Uncertainty of effective leakage areas determination through reductive sealing technique

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AIVC Webinar 2020

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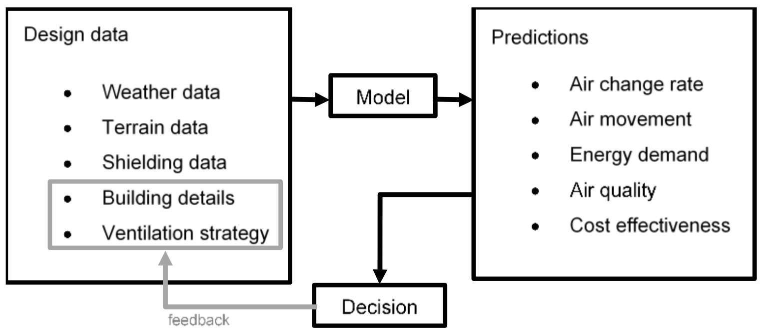
Air infiltration



Effective Leakage Areas

The area of a single orifice that would produce the same leakage as the group of leakages it represents at a reference pressure difference

- Typical form of expressing air leakage characteristics
  - building components
  - whole envelopes

$$ELA = \frac{10q}{3.6}\frac{\sqrt{\frac{\rho_0}{2\Delta p}}}{C_D}$$

$$ELA = \frac{10}{3.6} C_{env} \left(\frac{T_0}{T}\right)^{1-n} \left(\frac{\rho_0}{2}\right)^{0.5} \Delta p^{n-0.5}$$

Effective Leakage Areas

- Available extensively in ASHRAE and AIVC documentation
  - repeated measurements
  - compilation of laboratory and in situ experiments

Results using ordinary least squares regression in the airflow

No propagation of uncertainty in incremental sealing

Table 1 Effective Air Leakage Areas (Low-Rise Residential Applications Only)

	Units (see note)	Best Estimate	Minimum	Maximum
Ceiling				
General	cm^2/m^2	1.8	0.79	2.8
Drop	cm^2/m^2	0.19	0.046	0.19
Ceiling penetrations				
Whole-house fans	cm^2 ea	20	1.6	21
Recessed lights	cm^2 ea	10	1.5	21
Ceiling/Flue vent	cm^2 ea	31	28	31
Surface-mounted lights	cm^2 ea	0.82		
Chimney	cm^2 ea	29	21	36
Crawl space				
General (area for exposed wall)	cm^2/m^2	10	8	17
200 mm by 400 mm vents	cm^2 ea	129		
Door frame				
General	cm^2 ea	12	2.4	25
Masonry, not caulked	cm^2/m^2	5	1.7	5
Masonry, caulked	cm^2/m^2	1	0.3	1
Wood, not caulked	cm^2/m^2	1.7	0.6	1.7
Wood, caulked	cm^2/m^2	0.3	0.1	0.3
Trim	cm^2/lmc	1		
Jamb	cm^2/lmc	8	7	10
Threshold	cm^2/lmc	2	1.2	24
Doors				
Attic/crawl space, not weatherstripped	cm^2 ea	30	10	37
Attic/crawl space, weatherstripped	cm^2 ea	18	8	18.5
Attic fold down, not weatherstripped	cm^2 ea	44	23	86
Attic fold down, weatherstripped	cm^2 ea	22	14	43
Attic fold down, with insulated box	cm^2 ea	4		
Attic from unconditioned garage	cm^2 ea	0	0	0
Double, not weatherstripped	cm^2/m^2	11	7	22
Double, weatherstripped	cm^2/m^2	8	3	23
Elevator (passenger)	cm^2 ea	0.26	0.14	0.35
General, average	cm^2/lmc	0.31	0.23	0.45
Interior (pocket, on top floor)	cm^2 ea	14		
Interior (stairs)	cm^2/lmc	0.9	0.25	1.5
Mail slot	cm^2/lmc	4		
Sliding exterior glass patio	cm^2 ea	22	3	60
Sliding exterior glass patio	cm^2/m^2	5.5	0.6	15
Storm (difference between with and without)	cm^2 ea	6	3	6.2
Single, not weatherstripped	cm^2 ea	21	12	53

