Infiltration in Multi-Use Tall-Bldgs due to Stack-Effect & Wind-Press

Advantages and Limitations of the Excel Spreadsheet Program – V.C. Thomas

The attached spreadsheet calculates the infiltration for each specified floor and averages it for the floors specified, and multiplies it by the number of floors/section. The results are shown for each section as infiltration flow per unit area of envelope or perimeter zone**.**

The spreadsheet calculations are for a one hour design condition in summer and in winter. The program does not take into account perimeter zone exposure orientation and assumes the wind is direct and the same on every exposure. An estimate of the energy use due to infiltration is based on degree days. The energy estimate is therefore based on infiltration CFM and indoor-outdoor temp difference.

DESIGN Data	SMMR	WNTR		
Wnd (mph) Grnd	5	10	Site Altitude (ft)	500
Wnd (mph) Roof	15	25	Column Distance (ft)	31
Outdoor DB (F)	95	-20	Mech Floor Hgt (ft)	20
Outdoor WB (F)	75	-20	Mech Flr Leakg Coeff Cd	0.65
Degree-Days	2,680	7,981		
Indoor DB (F)	75	72		
Indoor WB (F)	62	55		

The floor is divided into 3 zones – Perimeter, Interior & Core. The Perimeter zone is based on the perimeter zone depth, the Core zone is based on the percent core area or core dimensions and the rest of the floor is the Interior zone. The Core areas include shafts (elevators, Stairs, mechanical) and exhaust spaces (toilets, storage and electrical, telecom & janitors closets).

The Plenum zone, which is at a different pressure from its space below, is not accounted for. Detailed floor zoning is not required for infiltration calculations as in contamination air flow between all zones in a hospital.

If the floor shape is not a rectangle (length and width), then there is an option to enter floor area and perimeter length. If both are entered, then area and perimeter is used. There is an option for core zone length and width or core area as percent of floor area. Percent core area overrides the dimensions if both are entered. **Omit the entries in red to use the dimensions.**

SCTN (max=5 chars)	1-Grd	2-Rtl	3-Fin	4-Ofc	5-Srv	6-Htl
Floor Type	Lobby	Retail	Tradg	Office	Htl-Srvc	Hotel
Typical Floor Length (ft)	320	280	240	200	200	160
Typical Floor Width (ft)	260	220	180	140	140	100
OR Non-Rctg Flr-A (ft2)	84,000					

OR Non-Rctg Flr Per (ft)	**1,025**					
CORE (Str-Elv-Toilt) Len (ft)	140	140	100	80	80	60
CORE (Str-Elv-Toilt) Wid (ft)	80	80	60	60	60	40
OR Core Area (% floor)	**15**					
Perimeter Zone Depth (ft)	20	20	15	15	15	20
Floor-Floor Height (ft)	20.0	18.0	15.0	13.5	15.0	10.0
Floor-Ceiling Height (ft)	15.0	14.0	13.0	10.0	11.0	9.5
No. of Section Floors	**3**	**15**	**30**	**55**	**30**	**30**
Mech Flr in Sectn Y/N	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

There is an option for (1) using leakage areas (such as the CONTAM library) and window dimensions for each section OR (2) entering leakage area and window area as percent of envelope for each section. Option-2 overrides Option-1, so in the attached file **if you delete the two rows for % leakage and % window, it will use leakage areas and window dimensions.**

Window Height (ft)	5	6	7	7	3	6
Wndw Unit Width (ft)	5.5	4.5	4.0	4.0	9.0	5.0
Wndw Unit Height (ft)	11.0	10.0	8.0	8.0	10.0	7.0
OR Window-A(%)	**60**	**50**	**65**	**65**	**60**	**45**
OR Leakg-A %Envl	**0.105**	**0.095**	**0.085**	**0.085**	**0.095**	**0.105**
Wall Leakg-A (ft2 / ft2)	0.00199	0.00199	0.00199	0.00199	0.00199	0.00199
Wndw Lkg-A (ft2 / ft2)	0.00065	0.00025	0.00017	0.00017	0.00035	0.00035
Leakg Flow Coeff - Cd	0.65	0.65	0.65	0.65	0.65	0.65
Indr-Outdr PD (in.wg)	**0.005**	**0.015**	**0.025**	**0.025**	**0.020**	**0.010**

Internal pressures are not calculated but the input for doing so exists. You can enter info on air systems for each section but it does NOT calculate and use internal pressures yet. This has to be entered as pressure drop (PD) across envelope. The pressure on either side of the envelope can make a big difference to infiltration.

