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MEMORANDUM

DOCKET
12-BSTD-1
DATE JUL 14 2011
RECD. MAY 15 2012

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FROM: Roger Hedrick

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DATE: 7/14/2011

SUBJECT: Commercial Building Infiltration Reduction Analysis Results

Adoption of air sealing requirements based on those in the 2012 IECC is under consideration for Title 24. The analysis is to investigate the potential energy savings that such requirements might achieve.

The 2012 IECC includes a number of requirements related to air sealing. The analysis will be based on Section 502.4.1.2.3 – Building Test. This section requires an air leakage test of the completed building having a leakage rate of not more than 2.0 L/s-m² @ 75 Pa (0.40 cfm/ft² @ 0.3" w.g.). This value will be used as the design leakage rate for the "proposed" case.

A report by PNNL, "Infiltration Modeling Guildelines for Commercial Building Energy Analysis," reported information from the Envelope Subcommittee of ASHRAE SSPC90.1. This committee had also been investigating the possibility of including an air sealing requirement in Standard 90.1. The Envelope Subcommittee recommended a value of 1.8 cfm/ft² @ 0.3" w.g. as a baseline leakage rate (the "before" case). PNNL reported that this rate corresponds to the base infiltration rate used in the DOE Benchmark buildings.

In EnergyPlus, the infiltration rate for a zone is calculated at each time step of the simulation using the equation:

$$Infiltration = I_{design} \cdot F_{schedule} \cdot \left(A + B \cdot \left|t_{zone} - t_{odb}\right| + C \cdot ws + D \cdot ws^2\right) \quad (1)$$

where:

- $Infiltration$ = zone infiltration airflow (m³/s-m²)
- I_{design} = design zone infiltration airflow (m³/s-m²)
- $F_{schedule}$ = fractional adjustment provided by a user input schedule (unitless)
- t_{zone} = zone air temperature (°C)
- t_{odb} = outdoor dry bulb temperature (°C)
- ws = the windspeed (m/s)
- A = overall coefficient (unitless)
- B = temperature coefficient (1/°C)
- C = windspeed coefficient (s/m)
- D = windspeed squared coefficient (s²/m²)

The PNNL report recommended using the DOE2 default infiltration coefficients, for which only the windspeed coefficient is non-zero. A windspeed coefficient of 0.224 s/m results in the infiltration being equal to the design infiltration rate when the wind speed is 10 mph (4.47 m/s). This approach, however, does not include the effects of stack effect.

The PNNL report describes a procedure for calculating appropriate coefficients for Equation 1, and provides a value for I_{design} of 0.2016 cfm/ft² of exterior, above grade, wall surface area as providing the base infiltration rate of 1.8 cfm/ft² at 0.3" w.g.

Using the same procedure to determine I_{design} for the proposed case of 0.4 cfm/ft² at 0.3" w.g. comes down to using a ratio of the flows, as all of the wind pressure terms remain fixed for the two cases. This means that the "proposed" case will use a value for I_{design} of 0.0448 cfm/ft².

The PNNL report concludes that more research is required to model infiltration due to stack effect. However, the ASHRAE Handbook Fundamentals (2009, Chapter 16, Equation 38) provides an equation for airflow due to stack effect:

$$Q = 60 \cdot C_D \cdot A \cdot \sqrt{2g \cdot \Delta H_{NPL} \cdot (T_i - T_o)/T_i} \tag{2}$$

where:

Q	= airflow (cfm)
C_D	= discharge coefficient (unitless, taken to be 0.65)
A	= area of opening (ft²)
g	= acceleration due to gravity (32.2 ft/s²)
ΔH_{NPL}	= height between midpoint of the opening and the neutral pressure level (ft)
T_i	= indoor temperature (°R)
T_o	= outdoor temperature (°R)

Equation 2 holds when T_i is above T_o. When T_o exceeds T_i, the term $(T_i - T_o)/T_i$ is replaced with $(T_o - T_i)/T_o$.