	Units (see note)	Best Estimate	Minimum	Maximum
Piping/Plumbing/Wiring penetrations				
Uncaulked	cm^2 ea	6	2	24
Caulked	cm^2 ea	2	1	2
Vents				
Bathroom with damper closed	cm^2 ea	10	2.5	20
Bathroom with damper open	cm^2 ea	20	6.1	22
Dryer with damper	cm^2 ea	3	2.9	7
Dryer without damper	cm^2 ea	15	12	34
Kitchen with damper open	cm^2 ea	40	14	72
Kitchen with damper closed	cm^2 ea	5	1	7
Kitchen with tight gasket	cm^2 ea	1		
Walls (exterior)				
Cast-in-place concrete	cm^2/m^2	0.5	0.049	1.8
Clay brick cavity wall, finished	cm^2/m^2	0.68	0.05	2.3
Precast concrete panel	cm^2/m^2	1.2	0.28	1.65
Low-density concrete block, unfinished	cm^2/m^2	3.5	1.3	4
Low-density concrete block, painted or stucco	cm^2/m^2	1.1	0.52	1.1
High-density concrete block, unfinished	cm^2/m^2	0.25		
Continuous air infiltration barrier	cm^2/m^2	0.15	0.055	0.21
Rigid sheathing	cm^2/m^2	0.35	0.29	0.41
Window framing				
Masonry, uncaulked	cm^2/m^2	6.5	5.7	10.3
Masonry, caulked	cm^2/m^2	1.3	1.1	2.1
Wood, uncaulked	cm^2/m^2	1.7	1.5	2.7
Wood, caulked	cm^2/m^2	0.3	0.3	0.5
Windows				
Awning, not weatherstripped	cm^2/m^2	1.6	0.8	2.4
Awning, weatherstripped	cm^2/m^2	0.8	0.4	1.2
Casement, weatherstripped	cm^2/lmc	0.24	0.1	3
Casement, not weatherstripped	cm^2/lmc	0.28		
Double horizontal slider, not weatherstripped	cm^2/lmc	1.1	0.019	3.4
Double horizontal slider, wood, weatherstripped	cm^2/lmc	0.55	0.15	1.72
Double horizontal slider, aluminum, weatherstripped	cm^2/lmc	0.72	0.58	0.8
Double-hung, not weatherstripped	cm^2/lmc	2.5	0.86	6.1
Double-hung, weatherstripped	cm^2/lmc	0.65	0.2	1.9
Double-hung with storm, not	cm^2/lmc	0.97	0.48	1.7

Reductive sealing

Offsetting results from blower door tests to attain the performance of individualized elements or groups

French database has 46 subcategories of leaks

Leak categories and occurrences.

