Measuring Air Leakage Pathways in Tall Buildings

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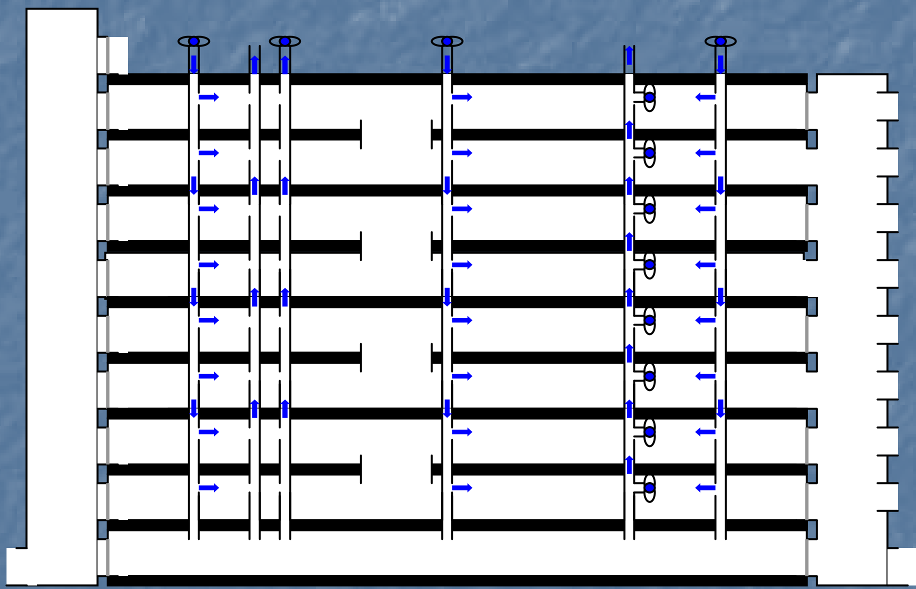


Myth

Buildings are smoke-tight

Reality

10 to 100 x more leaks than expected!

1993 WTC Garage Bomb

- Smoke on 25th floor in minutes

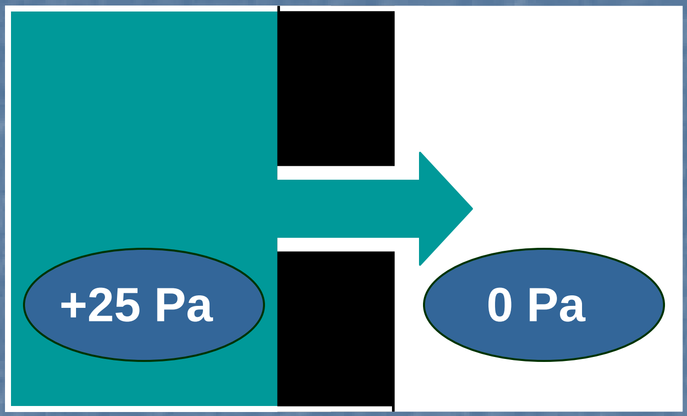
1980 MGM Grand Casino Fire

- Smoke deaths on 19th to 24th floors

- Now rooms tested for smoke tightness

Why Smoke Moves

- Pressure across a hole
  - Stack Pressures
  - HVAC (Heat Vent Air Conditioning) pressures
  - Wind
  - Diffusion – slow
  - MGM fire created 50 to 100 Pa



Why Smoke Moves

- Hole size measured with door fan

Minimum egress time calculation

Min. Egress Time= V x c x 1.271 / $Pa^{0.5}$ / ELA /F

V	=	Volume in m^3
c	=	Smoke concentration (1% in our examples)
1.271	=	Constant for flow formula (NFPA2001 Appendix C)
Pa	=	Driving force in Pa
ELA	=	Door-Fan measured leakage area with 0.61 discharge coefficient
F	=	Decimal fraction of portion of leaks subjected to smoke