Unfortunately, the opening area is unknown at this point. We can use another equation from the ASHRAE Handbook (2009, Chapter 16, Equation 41) which provides the equivalent leakage area for a residential building based on the airflow at a reference pressure:

$$A_L = 0.186 \cdot Q_r \cdot \frac{\sqrt{\rho / 2 \cdot \Delta p_r}}{C_D} \tag{3}$$

where:

A_L	= equivalent leakage area (in²)
Q_r	= airflow rate at Δp_r (cfm)
ρ	= density of air (lb_m/ft^3)
Δp_r	= reference pressure (" w.g.)
C_D	= discharge coefficient (unitless, taken to be 0.65)
0.186	= unit conversion factor

Taking Q_r as 1.8 cfm/ft² and Δp_r as 0.3" w.g., using ρ as 0.074 lb_m/ft^3 (based on 70°F, 50% rh), we find A_L to be 0.181 in²/ft² of wall area. This converts to 0.001256 ft² of opening/ft² of wall area. Using this value for A in equation 2, we can calculate Q on a floor by floor basis at a variety of outdoor air temperatures. We can then use linear regression to solve for the temperature coefficient (B) in equation 1 to be entered on a zone by zone basis into the EnergyPlus simulation. This procedure is repeated for the "proposed" case, except that A_L is found using 0.4 cfm/ft². This results in a value for A_L of 0.0002791 ft² of opening/ft² of wall area.

The analysis will be done using three of the EnergyPlus baseline models – the small office, medium office and the large office. All three models will use the same value for I_{design} and for the windspeed coefficient. The temperature coefficient, however, will vary based on the height of the zone relative to the midpoint of the building's height. The resulting stack effect infiltration is shown in Figure 1 below.

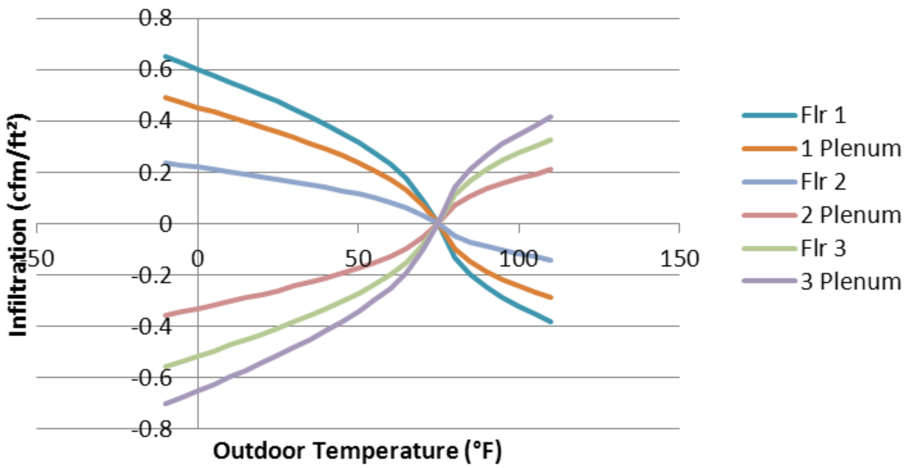


Figure 1 – Stack Effect Infiltration for the Medium Office Building

As is apparent from Equation 2 and Figure 1, infiltration rate is a function of the square root of the indoor-outdoor temperature difference. Unfortunately, EnergyPlus represents the infiltration using temperature difference to a power of 1 rather than 0.5. Therefore, each of the curves above will be approximated by a straight line determined by linear regression.

PNNL used a schedule which provides a value for $F_{schedule}$ for Equation 1 that is 1 when air handling systems are off and 0.25 when they are on. This is to account for the presumed pressurization of the building by the HVAC system with a resulting reduction in infiltration rate. Schedules which provide the same values for $F_{schedule}$ will be applied to each of the buildings.