In the attached example, if the "Indoor-Outdoor PD pressure drop across envelope P_I - P_O (in.wg.)" is high (= 0.05) for all sections then it is all infiltration in summer, and infiltration & exfiltration in winter. Using the rates shown in the example (0.010, 0.015, 0.020, 0.025) there is infiltration & exfiltration in summer & winter.

In the Excel program the inside pressures will be maintained by adjusting the Supply, Return & Exhaust air of each zone. In the EQUEST (DOE2.2) the default infiltration rates are 0.038 cfm/ft2 of envelope area for perimeter zones and 0.001 cfm/ft2 for the interior zones.

I need the theory and equations for calculating pressures in the zones and airflow between zones to add this feature to the Excel program. See theory & equations for stair pressurization http://bepan.info/engg-calcs - "4a - Fire-Smoke-Control - Stair-Pressurization".

Occup / Floor Area (P / ft2)	50	30	100	150	150	250
Outdoor Air / Person (cfm / P)	15	10	20	20	15	30
OR Percent Ventilation Air	**40**	**15**	**20**	**20**	**25**	**15**
Exhaust (cfm / ft2 Core-Zn)	1.50	1.50	1.50	1.50	1.50	1.50
OR Exhaust / floor (cfm)	**20,000**	**15,000**	**10,000**	**6,000**	**7,000**	**5,000**
Perm-Zone Sup Air (cfm / ft2)	2.10	2.10	2.10	2.10	2.10	2.10
Core-Zone Sup Air (cfm / ft2)	1.50	1.50	1.50	1.50	1.50	1.50
Inter-Zone Sup Air (cfm / ft2)	1.10	1.10	1.10	1.10	1.10	1.10
Percent Return Air (%)	50	60	70	80	50	20

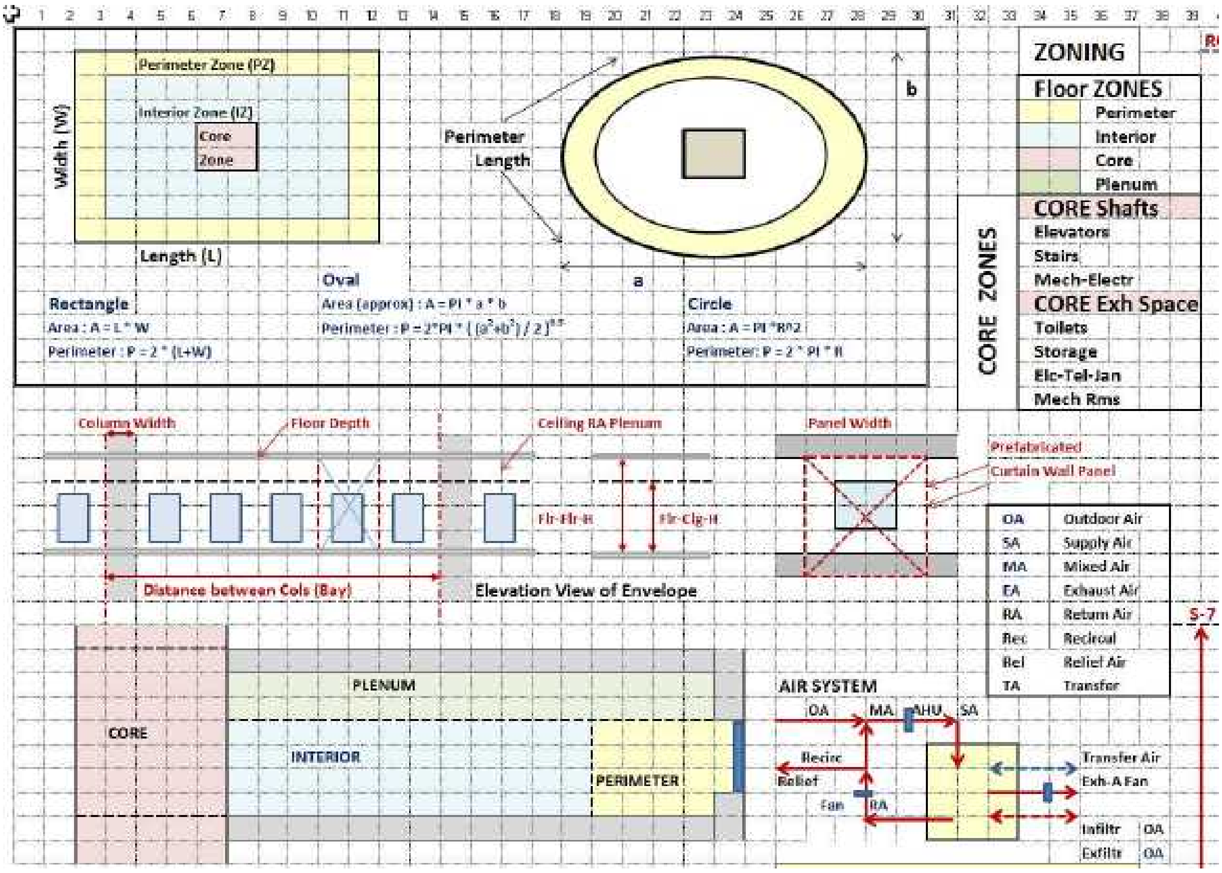
The building model shown below was calculated from the above input data.