Categories	Subcategories
A: Main envelope area	A1: Other leak on main envelope area
	A2: Vapour barrier membrane (or similar complex): adhesive junction between strips, puncture or tear
	A3: Liaisons mortar/glue between masonry blocks, panels between doublings
	A4: Opening (e.g.: wall plug) or not sealed junctions between panels
	A5: False ceiling slabs
B: Wall, roof and floor junctions	B1: Other leak on wall, roof and floor junctions
	B2: Junction between two vertical walls
	B3: Junction between wall base and floor
	B4: Junction between wall and high floor or pitched roof
	B5: Vapour barrier membrane (or similar complex): Attachment defective smooth with sill, intermediate floor, and top floor
C: Doors and windows	C1: Other leaks on doors and windows
	C2: Window and French window: frames (no seals or compression default of seals)
	C3: Window and French window: junction between glass and frame defective seal)
	C4: Landing door or fire door: poor compression of seals (excluding threshold bar)
	C5: Landing door or fire door: absent or ineffective threshold bar
	C6: Sliding door: Excessive space between window portions of sliding frame, and/or top and bottom of frame
	C7: Sliding door: Evacuation of condensates
	C8: Rolling shutter casing
D: Building component penetrating the envelope	D1: Another element through a wall
	D2: Vapour barrier membrane (or similar complex) through which duct, pipe, beams, hatches
	D3: Crossing Floor and walls and/or partitions (any type of plumbing pipes and electrical conduits ...)
	D4: Ventilation air terminals: leaks at periphery of exhaust or supply air vents
	D5: Beams: Linking beams or joist with walls
	D6: Beams: Liaison with ceiling beams or joists or floor
	D7: Stairs: Junction flooring/stairs or vertical walls/stairs
E: Trapdoor	E1: Another trapdoor
	E2: Trapdoor to attic (absent or ineffective seal)
	E3: Trapdoor to vertical technical duct (absent or ineffective seal)
F: Electrical component	F1: Another equipment
	F2: Electrical board
	F3: Grids built on the exterior walls
	F4: Grids built on the internal partition walls
	F5: Lighting components
G: Door/wall and windows/wall junctions	G1: Another leak on walls/doors and windows junction
	G2: Junction between walls and windows or French windows
	G3: Junction between walls and landing door or Fire door
	G4: Junction between internal panels and window and French window
	G5: Junction between internal panels and landing door or Fire door
	G6: Junction between vapour barrier membrane and door or window

Reductive sealing

Most frequent

- windows
- doors
- shutters

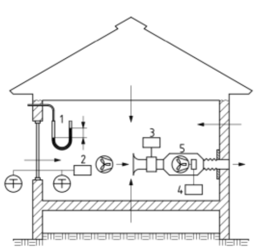
Most impactful

- lighting components
- junction between floor and wall
- electrical board
- junction between window and wall
- trapdoors to attics

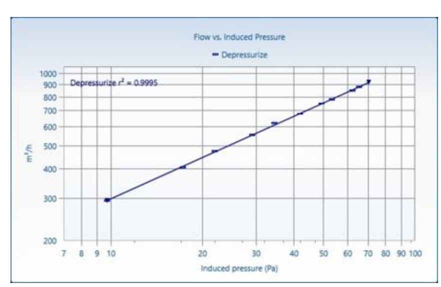
Leakage type assessment often qualitative – smoke tracer/thermography

Background leakage after initial assessment usually ranges from 45% to 75%

Regression models



1 pressure-measuring device
2 temperature-measuring device
3 air-flow measuring system
4 air-moving equipment
5 fan



Regression models

OLS – Ordinary least squares

WLOC – Weighted Line of Organic Correlation

OLS	OLS uncertainty	WLOC uncertainty
q readings: distance to regression values	q readings: fan accuracy t readings: sensors accuracy and resolution	q readings: fan accuracy t readings: sensors accuracy and resolution Δp and Δp0 readings: manometer accuracy and resolution zero-flow approximation

Uncertainty propagation

- Uncertainty propagation to the ELA

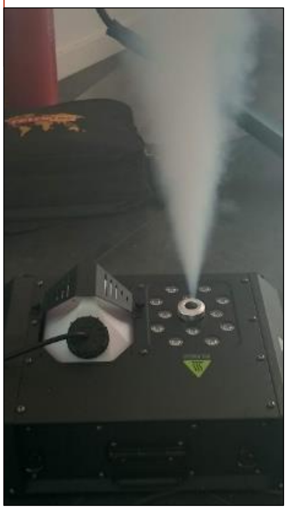
$$u(ELA) = \sqrt{\begin{array}{c} \left(2.155 C_{env} \Delta p^{n-0.5} \left(\frac{T_0}{T}\right)^{1-n} \ln\left(\Delta p \frac{T}{T_0}\right) u(n)\right)^2 + \left(2.155 C_{env}\, \Delta p^{n-0.5} \left(\frac{T_0}{T}\right)^{1-n} u(\ln(C_{env}))\right)^2 + \\ \left(2.155 \frac{C_{env} \Delta p^{n-0.5} (n-1)}{T} \left(\frac{T_0}{T}\right)^{1-n} u(T)\right)^2 + \\ 2\left(2.155 C_{env} \Delta p^{n-0.5} \left(\frac{T_0}{T}\right)^{1-n}\right)^2 \ln\left(\Delta p \frac{T}{T_0}\right) u(n)\, u(\ln(C_{env}))\, r(n, \ln(C_{env})) \end{array}}$$