Surprise #1

NFPA12A and NFPA2001 Clean Agent Standard

Clean Agent Suppression System

Ineffective smoke barrier

Holes seen from inside with lights out

Surprise #1

Unnecessary discharge

FM200 Discharge
Courtesy of Great Lakes Chemical

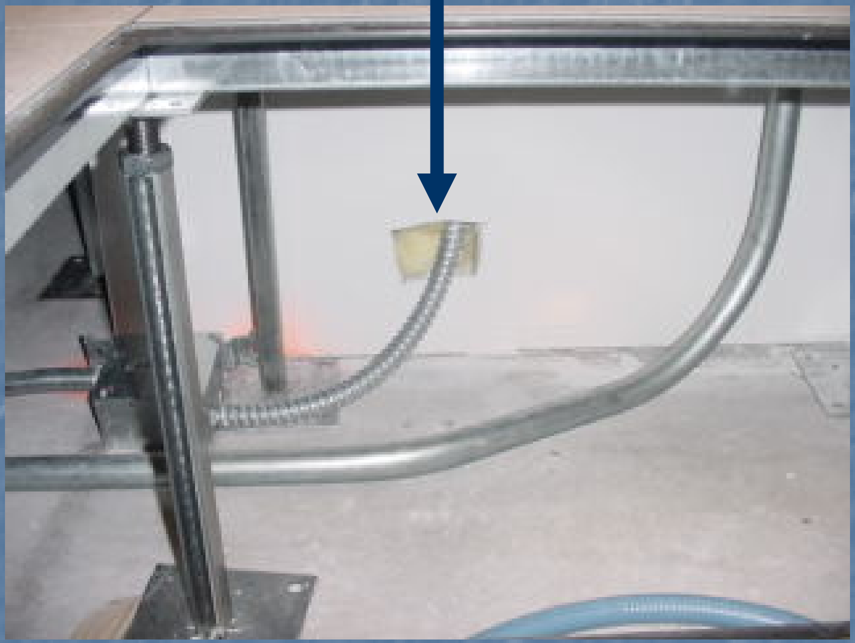
Surprise #2

Walls leak over a range of 500:1

Bottom and Tops of smoke barrier walls leak

Surprise #2

large hole for a small cable



Walls	Leaks	Egress
	cm²/m²	minutes
Extremely poor	50	1.40
UBC code	10	6.70
Typical maximum	5	13.00
Minimum measured	0.6	98.20
Achievable	0.1	600.00

Specific Leakage Areas cm^2/m^2 @ 50 Pa

(=0.5 $in^2/100ft^2$ EfLA @ 4 Pa) of surface area

Surprise #3

Stairwells fill with smoke quickly

- Doors leak
- Not re-evaluated

Surprise #3

Stairwells fill with smoke quickly

	Specific Leakage Area	Egress time
	cm^2/m^2	minutes
typical maximum	5	0.10
minimum measured	0.3	1.60
Achievable	0.1	4.80

Surprise #4

Dampers

Holes for phone lines

With fusible links don't keep out smoke

Surprise #5

Slabs leakage varies over range of 750:1

Walls	Leaks	Egress
	cm^2/m^2	minutes
Extremely poor, est.	15	0.3
UBC code	5	0.9
Maximum measured	0.97	4.0
Minimum measured	0.05	238.0
Achievable	0.02	280.0