SECTION No. >>	**1-Grd**	**2-Rtl**	**3-Fin**	**4-Ofc**	**5-Srv**	**6-Htl**
No. of Flrs (Incl Mech Flr)	**4**	**16**	**31**	**56**	**31**	**31**
Lowest Section Flr Elev (ft)	0	60	350	820	1583	2053
Area per Floor (ft2)	84,000	61,600	43,200	28,000	28,000	16,000
Envelope Perim Length (ft)	1,025	1,000	840	680	680	520
Perim Zone Area / Floor (ft2)	20,500	20,000	12,600	10,200	10,200	10,400
Core Zone Area / Floor (ft2)	12,600	11,200	6,000	4,800	4,800	2,400
Envelope Area per Flr (ft2)	20,500	18,000	12,600	9,180	10,200	5,200
% input based Wndw-Area (ft2)	12,300	0	0	0	0	0
L&W based input Wndw-A ft2)	165	174	168	168	114	144
Selected Percnt Window-A (%)	60	1	1	2	1	3
Selected Window-A per Flr (ft2)	12,300	174	168	168	114	144
Wall Area per Flr (ft2)	8,200	17,826	12,432	9,012	10,086	5,056
Wall Leakage Area per Flr (ft2)	16.3	35.5	24.7	17.9	20.1	10.1
Wndw Leakg Area per Flr (ft2)	8.0	0.0	0.0	0.0	0.0	0.1
Envl Leakg Area / Floor (ft2)	24.3	35.5	24.8	18.0	20.1	10.1
Totl Section Leakg Area (ft2)	97.3	568.3	767.8	1005.9	623.4	313.5
Totl Section Envel Area (ft2)	82,000	288,000	390,600	514,080	316,200	161,200
SECTION-Height (ft)	80	290	470	763	470	320
Total Section Floor Area (ft2)	336,000	985,600	1,339,200	1,568,000	868,000	496,000

The air system data shown below was calculated from the above input data.

SECTION No. >>	1-Grd	2-Rtl	3-Fin	4-Ofc	5-Srv	6-Htl
Perim-Zone Sup Air (cfm / flr)	43,050	42,000	26,460	21,420	21,420	21,840
Core-Zone Sup Air (cfm / flr)	18,900	16,800	9,000	7,200	7,200	3,600
Inter-Zone Sup Air (cfm / flr)	55,990	33,440	27,060	14,300	14,300	3,520
SA - Total Supply Air (cfm / flr)	117,940	92,240	62,520	42,920	42,920	28,960
OA - Ventil Air Supply (cfm / flr)	35,382	20,533	8,640	3,733	2,800	1,920
EA - Core Exhaust Air (cfm / flr)	20,000	16,800	9,000	7,200	7,200	3,600
RA - Total Return Air (cfm / flr)	48,970	45,264	37,464	28,576	17,860	5,072
SPA - Relief-Spill Air (cfm / flr)	33,588	26,443	16,416	10,611	22,260	21,968

Zoning & Air Systems



The weather info consists of DB and WB temps. **Besides the psychrometric equations, there are 3 pressurization equations for "Stack-Effect", "Wind-Pressure" & "Leakage- Air-Flow".** The calculations are done for the ground (first) floor row in Sheets "SMMR-calcs" and "WNTR-calcs". The only input is design DB & WB temps. The next (second) floor uses an equation to obtain the DB & WB temps for altitude. The remaining floors, representing the other altitudes or floor levels, are obtained by copying the second floor row into the rows for the other floors.