The analysis will be done using 6 climate zones, 3 (Bay Area, cooler), 6 (Coastal LA, cooler), 9 (Inland LA, moderate), 12 (Sacramento, representative of warm Central Valley), 14 (Desert, hot), and 16 (Mountainous regions, moderate to cold).

With three buildings, two infiltration conditions, and 6 climate zones, the analysis will require 36 total simulations.

The figures below show the infiltration results for selected zones from the small office and large office models.

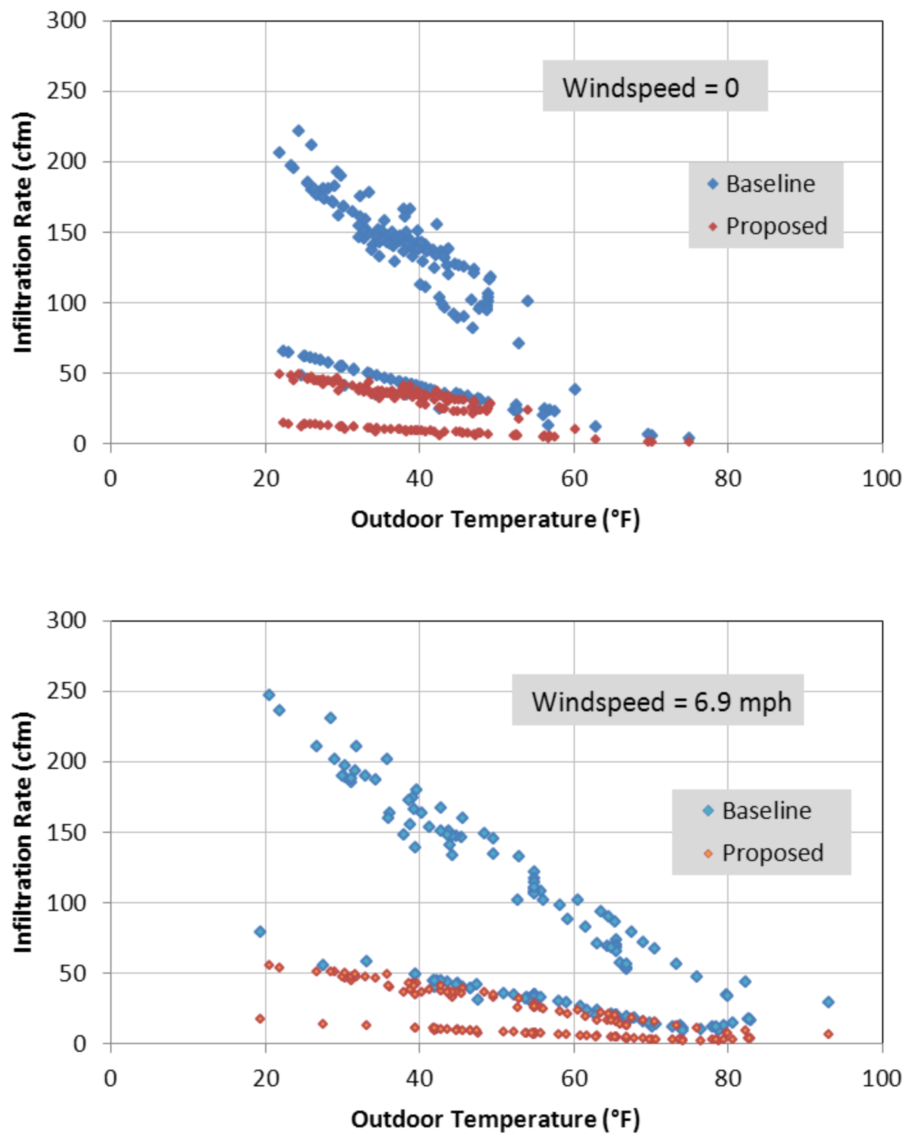
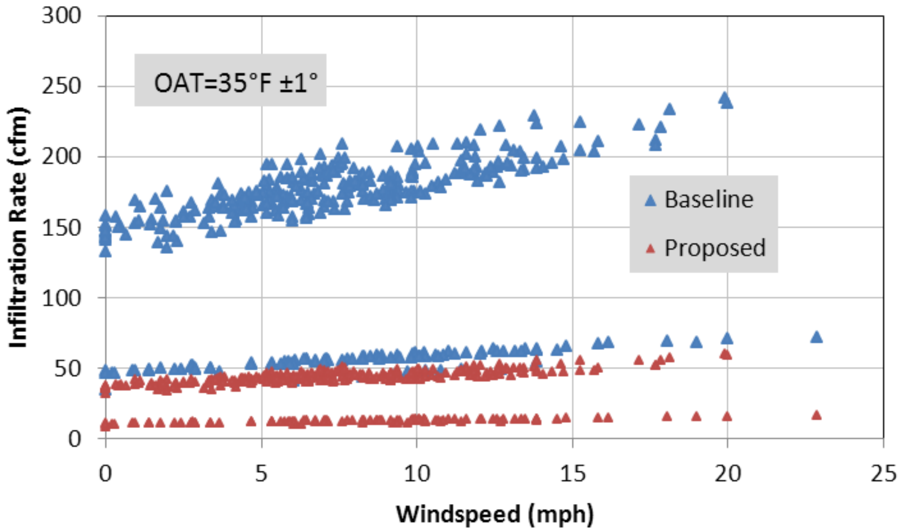