Vertical pipes through slab

Surprise #6

- Elevator Lobbies not isolated

Surprise #7

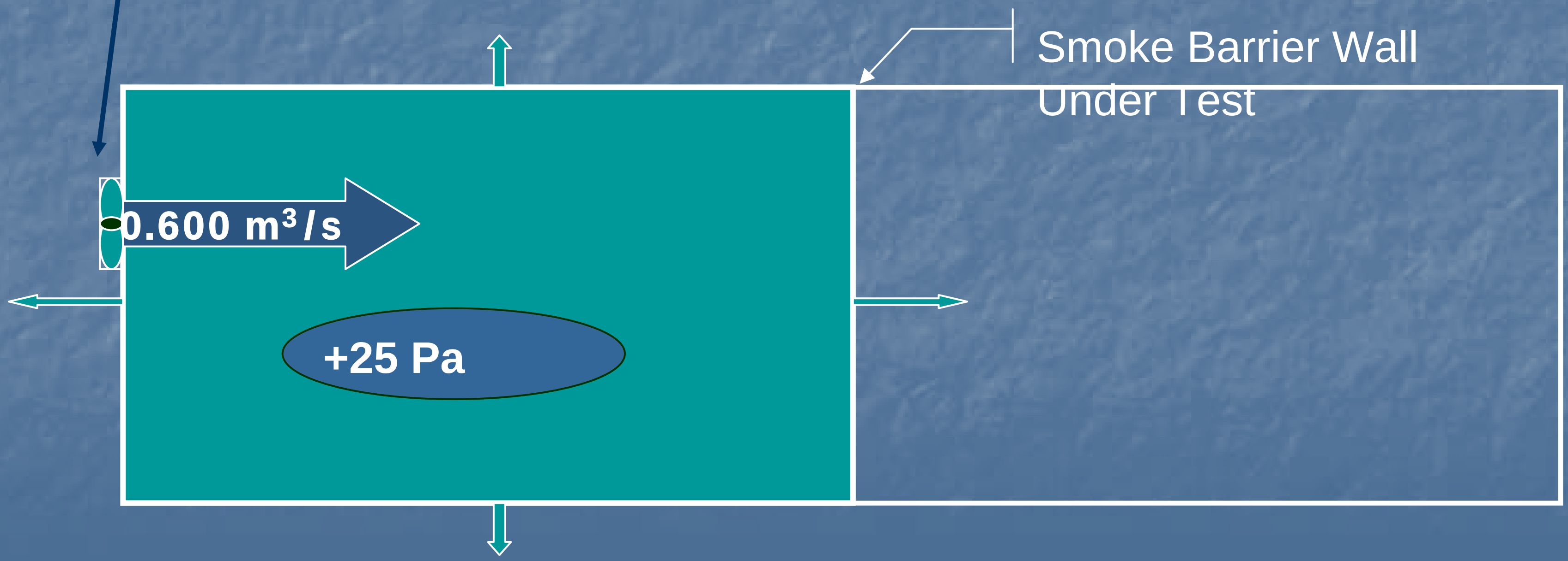
- Ducting often damaged

Isolating Component Walls

First,

the door-fan measures
total leaks

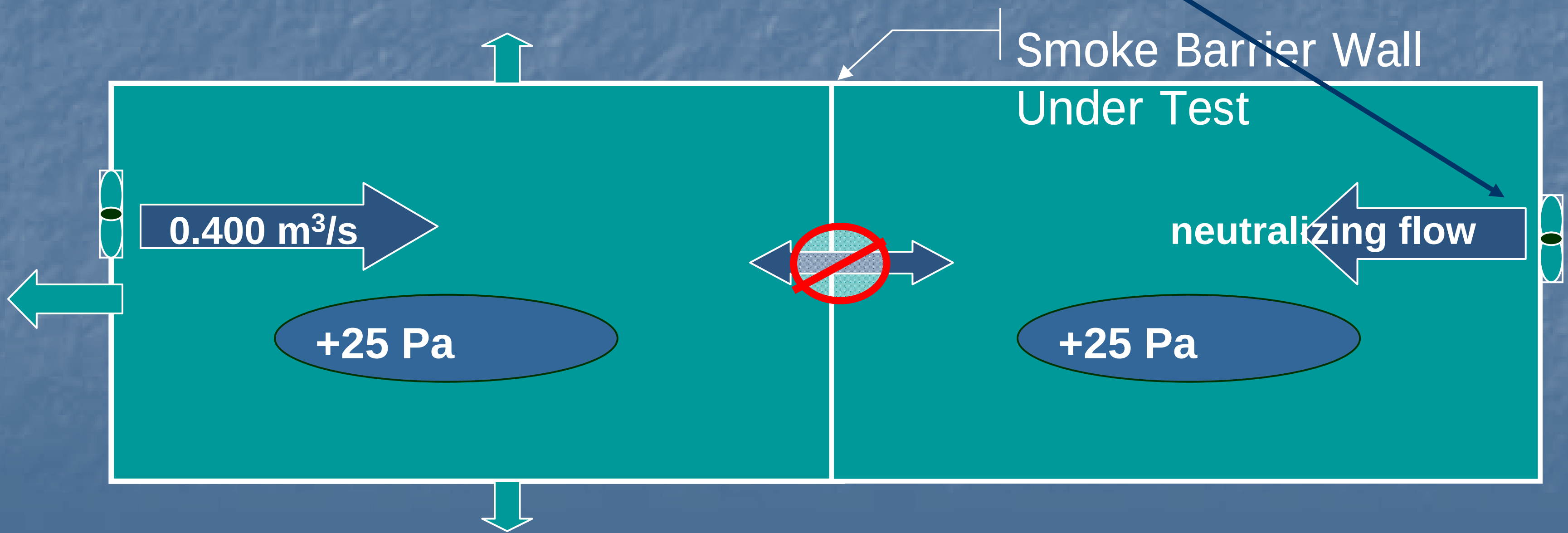
Flow (m3/s)	Press (Pa)	Leak (m2)
0.600	25	0.15