An estimate of the energy use due to infiltration is based on degree days. It can be done for 8760 hours using DOE2 bin or E+ epw files by converting them to Excel files but the spreadsheet is going to be big. The Sheets "SMMR-calcs" and "WNTR-calcs" will have to be repeated (just copied) 8760 times for each hour of the year using the 8760 hours of DB and WB values. See http://bepan.info/weather 11 - Template - Shanghai – DOE2-Weather-Analysis - Short

Building Model Summary

Site-Alt	# Flrs	Bldg-H	Ntrl-H	Bldg-Flr-A	Envelope-A	Leakg-A	% Lkg-A
0	201	2757	1,379	6,104,800	1,927,780	3677	0.191

Infiltration per Vertical Bldg Sections

SECTION No. >>	1-Grd	2-Rtl	3-Fin	4-Ofc	5-Srv	6-Htl
SM: Infltr - cfm / Section	5,443	53,056	79,720	52,016	16,725	9,847
SM: Infltr cfm/ft2 Envel	**0.07**	**0.18**	**0.20**	**0.10**	**0.05**	**0.06**
SM: Infltr cfm/ft2 Perim	**0.27**	**2.65**	**6.33**	**5.10**	**1.64**	**0.95**
SM: Infltr-Cooling Ton Yr	1,469	14,325	21,525	14,044	4,516	2,659
SM: Infl-Clg Kbtuh/SF/Yr	**0.05**	**0.17**	**0.19**	**0.11**	**0.06**	**0.06**
WN: Infltr - cfm / Section	11,403	102,639	133,691	63,330	56,198	39,592
WN: Infltr cfm/ft2 Envel	**0.14**	**0.36**	**0.34**	**0.12**	**0.18**	**0.25**
WN: Infltr cfm/ft2 Perim	**0.56**	**5.13**	**10.61**	**6.21**	**5.51**	**3.81**
WN: Infltr-Heating Kbtuh/Yr	36,944	332,551	433,160	205,189	182,080	128,278
WN: InflHtg btuh/SF/Yr	**0.11**	**0.34**	**0.32**	**0.13**	**0.21**	**0.26**

Using the Excel spreadsheet program helped me to understand how Stack Effect & Wind Pressure affects super tall (above 300 m) buildings. It does matter for super-tall buildings but might be small relative to other heating & cooling loads in the case of other large commercial buildings.

Using the Excel program might also help in understanding and planning how to develop a simpler (than CONTAM & COMIS) 8760 hour analysis model for simulation of tall buildings with numerous floors and zones. This cannot be done with the Excel spreadsheet. **It has to be computer program subroutine that can be inserted into energy programs.**

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All commercial buildings in the USA must comply with energy codes which are based on ASHRAE Standard 90.1. Computer programs for energy analysis are used to show compliance with the building energy code at the time of submitting construction documents. They are also used for US Green Building Council (USGBC) certification to show percent energy savings of the proposed building design over a building designed to ASHRAE standard 90.1.

Building energy analysis and simulation computer programs are done for the 8760 hours of the year. Infiltration can be assumed to be the same for a given envelope type and construction for most commercial buildings. It is typically estimated separately as airflow per unit area of the envelope or perimeter zone and entered as input into the energy program.

Tall and super-tall buildings are typically multi-purpose and include ground floor atrium-lobbies with entrance-exit doors, and floors for retail, offices, restaurants, hotel services, hotel rooms, apartments, parking and mechanical-electrical (M-E) systems. The floor to floor height and envelope construction varies with the floor type. Office floors are pressurized and have fixed windows and residential floors have operable windows. The M-E floors have wall openings and parking floors have no walls.