- Offset of uncertainties between sealing steps

$$ELA_{step,i} = ELA_{i-1} - ELA_i$$

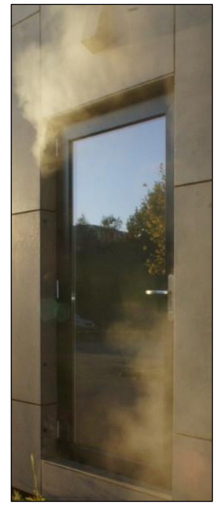
$$u(ELA_{step,i}) = \sqrt{u(ELA_{i-1})^2 + u(ELA_i)^2}$$

Application and best practices



Smoke tracer provides info for:

- Identification of predominant leaks
- Sealing step sequence



Application and best practices

Exterior finishings can be a challenge

Application and best practices

12 sealing steps
11 leakage path types

- default mode (DEF)
- mechanical ventilation (MEV)
- heating and air conditioning elements (HAC)
- electrical appliances (ELE)
- lighting (LIG)
- plumbing (PLU)
- wall/wall joints (WWJ)
- wall/floor joints (WFJ)
- wall/roof joints (WRJ)
- wall/openings joints (WOJ)
- openings (OPE)
- entrance door (ENT)

Application and best practices

- Significant dispersion of air flow rates between leakage paths
- No leakage path type exceeded 18% of the total air change rate
- WLOC provides higher calculated uncertainties in the airflow rates
- On average, 2.6 and 1.7 times greater than OLS and OLSu

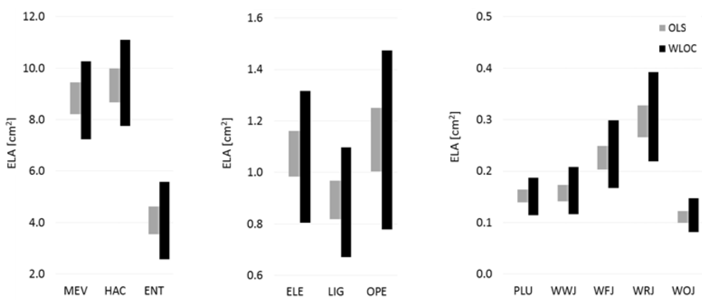
Average effective leakage area uncertainty

Pressure difference	OLS [%]	OLSu [%]	WLOC [%]
4	9.9	18.8	27.5

Application and best practices

Normalized ranges of ELAs

Ranges only provide (y – u(y); y + u(y))



Group	Qty.	Metric
MEV	4	item
HAC	4	item
ELE/	19	
LIG/	17	item
PLU	7	
WWJ/	40.8	
WFJ/	38.3	lm
WRJ/	38.3	
WOJ	35.1	
OPE	25.6	lm
ENT	5.9	lm

Application and best practices

- Less impacting air leakage types should be assessed first

  Minimize uncertainty accumulation effect in earlier steps

- Measure similar types of air leakage paths in a consecutive order

  If adjoining is needed for subsequent data treatment

- WLOC should be preferred since it considers the greatest number of error sources

  Even though a greater variability will result from its application

Application and best practices

Effective Leakage Areas are used primarily for input in airflow models

Risk assessment on health-related issues:

- minimum air renovations
- comfort concerns

Energy relevant aspects :

- ranges of heating and cooling loads

Support decision on intervention scenarios by:

- Cost
- Invasiveness
- Labour
- Time

With **truer** uncertainties → Most adequate leakage paths for intervention

THANK YOU FOR YOUR ATTENTION!

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