Figure 2 – Infiltration as a Function of Outdoor Temperature for the Small Office, Zone 3, Climate Zone 16



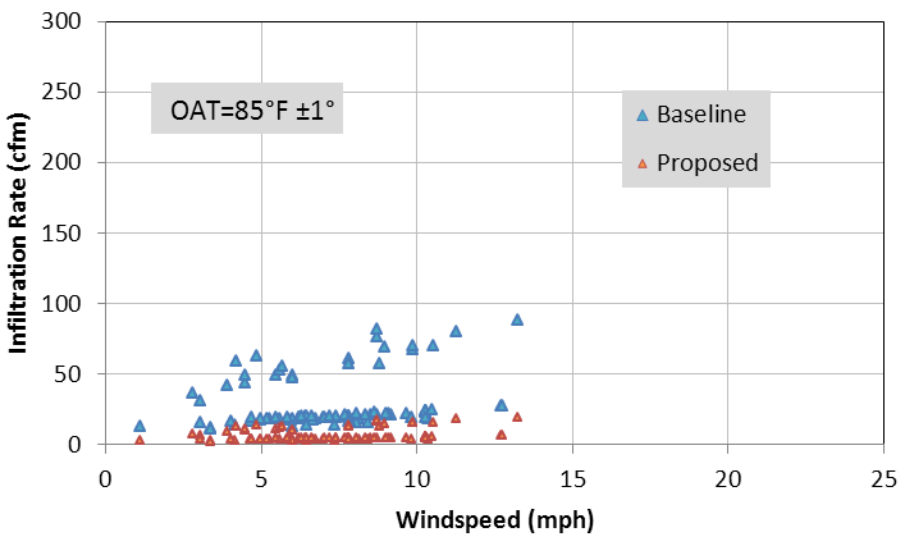


Figure 3 – Infiltration as a Function of Windspeed for the Small Office, Zone 3, Climate Zone 16