Air flow between zones and floors within the building depend on the type of inside floors, walls, partitions and doors. Zone, floor, elevator and stair shafts pressurization affect infiltration and air flow. Infiltration in tall buildings is affected by the floor elevation above the ground floor due to stack effect, the weather conditions outside, including wind velocity and direction. Wind and extreme outdoor temperatures are major factors. Prefabricated curtain walls that are manufactured off-site using computer driven numerical machines and hoisted and snapped to place in the building have low leakages.

CONTAM and COMIS type analysis with an 8760 hour energy simulation program will require a disproportionate amount of computer execution time.

COMIS models the air flow and contaminant distributions in buildings. The program can simulate several key components influencing air flow: cracks, ducts, duct fittings, fans, flow controllers, vertical large openings (windows and/or doors), kitchen hoods, passive stacks, and "user-defined components".

CONTAM is a multi-zone indoor air quality and ventilation analysis computer program designed to help you determine airflows: infiltration, exfiltration, and room-to-room airflows in building systems driven by mechanical means, wind pressures acting on the exterior of the building, and buoyancy effects induced by the indoor and outdoor air temperature difference.

Such analysis will produce more accurate results only if accurate values of the numerous input requirements for every surface of every zone of every floor of a tall building are assembled and organized accurately and correctly as a single model of the building. The CONTAM and COMIS programs also deal with contamination airflow movement between zones and this project is only interested in outdoor air infiltration which requires just 3 zones per floor – perimeter, core and interior.

Since a detailed floor by floor analysis is not practical because of time and cost constraints, a different perspective of the building is required. Instead of the conventional approach of analyzing horizontal floors with multiple zones, tall buildings should be analyzed as vertical zones of multiple similar floor types, preferably, vertical subzones of floors based on vertical sections of floors that are served by air systems and equipment.

Measurement of existing buildings on site is difficult and measurement under lab test conditions is expensive because it requires creating a lab. Testing & measurement under lab conditions (vary pressure, temperature, wind direction, etc.) are easier to do and will produce more reliable results.

Prefabricated curtain walls that are manufactured off-site using computer driven numerical Control machines and hoisted and snapped to place in the building have low leakages. Infiltration depends on the envelope type, materials, its manufacture off site and its construction on-site.

Since the building energy program infiltration is presently dependent on user estimate or simple stack effect analysis, it cannot be considered to compare the energy efficiency of the proposed building design with ASHRAE Standard 90.1 design, for code compliance or USGBC certification. The same infiltration rate has to be entered for baseline and proposed models. **No credit can be taken for energy savings based on infiltration due to efficient envelope and systems design**. Envelopes could be compared for infiltration if composite sections of the envelope (panels) can be rated. This can be done with envelope panels that are assembled off site by testing and rating them under lab conditions.

There is already a considerable amount measured data such as the CONTAM Software & Library
http://www.bfrl.nist.gov/IAQanalysis/index.htm
http://www.bfrl.nist.gov/IAQanalysis/CONTAM/libraries.htm ;
ORNL's Building Envelopes Program (BEP) website
http://www.ornl.gov/sci/roofs+walls/tour/index.html ; "
PNNL 18898 - Infiltration Modeling Guidelines for Commercial Building Energy Analysis" ;
AIVC - Air Infiltration & Ventilation Center http://www.aivc.org/ and
INFILTEC - Large Building Envelope Airtightness http://www.infiltec.com/inf-larg.htm .

Given the considerable amount of envelope performance test data available, standards can be set for envelope materials and prefabricated envelope panels leakage data for use by energy analysis programs similar to the standards for windows.

Absolute accuracy of building energy performance and leakage information is not realistic, but relative accuracy when comparing alternative options is important. For example, using two different energy simulation programs to compare the baseline model with the proposed model is not acceptable.

What is required is a simpler modeling & simulation system approach for tall buildings that will generate the information required by the 8760 hour energy simulation programs and that will be acceptable to code authorities to obtain credit for efficient envelope and systems design that minimizes infiltration in tall buildings due to stack-effect and wind-pressure.