Isolating Component Walls

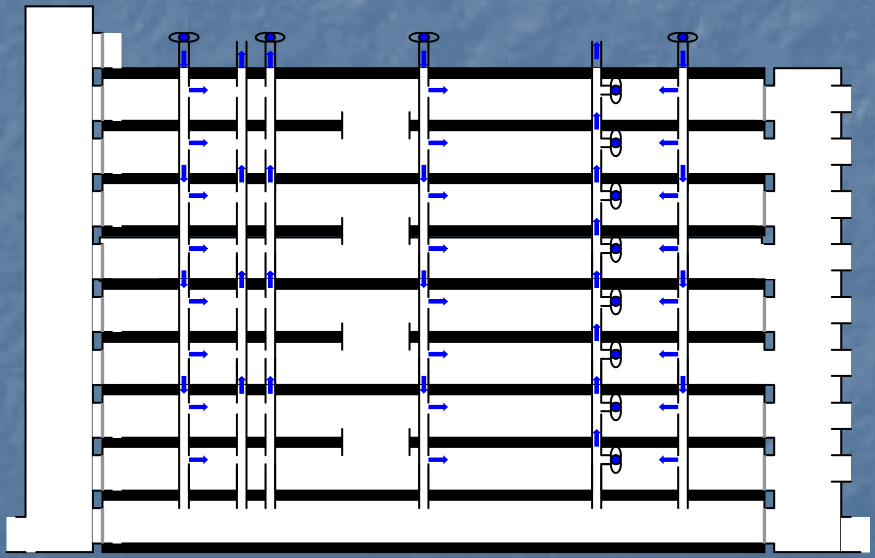
- Neutralized flow across component using 2nd door-fan

