further referred to as the “design leakage rate”). F_{schedule} is scheduled between 0.0 and 1.0 to account for the impacts of fan operation on leakage. $|\Delta T|$ is the absolute difference between indoor temperature (T_{in}) and outdoor temperature (T_{out}) in $^{\circ}\text{C}$ ^b, and W_s is the wind speed in $\text{m} \cdot \text{s}^{-1}$ ^c.

It should be noted here that the term “leakage” is used above (instead of “infiltration”) because infiltration is not a function of absolute temperature difference. When the $T_{\text{out}} < T_{\text{in}}$ (not accounting for wind direction or wind speed), air enters a building zone since $T_{\text{in}} - T_{\text{out}} > 0$. Conversely, when $T_{\text{out}} > T_{\text{in}}$ (not accounting for wind direction or wind speed), air leaves a building zone since $T_{\text{in}} - T_{\text{out}} < 0$.

Nevertheless, the term “infiltration” will be used for the rest of the tutorial since “infiltration” is a commonly used term for air leakage.

1.1. Infiltration in ASHRAE 90.1 and Prototype Buildings

The form of Eq. (1) that is in Appendix G of ASHRAE 90.1-2019 (ASHRAE 2019) and also in the latest versions of the US Department of Energy (DOE) commercial prototype buildings (Goel et al., 2014) is:

$$\text{Leakage rate} = I_{\text{design}} \cdot F_{\text{schedule}} [0.224 \cdot W_s] \quad (2)$$

where the effects of temperature are not included based on sensitivity analyses performed using the Medium Office Prototype Building, which has a square footprint and is three-stories tall (Gowri et al., 2009). The wind-squared term is also not included even though wind pressure on a

^a These units must be used in EnergyPlus. Divide $\text{cfm} \cdot \text{ft}^{-2}$ by 196 to get $\text{m}^3 \cdot \text{s}^{-1} \cdot \text{m}^{-2}$.

^b To calculate $|\Delta T|$ using temperatures in units $^{\circ}\text{F}$, first convert temperatures into $^{\circ}\text{C}$ ($^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times 5/9$), then take the absolute difference.

^c These units must be used in EnergyPlus. Multiply mph by 0.44 to get $\text{m} \cdot \text{s}^{-1}$.

building surface is defined in ASHRAE Fundamentals as function of the square of the wind speed (ASHRAE 2021).

In Eq. (2), the result from a building airtightness pressurization test at 75 Pa (0.3 in. w.c.) is often used as the I_{design} value. However, buildings typically do not operate at this high of a pressure difference.

Lastly, the F_{schedule} in the prototype building models is assumed to be 1.0 when the ventilation system is scheduled to be off and 0.25 when the ventilation is scheduled to be on.

1.2. Why NIST infiltration correlations are an improvement

To analyze the appropriateness of the assumptions in Eq. (2) used in ASHRAE 90.1-2019 and the DOE commercial prototype building models, the National Institute of Standards and Technology (NIST) performed simulation studies using CONTAM models of the DOE commercial prototype buildings. CONTAM is a physics-based, validated multizone airflow and contaminant transport program developed at NIST (Dols and Polidoro 2020).

NIST found that the EnergyPlus DOE prototype building models over-estimated infiltration rates in warmer climates and under-estimated them in colder climates, demonstrating the need to include temperature when estimating infiltration rates (Ng et al., 2021). On average, differences between CONTAM and EnergyPlus infiltration rates were 43 %. NIST also found that the assumption that infiltration is reduced ($F_{\text{schedule}} = 0.25$) during ventilation-on hours under-estimates infiltration by about 25 % annually.

Lastly, the benefits of air tightening are not fully captured in the EnergyPlus DOE prototype building models or by Appendix G ASHRAE 90.1-2019. Increasing the building envelope airtightness by 43 % on average, EnergyPlus estimated the ventilation-related annual energy savings were an average of $0.9 \text{ kBtu}\cdot\text{ft}^{-2}$ ^d for 11 DOE prototype buildings across eight climate zones. However, using the NIST correlations described in this tutorial, the average savings increased to $1.4 \text{ kBtu}\cdot\text{ft}^{-2}$, about a 55 % increase.

1.3. What are the NIST infiltration correlations?

Given the significant energy impacts of unintended infiltration on building energy use, NIST has been developing tools to better account for infiltration in building energy models. One of these tools was the development of weather-correlated infiltration inputs (or “NIST infiltration correlations”) for Eq. (1) using CONTAM (Ng et al., 2021).

CONTAM is a multizone airflow simulation software developed at NIST (Dols and Polidoro 2020). CONTAM accounts for room-to-room, infiltration and exfiltration airflows driven by temperature-induced pressures (i.e., stack effect), wind pressures acting on the building exterior, and mechanically-driven pressure differences (i.e., HVAC system flows). CONTAM is able to perform whole-building simulations for periods of up to one year, and its computational time is

^d This unit is also commonly referred to as energy use intensity (EUI). Multiply $\text{kBtu}\cdot\text{ft}^{-2}$ by $9.8\text{e-}5$ to get $\text{GJ}\cdot\text{m}^{-2}$.

not as intensive as other airflow simulation methods (e.g., computational fluid dynamics). CONTAM has been validated in terms of program integrity (Haghighat and Megri 1996), laboratory experiments (Haghighat and Megri 1996) and field studies in residential buildings (Chung 1996; Emmerich 2001; Emmerich et al., 2004; Haghighat and Megri 1996). There have also been studies using CONTAM to compare measured and simulated tracer gas concentrations in three large commercial buildings (Black and Price 2009).

CONTAM simulations of annual hourly infiltration were first performed for eleven DOE commercial prototype buildings (Goel et al., 2014) in eight cities and for two levels of building envelope airtightness. The prototype buildings used were:

1. Highrise Apartment
2. Hospital
3. Large Hotel
4. Medium Office
5. Midrise Apartment
6. Primary School
7. Secondary School
8. Small Hotel
9. Small Office
10. Stand Alone Retail
11. Strip Mall

There were five commercial prototype building models for which infiltration correlations were not developed. The two restaurant models, Large Office, Outpatient Hospital, and Warehouse were not included.