Varkie Thomas
http://www.iit.edu/arch/faculty/thomas_varkie.shtml

References

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ASHRAE-77 - Calculation of Wind & Stack Effect Infiltration in Tall Bldgs.pdf
ASHRAE-D-RP-1456-20110405 Ventil Models in Whole Bldg Simulations.pdf
ASHRAE- TC-9.12 - RP-935 – Protocol for Field Testing of Tall Buildings to determine Envelope Leakage Rates
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ASHRAE-Trans Vol-82 Part-1 122-134 - Studies on Exterior Wall Air Tightness and Air Infiltration of Tall Buildings
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2 - High-Rise-Apt-Bldgs - Ventil-Exhaust-Infiltr

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ASTM STP-1067 - Methods for Measuring Air Leakage in High-Rise Apartments," Air Change Rate and Airtightness in Buildings

3a - Tall-Bldgs-DOC - Press-Infiltr-Stack-Effect

BSD-110 HVAC in High-Rise Multifamily Buildings.docx

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3b - Tall-Bldgs-PDF - Press-Infiltr-Stack-Effect

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PNNL-18898 Infiltration Modeling Guidelines for Building Energy Analysis.pdf
USACE Air Leakage Test Protocol for Bldg Envelopes.pdf
York-JCI – Return + Exhaust Fans and Bldg-Pressurization.pdf

4 - NIST-CONTAM - LBNL-COMIS Documentation

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COMIS-User-Guide.pdf
CONTAM – Library.docx
CONTAM – Summary.docx
CONTAM User Guide and Program Documentation.pdf
CONTAM-30-Tutorial.pdf

Figures

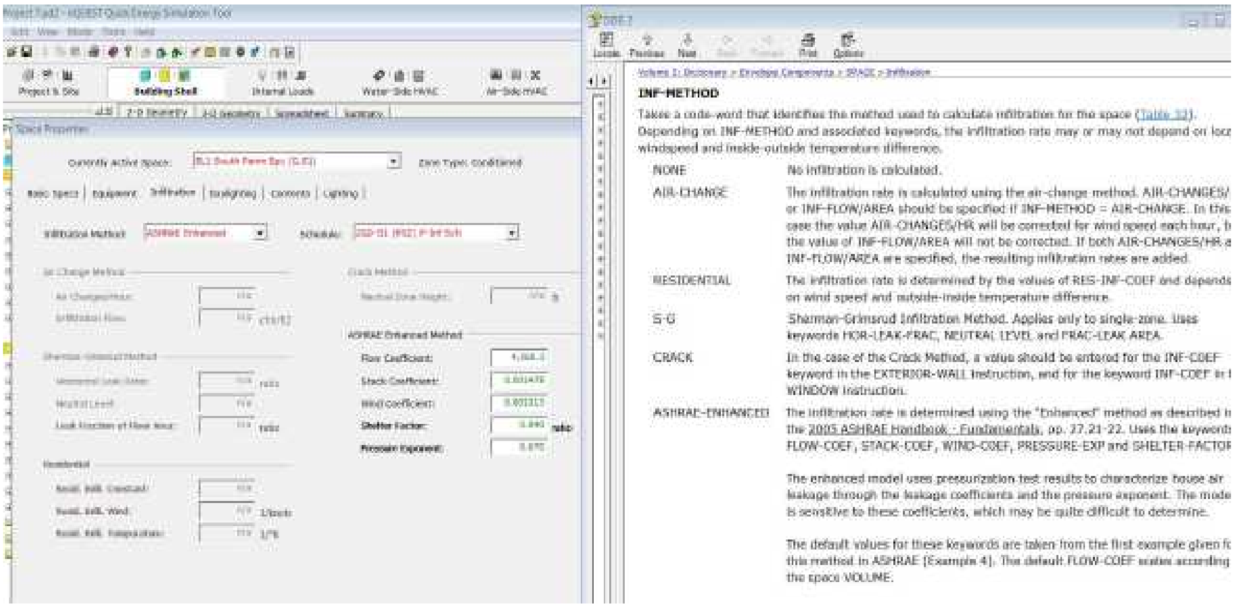

Figure 1 - Infiltration Methods used by DOE2 based program (eQUEST Shown)

