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

Advantages and Limitations of the Excel Spreadsheet 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. See http://bepan.info/proj-bldgs/p13-high-rise-bldg

Air flow between zones and floors within the building depend on the type of inside floors, walls, partitions, doors, zone, floor and elevator & stair shafts pressurization. Infiltration in tall buildings is also 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.

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.** An estimate of the energy use due to infiltration is based on degree days.

Note that the spreadsheet calculations are for a one hour design condition in summer and in winter. The wind is assumed to be direct on all exposures. You can enter the average rate of cfm/ft2 of envelope area for each section, calculated by the spreadsheet, for summer & winter, into a HVACR design "LOADS" program and apply an infiltration schedule for the design days.

You could also enter these summer and winter design values for each section into an energy program (eQUEST default is 0.06 cfm/ft2) but it would be assumed to be constant for every hour of the year. **The analysis has to done for 8760 hours of weather data**. It can be adjusted with an infiltration schedule for a typical day in summer, fall, winter & spring or for each month.

DESIGN Data	SMMR	WNTR
Wind (mph) Grnd	5	15
Wind (mph) Roof	10	20
~~Wind Dir (0-360)~~	~~180~~	~~315~~
Outdoor DB (F)	95	-16
Outdoor WB (F)	75	-16
Degree-Days	2,680	7,981
Indoor DB (F)	75	72
Indoor WB (F)	62	55

If the floor shape is not a rectangle, then there is an option to enter floor area and perimeter length. **The floor is divided into 3 zones – the Perimeter zone based on the perimeter zone depth, the Core zone based on the percent core area, and the rest of it is the Interior zone.** The program does not take into account perimeter zone exposure orientation and assumes the wind is direct and the same on every exposure orientation.

Typical Floor Length (ft)	320
Typical Floor Width (ft)	240
OR Non-Rectg Floor-A (ft2)	
OR Non-Rectg Flr Perm (ft)	
Floor-Floor Height (ft)	20.0
Floor-Ceiling Height (ft)	15.0
Number of Section Floors	2
Mech Floor in Section (**Y/N**)	**N**

Mechanical Flr-Flr-H	**20.0**
Core Area (%)	**15.0**
Perim-Zone-Depth	**15.0**

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.**

No. of Windows per Bay	5
Window Unit Width (ft)	5.5
Window Unit Height (ft)	11.0
OR Window Area (%)	**60**
OR Lkg-A % Envl (0.01-0.15)	**0.450**
Wall Leakage Area (ft2 / ft2)	0.00199
Wndw Leakg Area (ft2 / ft2)	0.00065
Envel Leakage Flow Coeff	0.65
Indr-Outdr PD (in.wg) P_I - P_O	**0.005**

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.

The floors have 3 horizontal zones (Perimeter, Interior & Core). Detailed floor zoning is not required for infiltration calculations as in contamination air flow between all zones in a hospital. In the Excel program the inside pressures will be maintained by adjusting the Supply, Return & Exhaust air of each zone. An example is http://bepan.info/engg-calcs "4a - Fire-Smoke-Control - Stair-Pressurization". **I need the theory and equations for calculating pressures in the zones and airflow between zones to add this feature to the Excel program.**

Occup / Floor Area (P / ft2)	50
Outdr Air / Person (cfm / P)	15
Exhaust (cfm/ft2 Core-Zn)	1.50
OR Exhaust / floor (cfm)	
Perm-Zone Sup Air (cfm / ft2)	2.10
Core-Zone Sup Air (cfm / ft2)	1.50
Inter-Zone Sup Air (cfm / ft2)	1.10

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

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.**

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

"A multi-component building envelope system that is engineered, fabricated, and assembled by the manufacturer can reduce design efforts, errors, and associated liability, if architects and specifiers can define the required performance criteria. Because the system can be tested as an assembly extensively in labs, it avoids field-testing, which is often required for large-scale buildings or critical facilities. The systems also benefit owners of large and multiple facilities because of the standardization of facility design and management. They generally simplify construction planning and shorten project duration," Barbara A. Nadel, FAIA, Architectural Record, August 2006.

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 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 library 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 ; and "PNNL 18898 - Infiltration Modeling Guidelines for Commercial Building Energy Analysis". What is lacking is input and support from A-E design firms in developing systems that would use the information that is already available, in applying it to evaluate tall buildings.

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.

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

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ASHRAE-Trans Vol-82 Part-2 179-190 - Air Leakage Data for the Design of Elevator and Stair Shaft Pressurization Systems
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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

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4 - NIST-CONTAM - LBNL-COMIS Documentation

COMIS Multi-zone Air Flow Model.docx
COMIS-User-Guide.pdf
CONTAM – Library.docx
CONTAM – Summary.docx
CONTAM User Guide and Program Documentation.pdf
CONTAM-30-Tutorial.pdf