The DOE commercial prototype buildings were originally created in EnergyPlus to support the development of ASHRAE Standard 90.1.

The eight cities (and climates zones, CZ) were:

1. Miami (CZ1)
2. Phoenix (CZ2)
3. Memphis (CZ3)
4. Baltimore (CZ4)
5. Chicago (CZ5)
6. Helena (CZ6)
7. Duluth (CZ7)
8. Fairbanks (CZ8)

Two design leakage rates were used:

- Without air barrier $3.8 \text{ L}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ @ 75 Pa ($0.75 \text{ cfm}\cdot\text{ft}^{-2}$ @ 0.3 in. w.c.) (5-sided value)
- With air barrier $2.2 \text{ L}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ @ 75 Pa ($0.42 \text{ cfm}\cdot\text{ft}^{-2}$ @ 0.3 in. w.c.) (average 5-sided values).

It should be noted when airtightness guidance is given as “5-sided”, it means the pressurization test result is normalized over 5 sides of a building (walls + roof). When airtightness guidance is given as “6-sided”, it means the pressurization test result is normalized over 6 sides of a building (walls + roof + floor). The design leakage rate of the building models with air barriers above were derived from 6-sided values in existing literature ($1.4 \text{ L}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ @ 75 Pa or $0.27 \text{ cfm}\cdot\text{ft}^{-2}$ at 0.3 in. w.c.) (Emmerich and Persily 2014).

The 5-sided design leakage rates were converted to I_{design} ($\text{m}^3\cdot\text{s}^{-1}\cdot\text{m}^{-2}$) @ 4 Pa (0.02 in. w.c.) for use in the EnergyPlus `ZoneInfiltration:DesignFlowRate` object (see values in Table 1).

Buildings do not operate at a constant pressure difference. Using a 4 Pa (0.02 in. w.c.) value may also be unrealistic because even an average operational pressure difference will be unique to each building. Nevertheless, 4 Pa (0.02 in. w.c.) is used here because the DOE commercial prototype building models adopted this pressure difference for I_{design} . Also listed in Table 1 is the general HVAC operation schedule and what EnergyPlus objects are needed to implement the NIST infiltration correlations. Any buildings with 24 h HVAC operation (e.g., Highrise Apartment, Hospital, Large Hotel, Midrise Apartment, and Small Hotel), require a `ZoneInfiltration:DesignFlowRate` object with an associated `Infiltration-ON` schedule. For the remaining buildings (Medium office, Primary School, Secondary School, Stand Alone Retail, and Strip Mall), a second `ZoneInfiltration:DesignFlowRate` object is needed with an associated `Infiltration-OFF` schedule.

All buildings require a `ZoneList` object.

It should be noted that many factors contribute to the tightness of a building envelope and does not solely depend on an air barrier. Sealing joints and other measures are also necessary to achieve a continuous air barrier as required in building standards and codes. Nevertheless, the terms “without air barriers” and “with air barriers” are used in this tutorial to represent the building models with two different building envelope airtightness values.

Table 1. Summary of 11 DOE prototype buildings and EnergyPlus objects needed for NIST infiltration correlations

	Highrise Apartment	Hospital	Large Hotel	Medium Office	Midrise Apartment	Primary School	Secondary School	Small Hotel	Small Office	Stand Alone Retail	Strip Mall
Height (m) ^e	30	24	19	12	12	4	8	12	3	6	5
Floor area (m ²) ^f	7837	22436	11345	4982	3135	6871	19592	4014	511	2294	2090
A _{s5} (m ²)	4639	8937	6005	3638	2326	9383	18286	2698	282	3471	3274
A _{s6} (m ²)	5422	13107	8429	5299	3109	16254	30188	3702	643	5765	5365
Volume (m ³) ^g	23884	79802	30359	19741	9554	27484	95216	11622	1559	13984	10828
General HVAC operation											
Weekdays	24 h	24 h	24 h	6 a.m. to 10 p.m.	24 h	7 a.m. to 9 p.m. ^h	7 a.m. to 9 p.m. ^h	24 h	6 a.m. to 7 p.m.	7 a.m. to 9 p.m.	7 a.m. to 9 p.m.
Saturdays	24 h	24 h	24 h	6 a.m. to 10 p.m.	24 h	Off	Off	24 h	Off	7 a.m. to 10 p.m.	7 a.m. to 7 p.m.
Sundays & Holidays	24 h	24 h	24 h	Off	24 h	Off	Off	24 h	Off	9 a.m. to 7 p.m.	8 a.m. to 6 p.m.
Pressurized (Y/N)	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
I_{design} (m³•s⁻¹•m⁻²) @ 4 Pa (0.02 in. w.c.)ⁱ											
Without air barrier	5.69-04										
With air barrier	2.42E-04	3.04E-04	2.91E-04	3.02E-04	2.77E-04	3.59E-04	3.42E-04	2.84E-04	4.68E-04	3.44E-04	3.39E-04
EnergyPlus objects needed											
ZoneInfiltration :DesignFlowRate	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Infiltration-ON	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Infiltration-OFF				Y		Y	Y		Y	Y	Y
ZoneList	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

^e Multiply m by 3.28 to get ft.

^f Multiply m² by 10.76 to get ft².

^g Multiply m³ by 35.31 to get ft³.

^h Note that Primary and Secondary Schools have reduced operating hours in the summer.

ⁱ Multiply m³•s⁻¹•m⁻² by 196 to get cfm•ft⁻².

1.4. How were the NIST infiltration correlations developed?

The process used to develop the NIST infiltration correlations for Equation (1) is outlined below and visualized in Figure 1.

Step 1: Perform annual CONTAM simulations using the design HVAC supply airflow rates, fan schedules, indoor temperature schedules based on thermostat setpoint schedules, occupancy schedules, and outdoor ventilation rates from EnergyPlus prototype building model results as inputs. Use Typical Meteorological Year 3 (TMY3) weather data for each city (NREL 2015).

Step 2: Normalize CONTAM hourly whole-building infiltration results by 5-sided external surface areas.

Step 3: Combine the CONTAM simulation results, indoor and outdoor temperature, and wind speed into files for processing in Step 4. Correct the wind speed from the TMY3 file using the wind speed adjustment factors in Table 1. See more on the wind speed adjustment below.