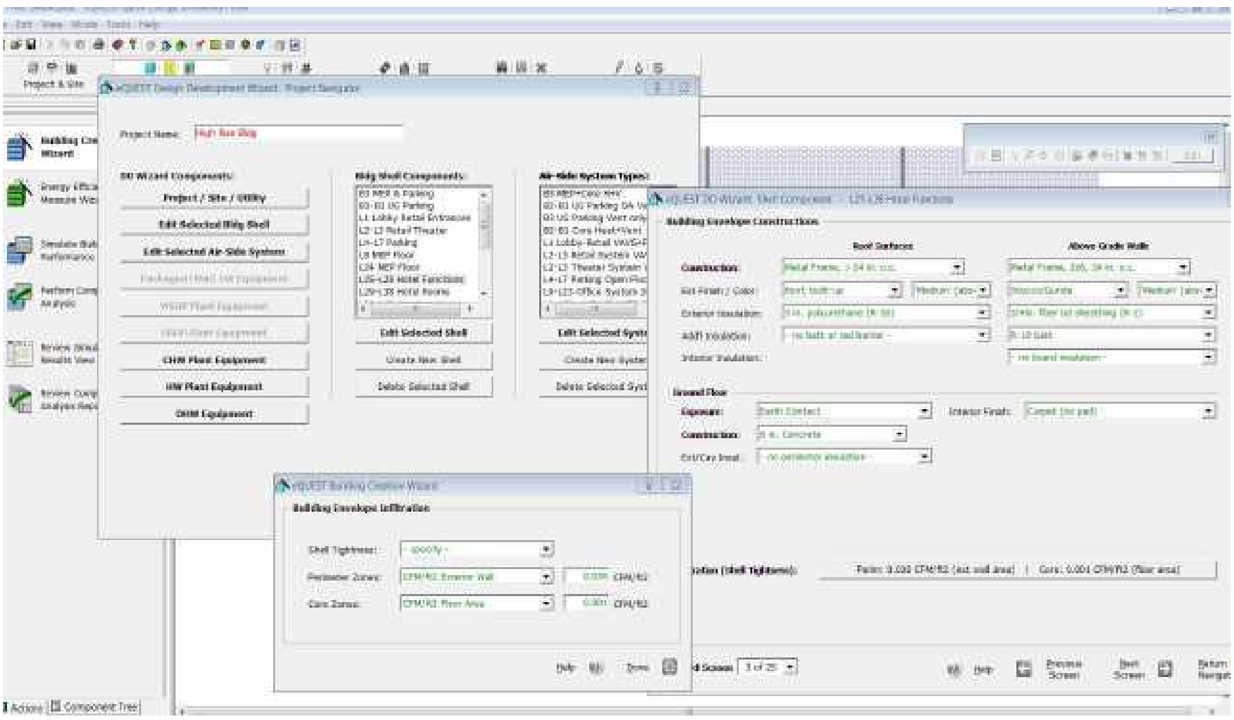

Figure 2 - Infiltration Input by Vertical Sections of Building (eQUEST Shown)