Flow (m^3/s)	Press (Pa)	Leak (m^2)
0.600	25	0.15
0.400	25	0.10
Leakage →		0.05



Test Example

9 Storey University Residence

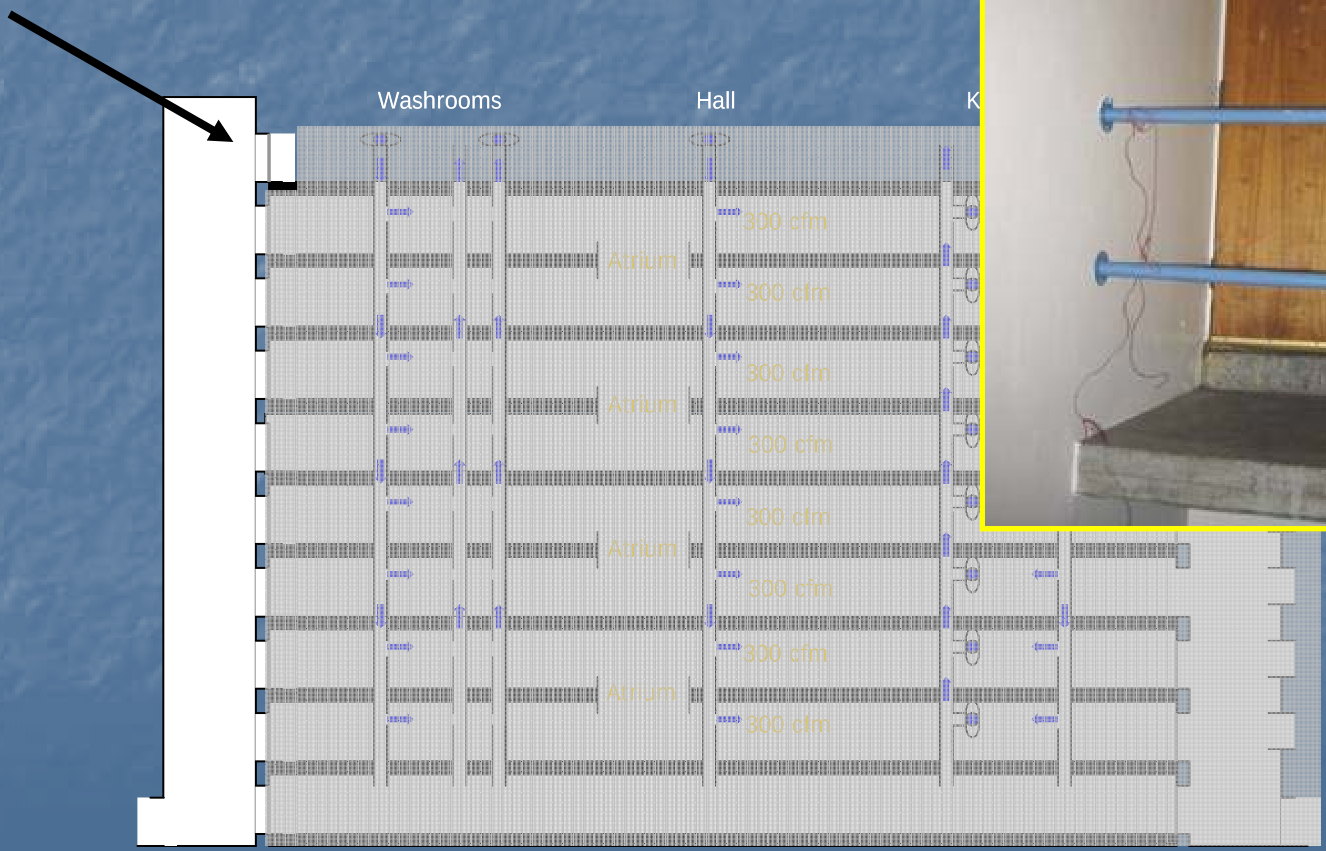