Step 4: Perform least squares analysis to determine the EnergyPlus infiltration inputs A , B , and D in Equation (1) and $C = 0$.

Because wind pressure on the building surface is a function of the square of the wind speed, the coefficient C was set to zero (Walton and Dols 2013). The NIST infiltration correlations include values for A , B , and D for both system-on and system-off conditions. It was assumed that $A = 0$ when the HVAC system was off because when $|\Delta T|$ and W_s are zero, the system-off infiltration rate should be zero. During system-on hours, A is nonzero.

A wind speed adjustment factor is included in the least squares analysis because EnergyPlus adjusts the local wind speed for each zone based on its height above ground. CONTAM does not make this adjustment because the physics of airflow at heights close to the ground and between buildings is complex and most accurately determined by wind tunnel experiments or computational fluid dynamics (CFD) simulations (Sandberg et al., 2015). Thus, a “wind speed adjustment factor” was calculated by dividing the EnergyPlus Output:Variable “Zone Outdoor Air Wind Speed” for each zone by the EnergyPlus Output:Variable “Site Wind Speed” and taking the average over all of the levels of the building. This factor was then multiplied by the wind speed in the TMY3 file and used in Eq. (1).

Additional details can be found in Ng et al., (2015), Ng et al., (2018), and Ng et al., (2021).

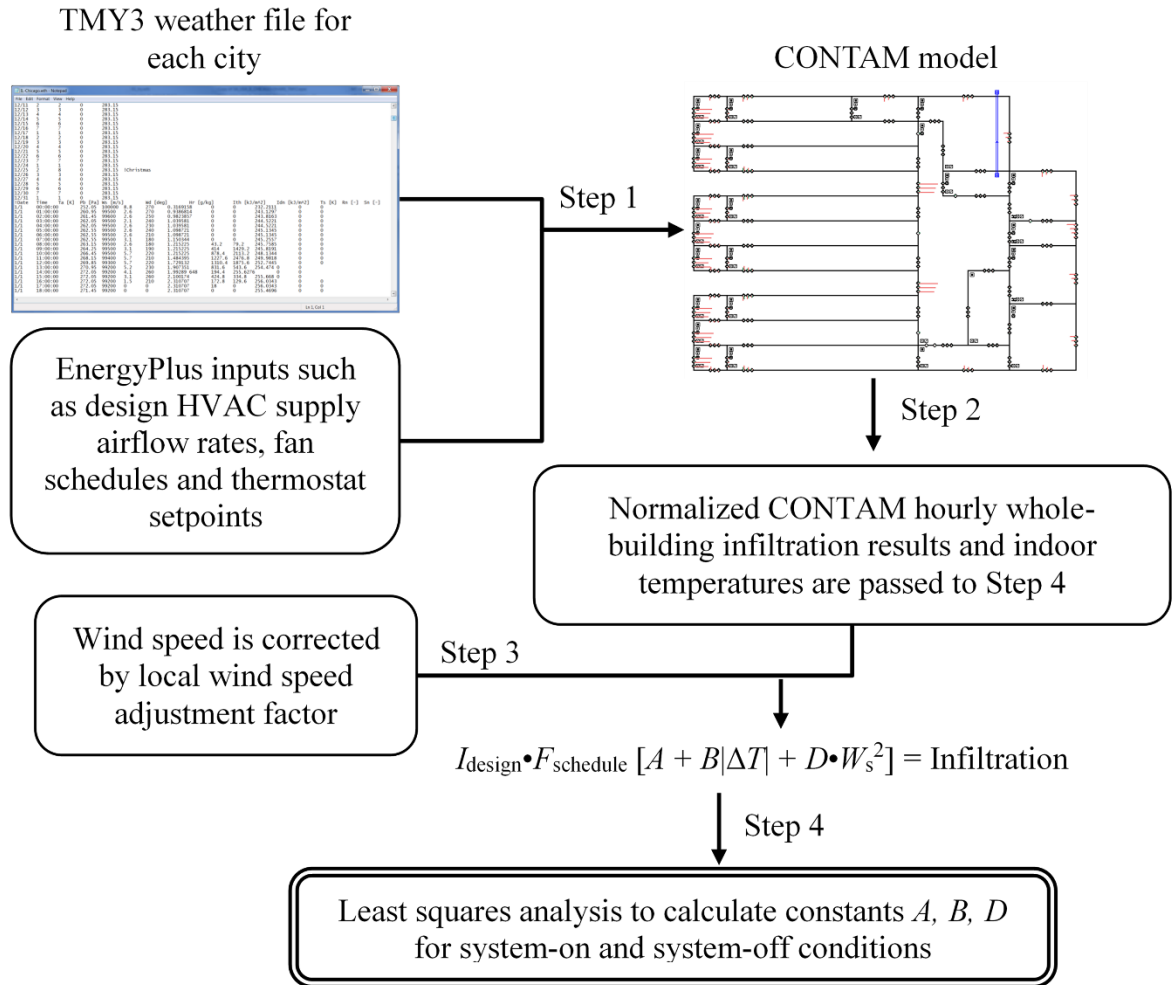


Figure 1. Infiltration correlation process from Ng et al., (2021)

A worksheet is available for download here (<https://doi.org/10.18434/mds2-2598>) (Ng 2022) that contains the NIST infiltration correlations for eleven buildings in eight cities, for both levels of airtightness and for system-on and system-off conditions.

If the user is not simulating a DOE prototype building, select the building type with the characteristics that most closely matches the building of interest. For example, if the user is modeling an office building, select among the small, medium or large office based on floor height (similarly for the hotel). If the user is modeling a school, choose the Primary School for a single-story building and the Secondary School for a taller school. Nonetheless, sensitivity analysis on the NIST infiltration correlations have not been performed so users should be aware of possible inaccuracies between actual and predicted infiltration rates based on actual building geometry, ventilation system operation, and local weather.

The user should select the city name in the climate zone where their building is located. There have been no infiltration correlations developed for climate zone 0.