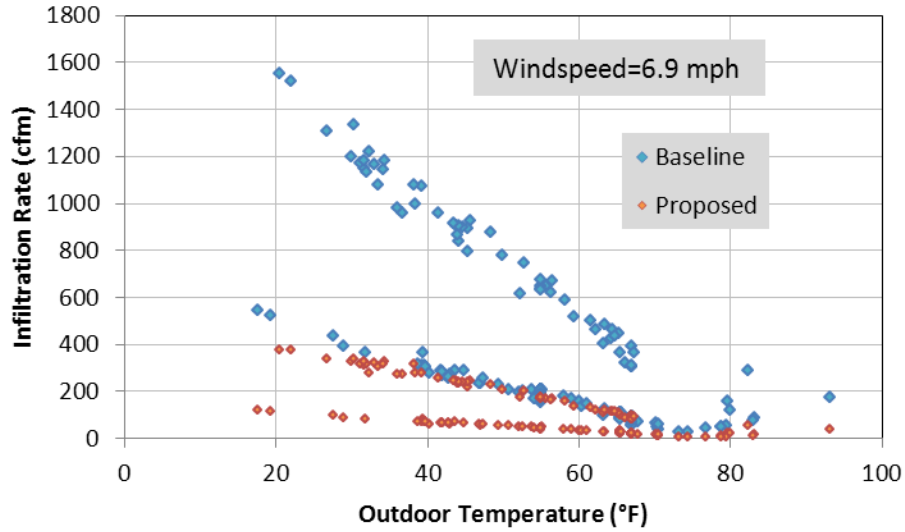


Figure 4 – Infiltration as a Function of Outdoor Temperature for the Large Office, Bottom Zone 1, CZ 16

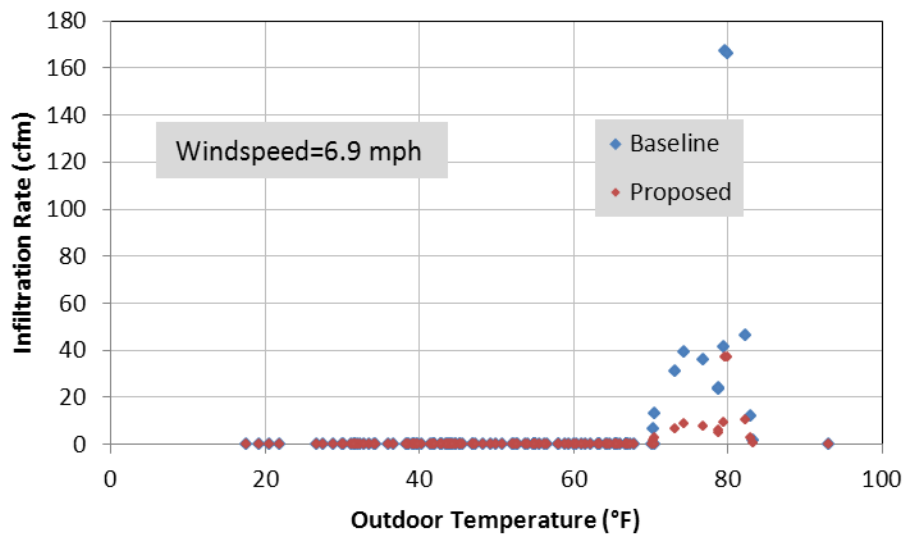
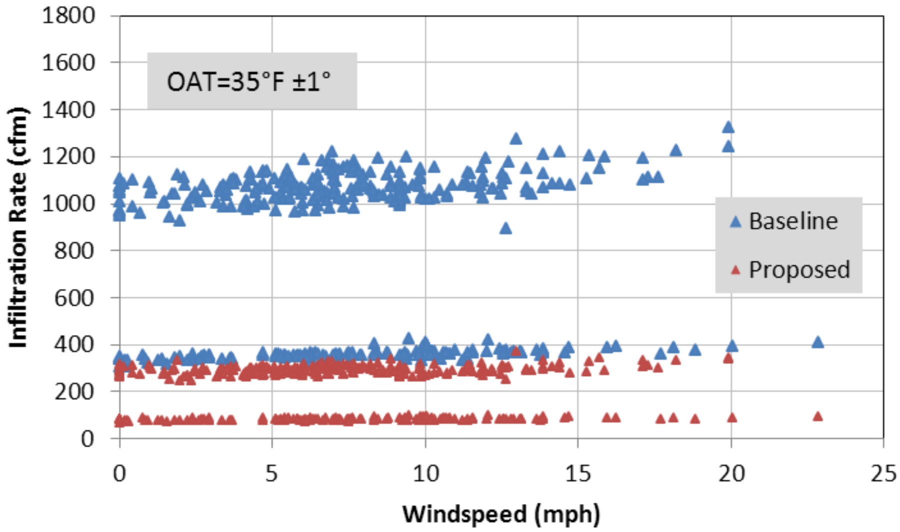