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$----------------------------------------------------------------------------------$
$ --Wall/Window/Door Infltr CFMs are added to Space Infltr CFM (ACH or CFM/SF) $
                        $ Typical Infiltration Coefficients for Exterior Walls $
$ 13" Brick Wall with Plastered Surface      cfh/ft2 = 0.01  Inf-Coeff = 0.002 $
$ 8" Brick Wall Plain                        cfh/ft2 = 5.00  Inf-Coeff = 0.915 $
$ Curtain Wall, Pressurized Building                         Inf-Coeff = 0.005 $
                               $ Typical Infiltration Coefficients for Windows $
$ Sealed Windows (Curtain Wall) Pressurized Building         Inf-Coeff = 0.5   $
$ 1/8" Crack (Wall or Window)                 cfm/ft = 0.30  Inf-Coeff = 1.342 $
$ 1/4" Crack (Wall or Window)                 cfm/ft = 0.50  Inf-Coeff = 2.236 $
$ 1/2" Crack (Wall or Window)                 cfm/ft = 1.10  Inf-Coeff = 4.919 $
                                 $ Typical Infiltration Coefficients for Doors $
$ 3' x 7' Closed Door Residential with Weather Stripping     Inf-Coeff = 2.400 $
$ 3' x 7' Closed Door Residential without Weather Stripping  Inf-Coeff = 12.00 $
$ 3.5' x 7' Closed Door OFFC                                 Inf-Coeff = 3.100 $
$ 3.5' x 7' Closed Door OFFC Open 10%                        Inf-Coeff = 13.50 $
$ 3.5' x 7' Closed Door OFFC Open 25%                        Inf-Coeff = 55.00 $
$ 3.5' x 7' Closed Door OFFC Open 50%                        Inf-Coeff = 153.0 $
$ 3.5' x 7' Closed Door OFFC Open 10% + Vestibule            Inf-Coeff = 9.300 $
$ Revolving Door (average use)                               Inf-Coeff = 12.00 $
$ Garage or Shipping Room Door (average use)                 Inf-Coeff = 60.00 $
$------------------------------------------------------------------------------$
PARAMETER         $ Use this Command to vary design criteria, dimensions, etc. $
   OFC-BLDG-HEIGHT = 400                                     $ Building Height $
   BLDG-NEUTRAL-LVL = 0.5              $ Neutral Level (fraction of Bldg Hgt) $
   OFC-WALL-INFL-C = 0.005                                $ Wall Infiltr Coeff $
   OFC-WNDW-INFL-C = 0.5           $ Window Infiltr Coeff. Sealed Pressurized $
   OFC-DOOR-INFL-C = 20                                   $ Door Infiltr Coeff $
     $ Infiltration at 2 cfm/LF of window perimeter =  [2x(220+9)]x2 = 916 cfm $
                    $ ACH = (916 x 60)/40000 = 1.37.  cfm/SF = 916/4000 = 0.23 $
   OFC-INFL-ACH = 1.37                    $ Space Infiltr Air Changes per Hour $
   OFC-INFL-CFM/SF = 0.23                         $ Space Infiltr CFM per SQFT $
   OFC-PLEN-ACH = 0.1      $ Infiltr Air Changes per Hour into Ceiling Plenum $
..                                                  $ End of Parameter Command $
$-----------Infiltration Schedules-------------------------------------------$
SCH-INFL-WNDW = SCHEDULE    $ Infltr_CFM = Design_Infltr_CFM x Infltr_Fraction $
   THRU FEB 28  (ALL) (1,24)=(1.0)
   THRU APR 30  (ALL) (1,24)=(0.7)
   THRU OCT 31  (ALL) (1,24)=(0.5)
   THRU NOV 30  (ALL) (1,24)=(0.7)
   THRU DEC 31  (ALL) (1,24)=(1.0)    ..
SCH-INFL-WALL = SCHEDULE
   THRU FEB 28  (ALL) (1,24)=(1.0)
   THRU APR 30  (ALL) (1,24)=(0.7)
   THRU OCT 31  (ALL) (1,24)=(0.2)
   THRU NOV 30  (ALL) (1,24)=(0.7)
   THRU DEC 31  (ALL) (1,24)=(1.0)    ..
SCH-INFL-DOOR = SCHEDULE
$----------------------Space Conditions---------------------------------------$
SC-OFC-EXT = SPACE-CONDITIONS    $ Office Design Criteria for Perimeter Spaces $
ZONE-TYPE = CONDITIONED                        $ or = UNCONDITIONED, = PLENUM $
INF-METHOD = CRACK               $ Wall/Window/Door Infl based on Po, Pi diffr $
                                  $ Enter INF-COEF in WALL/WINDOW/DOOR Command $
 $ INF-CFM/SQFT = OFC-INFL-CFM/SF  Added to values by other methods if entered $
INF-SCHEDULE = SCH-INFL-WNDW
NEUTRAL-ZONE-HT = OFC-BLDG-HEIGHT       $ Abbrev = N-Z-H = Hi-Rise Bldg height $
NEUTRAL-LEVEL = BLDG-NEUTRAL-LVL  $ Default = 0.5 (0.5 x N-Z-H). Limits: (0,1) $
..
$----------------------Wall and Window Defaults-------------------------------$
SET-DEFAULT FOR EXTERIOR-WALL      $ Exposed Widths of all 4 Bldg Sides = 220' $
    INF-COEF = OFC-WALL-INFL-C  $ Infilt CFM = Coeff x (Pi-Po)^0.8 x Wall Area $
                                            $ Pi,Po = Inside, Outside Pressure $
..
SET-DEFAULT FOR WINDOW                         $ Applies to all 4 Bldg Sides $
    INF-COEF = OFC-WNDW-INFL-C $ Infilt CFM = Coeff x (Pi-Po)^0.5 x Wndw Perim $
                                            $ Pi,Po = Inside, Outside Pressure $
..
$------------------------------------------------------------------------------$
```

Figure 3 - Infiltration Input into DOE2.1E program