2. Purpose

The purpose of this document is to provide step-by-step instructions on how to implement the NIST infiltration correlations into EnergyPlus. The DOE prototype buildings are used as example building models, but the instructions can be generalized to similar buildings. In the Appendix, special considerations for each of the eleven prototype buildings that may need to be made before implementing the NIST infiltration correlations are provided.

3. Outline

First, a quick overview of the EnergyPlus IDF editor is provided since that tool is referenced throughout this tutorial.

Next, step-by-step instructions on how to implement the NIST infiltration correlations are provided using the Highrise Apartment and Medium Office prototype buildings as examples. Instructions are also provided to apply the correlations for buildings similar to the prototype buildings. It is assumed that the reader of this tutorial is familiar with EnergyPlus and creating or using existing building models (DOE 2020).

This set of instructions is applicable to most versions of EnergyPlus. If negative values are not allowed in the `ZoneInfiltration:DesignFlowRate` object of the EnergyPlus version you are using, you may need to edit the file `Energy+.idd` (refer to the *Interface Developer* tutorial on the EnergyPlus website).

4. Video Tutorial

A video of this written tutorial is on the Air Barrier Association of America (ABAA) website <https://www.airbarrier.org/nist-infiltration/>.

5.Quick Overview of the EnergyPlus IDF Editor

In this tutorial, the NIST infiltration correlations are implemented in EnergyPlus using the IDF Editor (DOE 2020). Users who are familiar with the EnergyPlus input file (.idf) may also choose to complete the tutorial using a text editor. A partial screenshot of the IDF Editor is shown in Figure 2 below. The EnergyPlus objects are listed in the upper left box and the inputs are located in the lower third of the screenshot. The toolbar shown in Figure 3 is also referenced later in this tutorial.

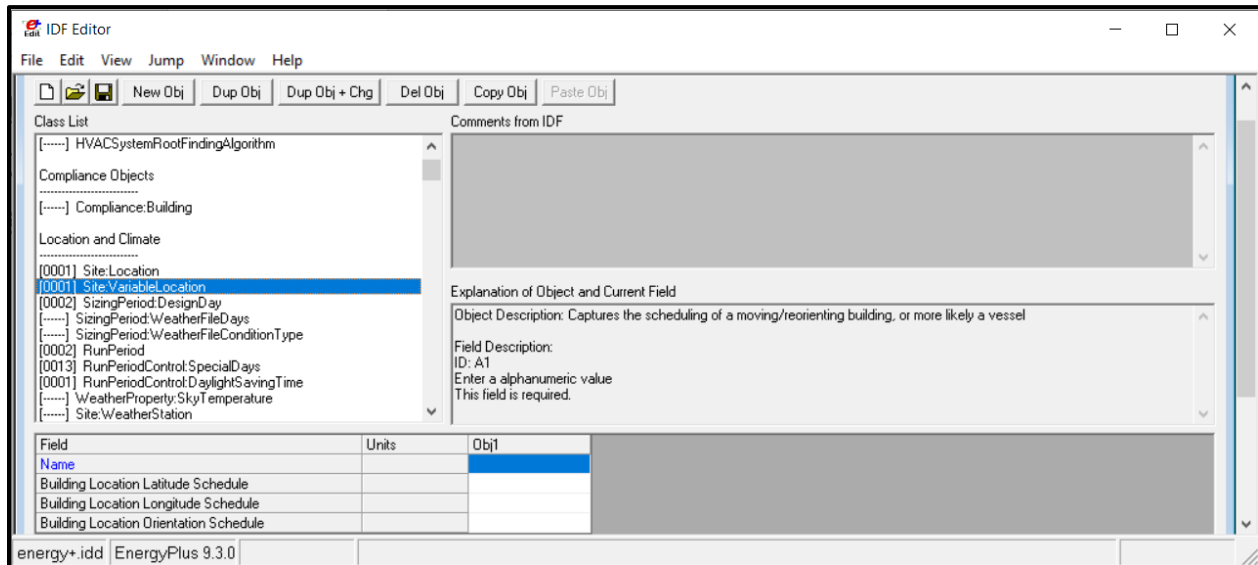


Figure 2. Partial screenshot of IDF Editor

The numerical labels in Figure 3 below describe each function as follows:

- i. Create New IDF File
- ii. Open IDF File
- iii. Save Current IDF File
- iv. New Obj
Creates a new instance of the currently selected object. The fields of the new object will be set to blanks, zeros, or default values and will be added to the far right of the grid.
- v. Dup Obj
Copies the values of the fields of the currently selected object and adds the duplicated object to the far right of the grid. The new object should then be provided with a different name.
- vi. Dup Obj + Chg
Copies the values of the fields of the currently selected object and allows the user to change one of the original text fields during the duplication process.
- vii. Del Obj
Deletes the currently selected object.

viii. Copy Obj & Paste Obj

Used to copy and paste a selected object or group of objects. If multiple IDF files are open within the same editor instance, then objects can be copied between IDF files.

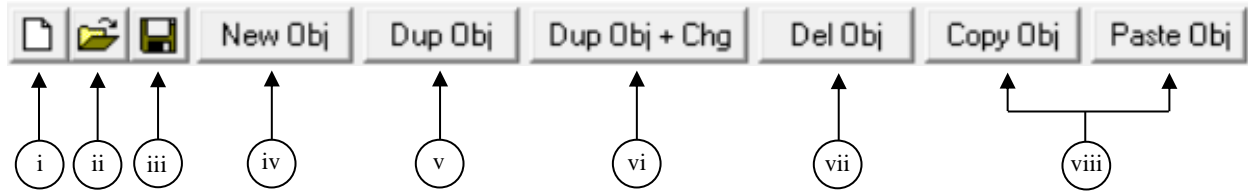


Figure 3. Screenshot of IDF Editor Tool Bar Buttons

6. Instructions

The NIST infiltration correlations were developed to provide the coefficients for the EnergyPlus ZoneInfiltration:DesignFlowRate object which implements Equation (1) assuming $C = 0$ (Equation (3)).

$$\text{Infiltration} = I_{\text{design}} [A + B|\Delta T| + D \cdot W_s^2] \quad (3)$$

6.1. Steps 1-8

Use the following seven steps to define infiltration in an EnergyPlus IDF file based on NIST infiltration correlations. The eighth and last step is to check the results.