Figure 5 – Infiltration as a Function of Outdoor Temperature for the Large Office, Top Zone 1, CZ 16



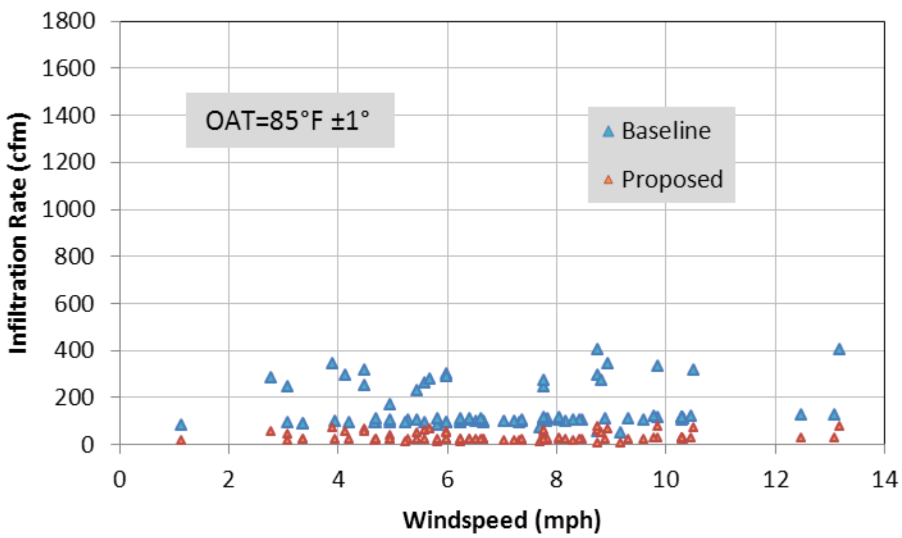


Figure 6 – Infiltration as a Function of Windspeed, Large Office, Bottom Zone 1, Climate Zone 16

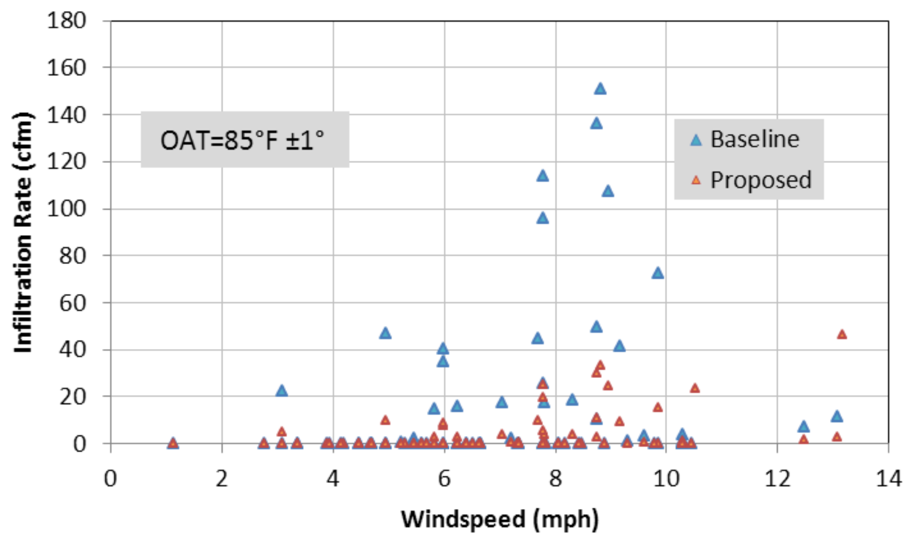


Figure 7 – Infiltration as a Function of Windspeed, Large Office, Top Zone 1, Climate Zone 16

Because stack effect is pushing air up the large office tower, the result is exfiltration (infiltration = 0) for cool temperatures. At warm temperatures, stack effect is drawing air into the upper floors, but the terperature differences are small.