Building Features

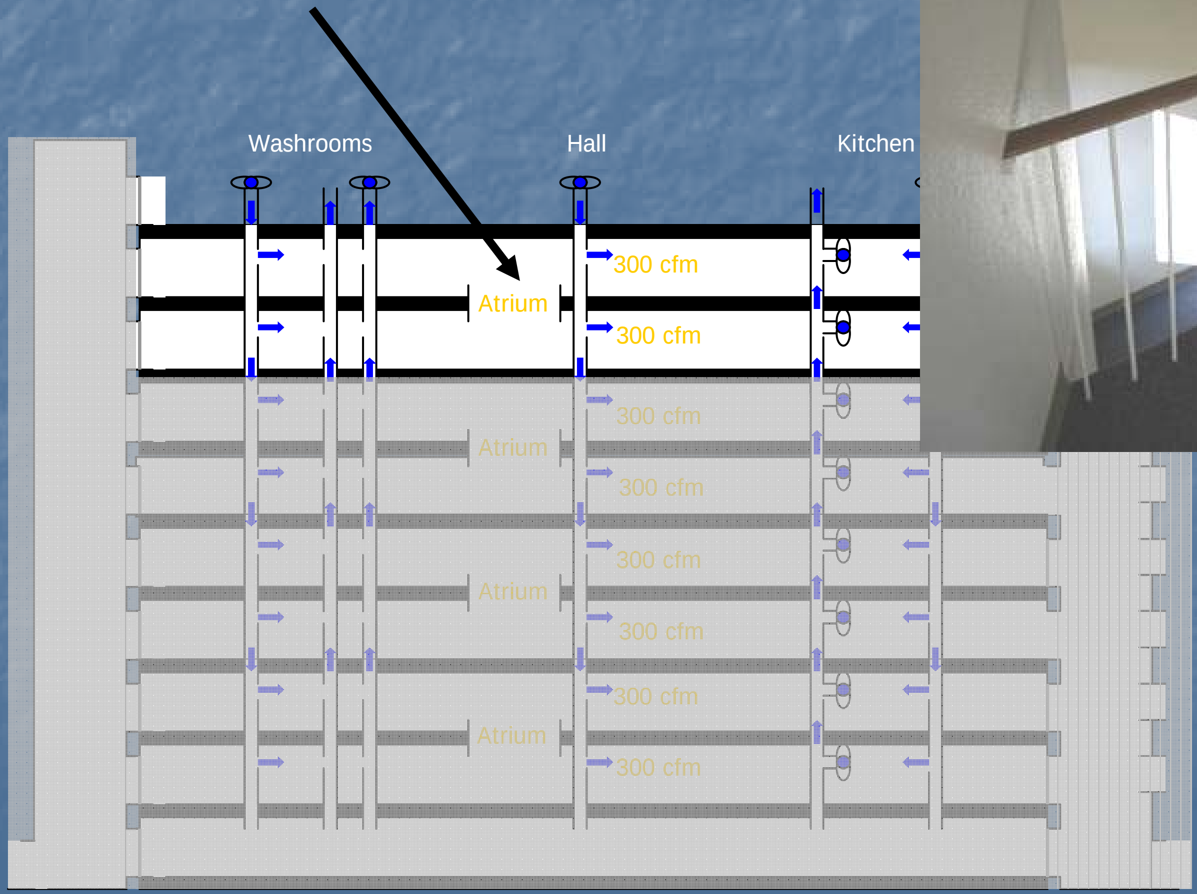
9 Storey University Residence

Building Features

Stairwell #1



Building Features



Building Features

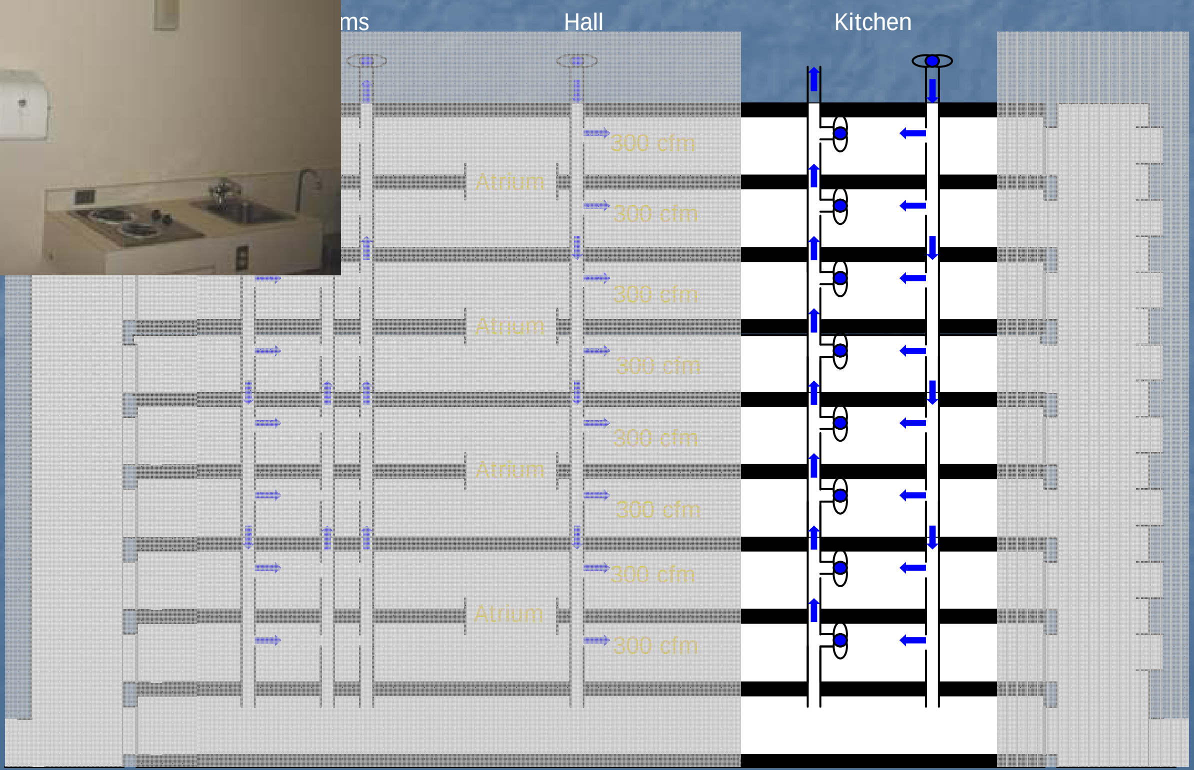