1. **Download NIST infiltration correlations worksheet from here** (<https://doi.org/10.18434/mds2-2598>) (Ng 2022).
2. **Navigate to the appropriate tab in the worksheet – either “WithoutAirBarrier” or “WithAirBarrier” (Figure 4), building and city/climate zone.**
3. **Open the EnergyPlus IDF file using IDF Editor.** This can be a DOE prototype building model or generally any EnergyPlus model.
4. **Delete any existing ZoneInfiltration:DesignFlowRate objects except one.**
5. **Replace the field values of the ZoneInfiltration:DesignFlowRate object with values from the worksheet.**
6. **Create the ZoneList object**
7. **Create the inf-ON-sch (and inf-OFF-sch, if applicable) schedule(s)**

8. Simulate EnergyPlus model and check results

Additional details on these steps 5 through 8 are provided below in Sec. 6.2 to Sec. 6.4 below.

	Medium Office	Midrise Apartment	Primary School	Secondary School
	Chicago (CZ 5)			
A on	-0.0445	0.0917	0.0025	0.1019
B on	0.0055	0.0059	0.0034	0.0077
D on	0.0295	0.0328	0.0340	0.0877
A off	0.0000	#N/A	0.0000	0
B off	0.0155	#N/A	0.0066	0.0156
D off	0.0344	#N/A	0.0423	0.1050
	Helena (CZ 6)			
A on	-0.0382	0.0697	-0.0043	0.0798
B on	0.0042	0.0059	0.0030	0.0061
D on	0.0206	0.0216	0.0215	0.0590
A off	0.0000	#N/A	0.0000	0
B off	0.0139	#N/A	0.0056	0.0125
D off	0.0264	#N/A	0.0305	0.0779
	Duluth (CZ 7)			
A on	-0.0506	0.0892	0.0035	0.1016
B on	0.0059	0.0060	0.0036	0.0084
D on	0.0263	0.0274	0.0272	0.0730
A off	0.0000	#N/A	0.0000	0
B off	0.0142	#N/A	0.0061	0.0144
D off	0.0298	#N/A	0.0361	0.0909

Figure 4. Partial screenshot of spreadsheet containing NIST infiltration correlations. Chicago (CZ5) correlations highlighted for Medium Office without air barrier for use in example later in tutorial.

6.2. Additional details on Step 5: replacing field values of ZoneInfiltration:DesignFlowRate object

Use the values from the NIST infiltration correlations worksheet (Figure 4) to replace the field values of the ZoneInfiltration:DesignFlowRate object(s). Table 2 below lists the fields of the ZoneInfiltration:DesignFlowRate object for system-on hours and where to find the value for it in the NIST infiltration correlations worksheet. Table 3 below lists the fields of the ZoneInfiltration:DesignFlowRate object for system-off hours.

Table 2. Input fields and values in IDF Editor for system-on hours of ZoneInfiltration:DesignFlowRate object

Name:	Infiltration-ON
Zone or ZoneList Name: *	AllZones
Schedule Name:	inf-ON-sch
Design Flow Rate Calc Method:	Flow/ExteriorArea
Flow per Exterior Surface Area:	“Design leakage rate @ 75 Pa ($\text{m}^3 \cdot \text{s}^{-1} \cdot \text{m}^{-2}$) - 5 sided” (provided in worksheet)
Constant Term Coefficient:	“A on” (provided in worksheet)
Temperature Term Coefficient:	“B on” (provided in worksheet)
Velocity Term Coefficient:	0.0
Velocity Squared Term Coefficient:	“D on” (provided in worksheet)

*See Sec. 6.3 for more details on the Zone List object

Table 3. Input fields and values in IDF Editor for system-off hours of ZoneInfiltration:DesignFlowRate object

Name:	Infiltration-OFF
Zone or ZoneList Name: *	AllZones
Schedule Name:	inf-OFF-sch
Design Flow Rate Calc Method:	Flow/ExteriorArea
Flow per Exterior Surface Area:	“ I_{design} @ 4 Pa value ($\text{m}^3 \cdot \text{s}^{-1} \cdot \text{m}^{-2}$) – 5 sided” (provided in worksheet)
Constant Term Coefficient:	0.0
Temperature Term Coefficient:	“B off” (provided in worksheet)
Velocity Term Coefficient:	0.0
Velocity Squared Term Coefficient:	“D off” (provided in worksheet)

The design leakage rates listed in the worksheet ($\text{m}^3\cdot\text{s}^{-1}\cdot\text{m}^{-2}$) are converted from the design leakage rates ($\text{L}/\text{s}\cdot\text{m}^2$) listed in the Introduction. If the building you are modelling has a different known leakage rate (e.g., from a specification or test value), you should use your value.

For details on the zone list(s) required to implement the NIST infiltration correlations, refer to Sec. 6.3. For details on the schedules, refer to Sec. 6.4.

6.3. Additional details on Step 6: creating zone lists

To apply the `ZoneInfiltration:DesignFlowRate` objects to all zones, create a `ZoneList` object using the IDF Editor called `AllZones` as shown in Table 2 and Table 3. This list should contain all the zones in the IDF. If zones do not have exterior surfaces (i.e., interior hallways), EnergyPlus will not calculate infiltration for them.

6.4. Additional details on Step 7: creating schedules

The `inf-ON-sch` schedule should reflect the schedule when the HVAC fans are available to be on. Locate the `Fans` group in the IDF Editor and identify the `Availability Schedule Name` that best represents the scheduled on times for your IDF. This is the `Availability Schedule` that will be used to create the `inf-ON-sch` schedule (and `inf-OFF-sch` if needed).

In the DOE prototype commercial building models, `HVACOperationSchd` is the most common fan schedule. See the Appendix of this document for exceptions. If the fans in the IDF have different fan schedules, choose the one (or create one) that has the most on-hours. For example, in the Strip Mall the fans in the IDF are assigned to one of three different fan schedules. Thus, an `inf-ON-sch` was created that covered the hours in which a fan was scheduled to be on. See Appendix of this document for details.