The results are presented in terms of:

- TDV energy savings,
- Percent TDV energy savings,
- Electric and gas consumption savings,
- Percent site energy savings,
- TDV savings per unit wall area, and
- Site energy savings per unit wall area.

All cases showed reductions in gas consumption. In most of the climates, electricity consumption increased with the reduced infiltration. The gas savings on a site energy basis were always larger than the electricity increases, for net site energy savings (Table 1). However, on a TDV basis, the net effect was negative in some cases in climate zones 3 and 6. All cases showed positive TDV energy savings in climate zones 9, 12, 14 and 16 (Table 2).

For climate zones 3, 6, and 9, the site energy savings were small, less than 1% of total energy consumption. For climate zone 12, the savings were approximately 1.4% and for climate zone 14, they were around 3%. For climate zone 16, the savings were substantial, exceeding 5% of total building energy consumption. TDV savings followed the same pattern, except that they were negative in some cases in climate zones 3 and 6, and were slightly less than 5% for the small office and medium office in climate zone 16 and less than 3% for the large office in climate zone 16.

Table 1 – Site Energy Impacts of Infiltration Reductions

		Electric Savings (kWh)	Gas Savings (kBtu)	Percent Site Energy Savings	Savings/Wall Area (kBtu/ft²)
Climate Zone 3	Small Office	(278)	1,175	0.14%	0.08
	Medium Office	(2,455)	21,231	0.79%	0.60
	Large Office	(17,068)	188,559	0.94%	1.04
Climate Zone 6	Small Office	(119)	559	0.09%	0.05
	Medium Office	(1,972)	9,981	0.19%	0.15
	Large Office	(16,935)	69,854	0.09%	0.10
Climate Zone 9	Small Office	42	569	0.43%	0.23
	Medium Office	(941)	11,241	0.46%	0.38
	Large Office	(9,031)	94,327	0.44%	0.51
Climate Zone 12	Small Office	31	2,294	1.44%	0.79
	Medium Office	(1,416)	27,686	1.31%	1.07
	Large Office	(8,423)	237,125	1.44%	1.67
Climate Zone 14	Small Office	358	4,313	3.14%	1.83
	Medium Office	131	40,368	2.29%	1.92
	Large Office	3,746	504,466	3.47%	4.15
Climate Zone 16	Small Office	447	13,573	7.84%	4.98
	Medium Office	(966)	107,340	5.57%	4.89
	Large Office	200	1,215,026	7.76%	9.75

Table 2 – TDV Impacts of Infiltration Reductions

		Total TDV Savings (kBtu)	Percent TDV Savings	TDV Savings/Wall Area (kBtu/ft²)
Climate Zone 3	Small Office	(1,081)	(0.11%)	(0.36)
	Medium Office	40,026	0.41%	1.88
	Large Office	(104,876)	(0.12%)	(0.84)
Climate Zone 6	Small Office	294	0.03%	0.10
	Medium Office	(531)	(0.01%)	(0.02)
	Large Office	(348,854)	(0.38%)	(2.80)
Climate Zone 9	Small Office	5,336	0.51%	1.76
	Medium Office	45,599	0.41%	2.14
	Large Office	53,495	0.06%	0.43
Climate Zone 12	Small Office	11,525	1.13%	3.80
	Medium Office	127,007	1.19%	5.97
	Large Office	292,534	0.32%	2.34
Climate Zone 14	Small Office	24,406	2.30%	8.05
	Medium Office	224,737	2.05%	10.56
	Large Office	1,167,625	1.26%	9.36
Climate Zone 16	Small Office	47,988	4.38%	15.84
	Medium Office	458,895	4.32%	21.56
	Large Office	2,177,117	2.40%	17.45