Figures

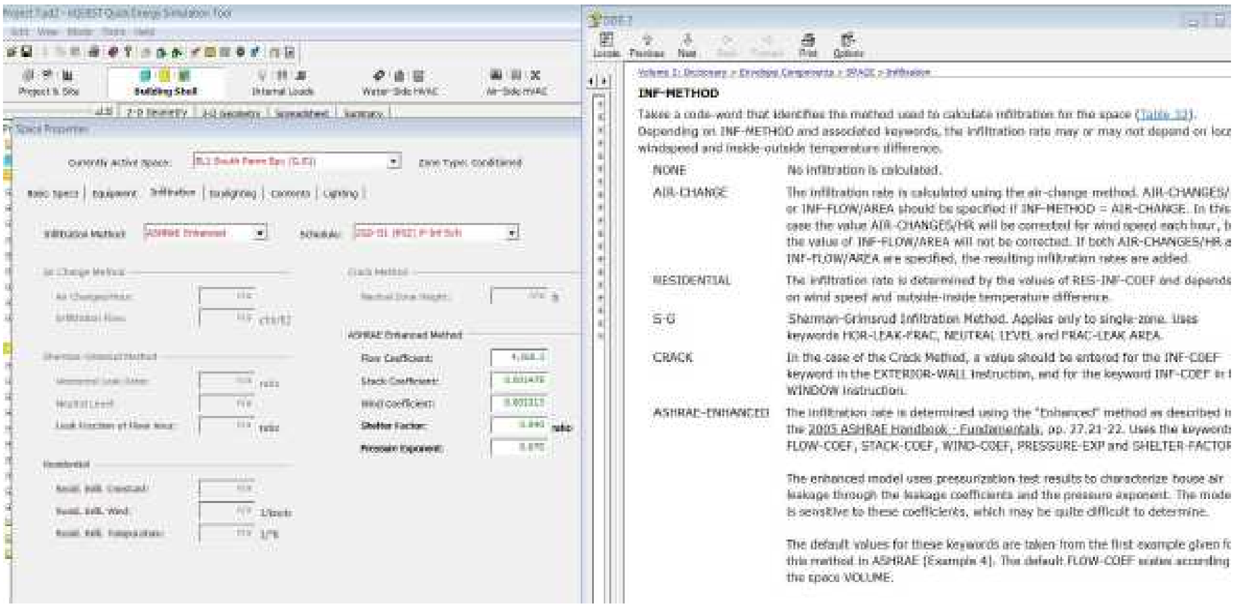

Figure 1 - Infiltration Methods used by DOE2 based program (eQUEST Shown)

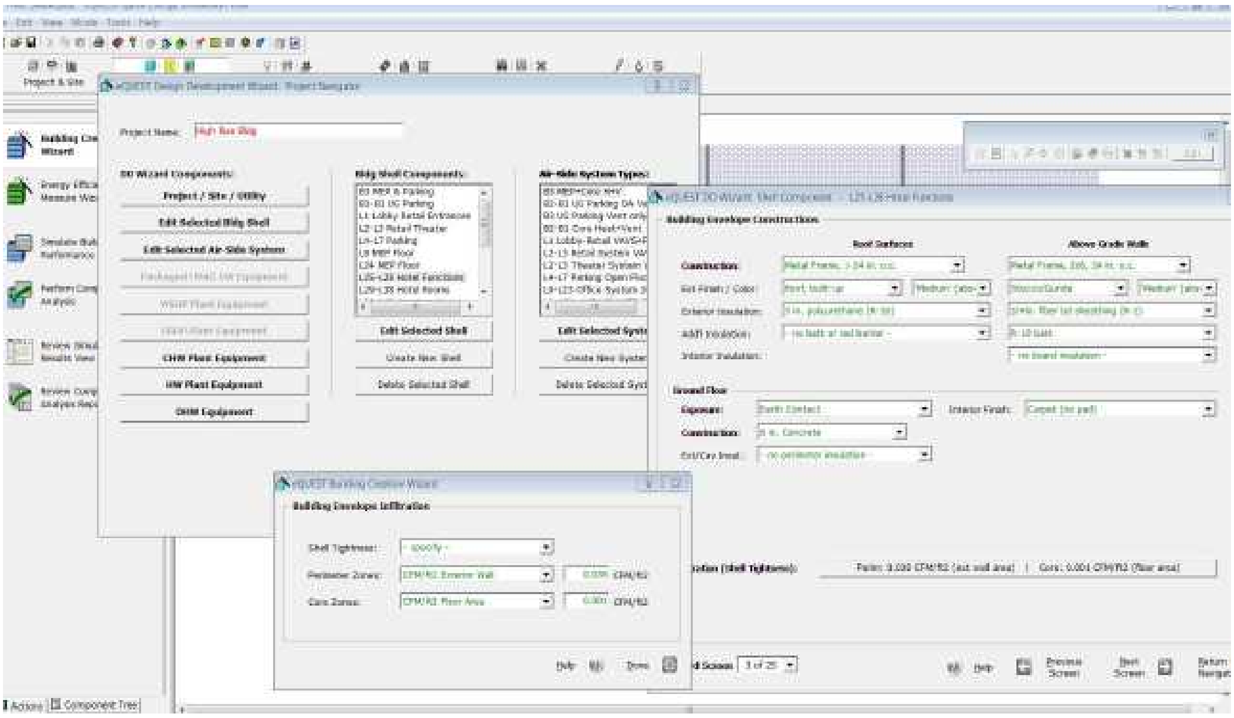

Figure 2 - Infiltration Input by Vertical Sections of Building (eQUEST Shown)

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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 $
..
$-------------------------------------------------------------------------------$
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Figure 3 - Infiltration Input into DOE2.1E program