Make a copy of the selected `Fans Availability Schedule` by clicking `Dup Obj` in the IDF Editor tool bar (Figure 5). If there are system-off hours in the building, make a second copy of the `HVACOperationSchd`.

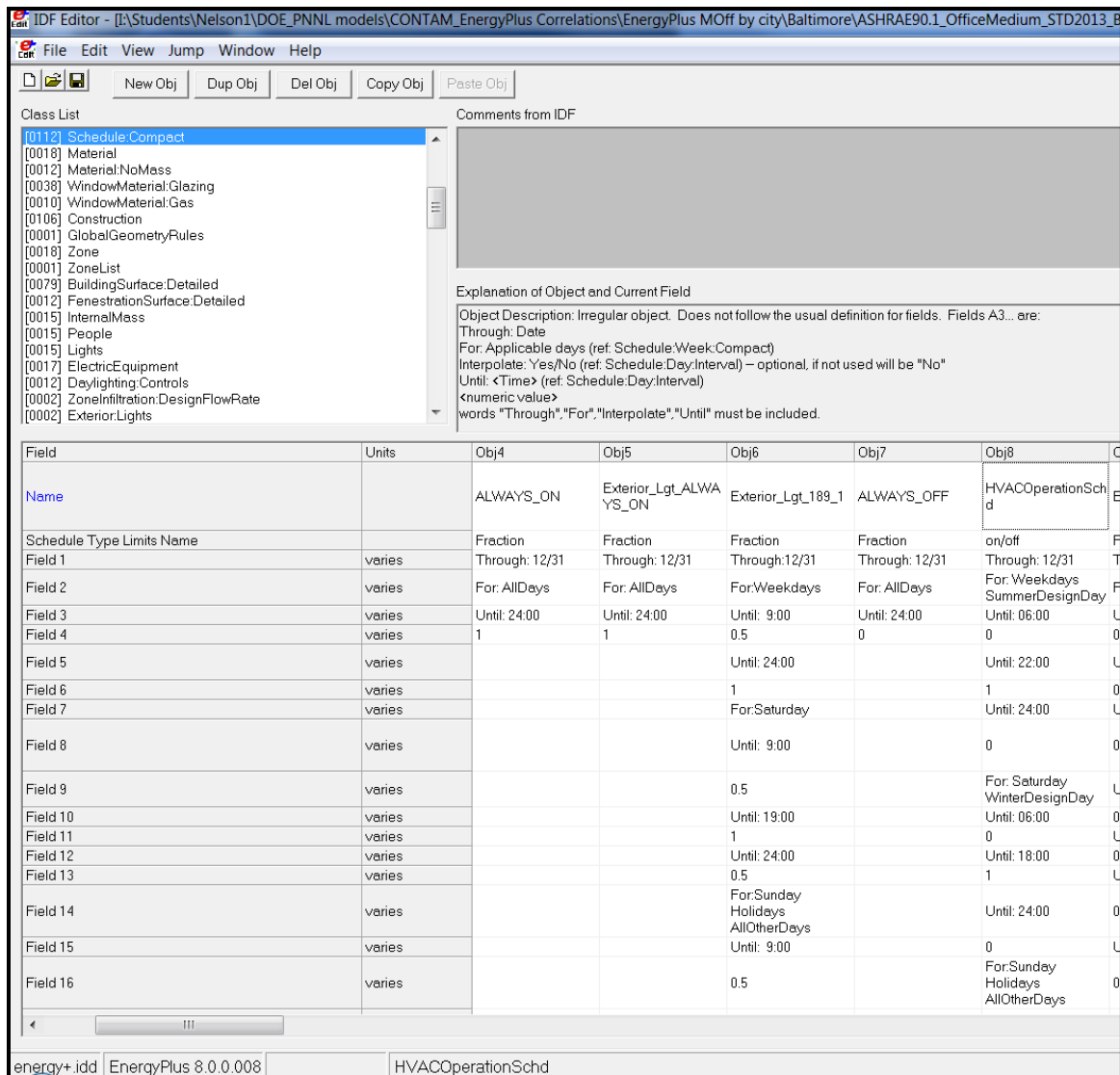


Figure 5. Partial screenshot showing Dup Obj button in IDF editor.

Rename one of the duplicates inf-ON-sch and the other (if applicable), inf-OFF-sch. Change the Schedule Type Limits Name to Fraction in both schedule objects. For the inf-OFF-sch schedule, replace only the 1's with 0's and replace the 0's with 1's. In other words, when the inf-ON-sch object has an "on" value (or a value of 1), it should be off (or have a value of 0) in the inf-OFF-sch object. The two schedules are complements of one another as shown in Figure 6.

Name		inf-ON-sch	inf-OFF-sch
Schedule Type Limits Name		fraction	fraction
Field 1	varies	Through: 12/31	Through: 12/31
Field 2	varies	For: Weekdays SummerDesignDay	For: Weekdays SummerDesignDay
Field 3	varies	Until: 06:00	Until: 06:00
Field 4	varies	0	1
Field 5	varies	Until: 22:00	Until: 22:00
Field 6	varies	1	0
Field 7	varies	Until: 24:00	Until: 24:00
Field 8	varies	0	1
Field 9	varies	For: Saturday WinterDesignDay	For: Saturday WinterDesignDay
Field 10	varies	Until: 06:00	Until: 06:00
Field 11	varies	0	1
Field 12	varies	Until: 18:00	Until: 18:00
Field 13	varies	1	0
Field 14	varies	Until: 24:00	Until: 24:00
Field 15	varies	0	1
Field 16	varies	For: Sunday Holidays AllOtherDays	For: Sunday Holidays AllOtherDays
Field 17	varies	Until: 24:00	Until: 24:00
Field 18	varies	0	1

Figure 6. Screenshot of inf-ON-sch and inf-OFF-sch schedule objects.

6.5. Checking Results

Before running the simulation, click on the View menu, then on the `Validity Check` option to ensure there were no errors while implementing the NIST infiltration correlations. The user can check that the implementation was successful by running a simulation, being sure to enable the `Output:Variable,*,Zone Infiltration Current Density Volume Flow Rate`.