Washrooms

Building Features

0.141 m^3/s Supply in Hall

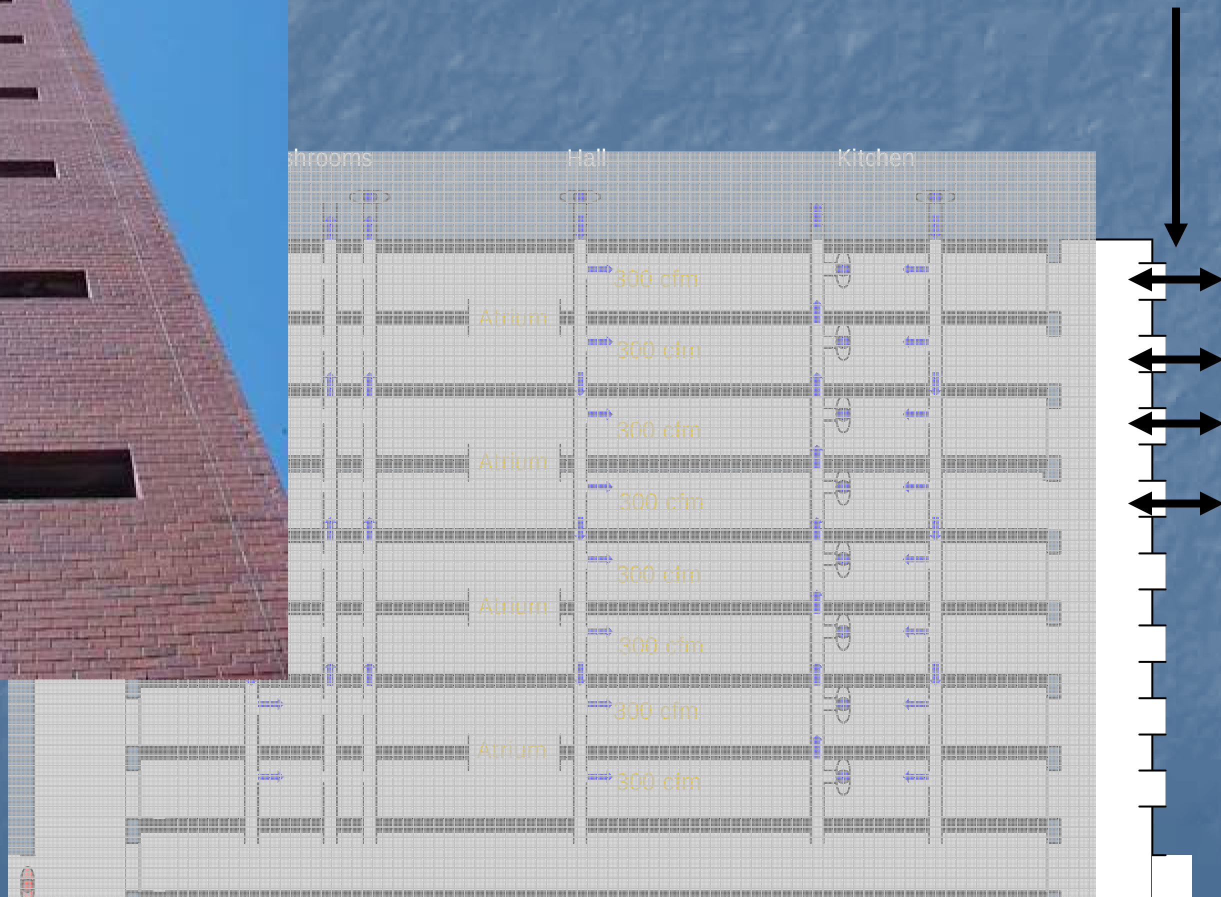
Building Features

Kitchen



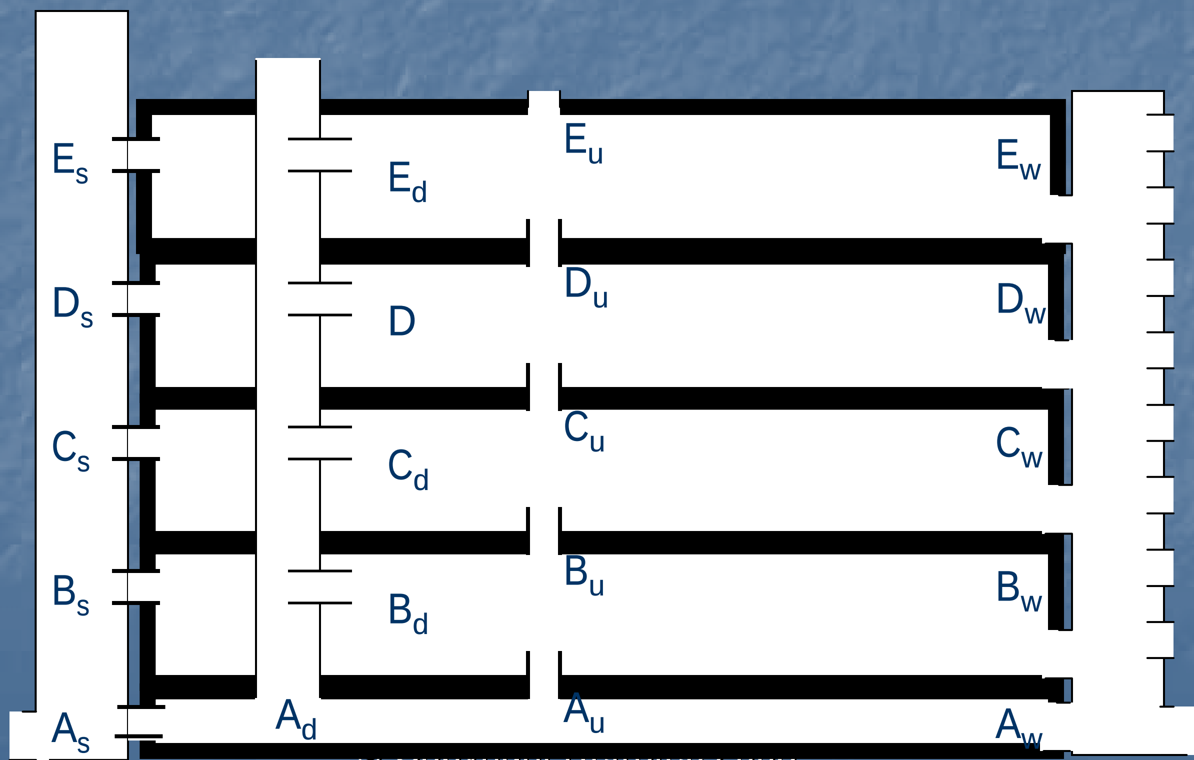