When the user plots the infiltration rate versus the difference between the indoor and outdoor temperature (dT) (Figure 7 for system off conditions), there should be less infiltration as dT approaches 0. A “✓” shape can be observed in the data using the NIST infiltration correlations. Only data when the wind speed was $< 2 \text{ m}\cdot\text{s}^{-1}$ (4.47 mph) was shown to isolate the temperature effects. The “✓” shape is not as noticeable for system on conditions (Figure 8) due to the infiltration rates being lower than for the system off conditions.

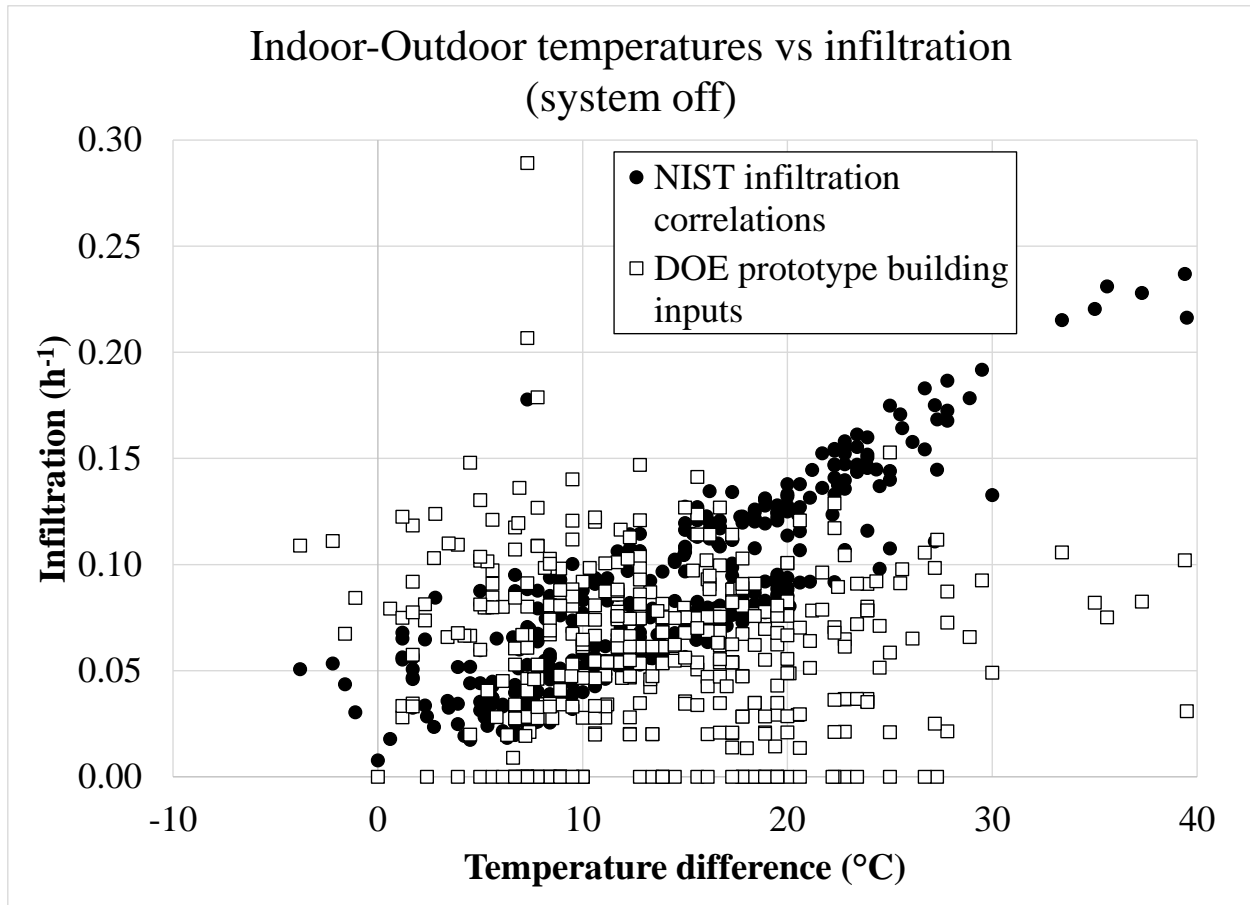


Figure 7. Infiltration versus Indoor-outdoor temperature difference using the NIST infiltration correlations and original inputs (wind speeds $2 \text{ m}\cdot\text{s}^{-1}$ (4.47 mph) to isolate temperature effects) – system off – Medium Office Miami

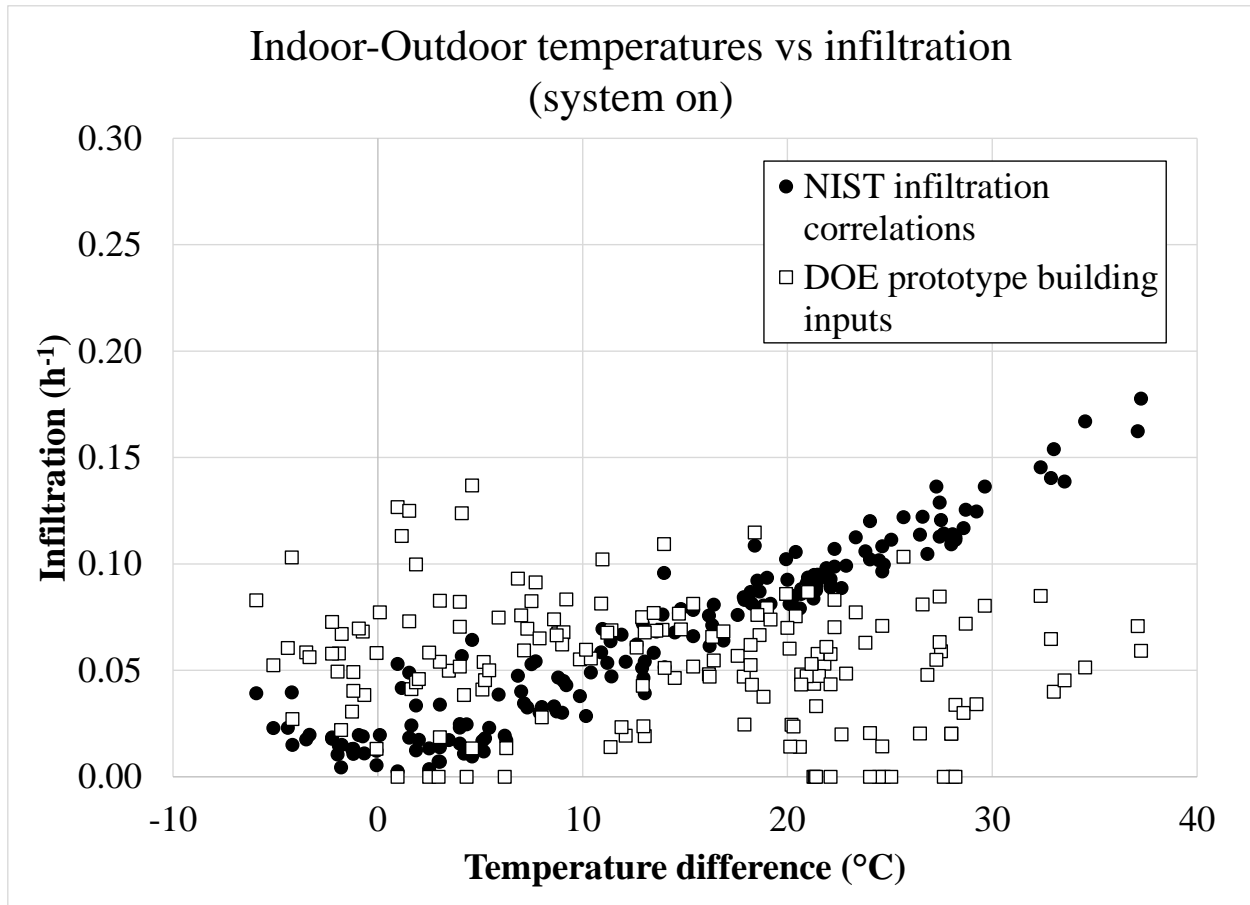


Figure 8. Infiltration versus indoor-outdoor temperature difference using the NIST infiltration correlations and original inputs (wind speeds $2 \text{ m}\cdot\text{s}^{-1}$ (4.47 mph) to isolate temperature effects) – system on – Medium Office Miami

7. Acknowledgements

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9. Appendix

This Appendix describes what objects were deleted or used for implementing the NIST infiltration correlations in EnergyPlus in the eleven prototype buildings. Refer to Goel et al., (2014) for more details on the prototype buildings.

9.1. Highrise Apartment

The original Highrise Apartment prototype model has `ZoneVentilation:WindandStackOpenArea` objects that represent patio door openings when outdoor conditions were favorable. These objects should be removed before using the NIST infiltration correlations. The `AllOn` fan availability schedule should be used to create the `inf-ON-sch` object.

9.2. Hospital

The `HVACOperationSchd` fan availability schedule should be used to create the `inf-ON-sch` object.

9.3. Large Hotel

The original Large Hotel prototype model has `ZoneVentilation:WindandStackOpenArea` objects that represent patio door openings when outdoor conditions were favorable. These objects should be removed before using the NIST infiltration correlations. The `HVACOperationSchd` fan availability schedule should be used to create the `inf-ON-sch` object.

9.4. Medium Office

The `HVACOperationSchd` fan availability schedule should be used to create the `inf-ON-sch` and `inf-OFF-sch` objects.

9.5. Midrise Apartment

The original Midrise Apartment prototype model has `ZoneVentilation:WindandStackOpenArea` objects that represent patio door openings when outdoor conditions were favorable. These objects should be removed before using the NIST infiltration correlations. The `AllOn` fan availability schedule should be used to create the `inf-ON-sch` object.

9.6. Primary School

The `HVACOperationSchd` fan availability schedule should be used to create the `inf-ON-sch` and `inf-OFF-sch` objects.

9.7. Secondary School

The HVACOperationSchd fan availability schedule should be used to create the inf-ON-sch and inf-OFF-sch objects.

9.8. Small Hotel

The original Small Hotel prototype model has ZoneVentilation:WindandStackOpenArea objects that represent patio door openings when outdoor conditions were favorable. These objects should be removed before using the NIST infiltration correlations. The AlwaysOn fan availability schedule should be used to create the inf-ON-sch object.

9.9. Small Office

The HVACOperationSchd fan availability schedule should be used to create the inf-ON-sch and inf-OFF-sch objects.

9.10. Stand Alone Retail

The HVACOperationSchd fan availability schedule should be used to create the inf-ON-sch and inf-OFF-sch objects.

9.11. Strip Mall

The original Strip Mall prototype model has ZoneInfiltration:DesignFlowRate objects associated with doors (e.g., LGstore1_Door_Infiltration, SMstore1_Door_Infiltration) that attribute leakage to exterior doors. These objects should be removed before using the NIST infiltration correlations.

The Strip Mall prototype model has three Availability Schedule Names attributed to the HVAC fans in the Fan:ConstantVolume object: Type1_FAN_SCH, Type2_FAN_SCH, and Type3_FAN_SCH. All three fan schedules were simulated in CONTAM. However, when developing the NIST correlations, a single inf-ON-sch object (and corresponding inf-OFF-sch object) was created as shown in Table 4.

Table 4. inf-ON-sch and inf-OFF-sch for Strip Mall

	Prototype model Type1_FAN_SCH on times	Prototype model Type2_FAN_SCH on times	Prototype model Type3_FAN_SCH on times	NIST infiltration correlations inf- ON-sch on times	NIST infiltration correlations inf- Off-sch on times
Monday to Thursday	8 a.m. to 12 a.m.	7 a.m. to 9 p.m.	8 a.m. to 9 p.m.	7 a.m. to 9 p.m.	9 p.m. to 7 a.m.
Friday and Saturday	8 a.m. to 1 a.m.	7 a.m. to 7 p.m.	8 a.m. to 7 p.m.	7 a.m. to 1 a.m.	1 a.m. to 7 a.m.
Sundays and Holidays	8 a.m. to 12 a.m.	8 a.m. to 6 p.m.	9 a.m. to 6 p.m.	8 a.m. to 6 p.m.	6 p.m. to 8 a.m.