Building Features

Stairwell #2



Building Features

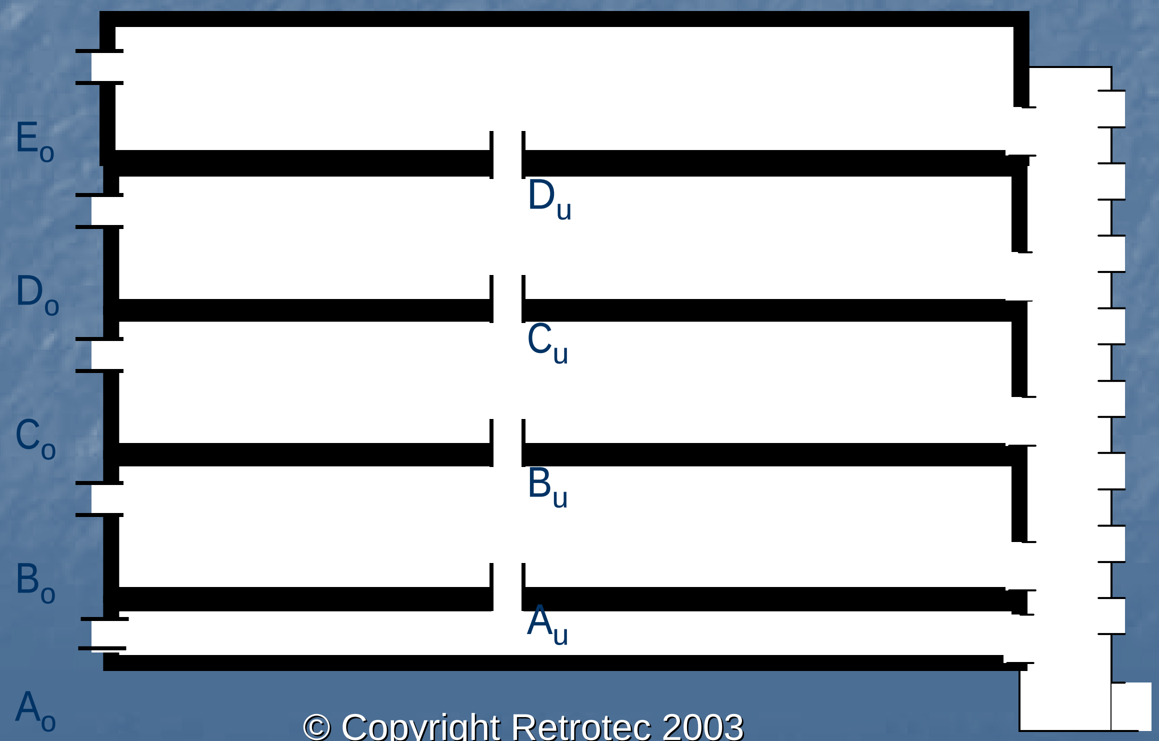
This Reduces to...



Building Features

...And Simplifies Even More To...

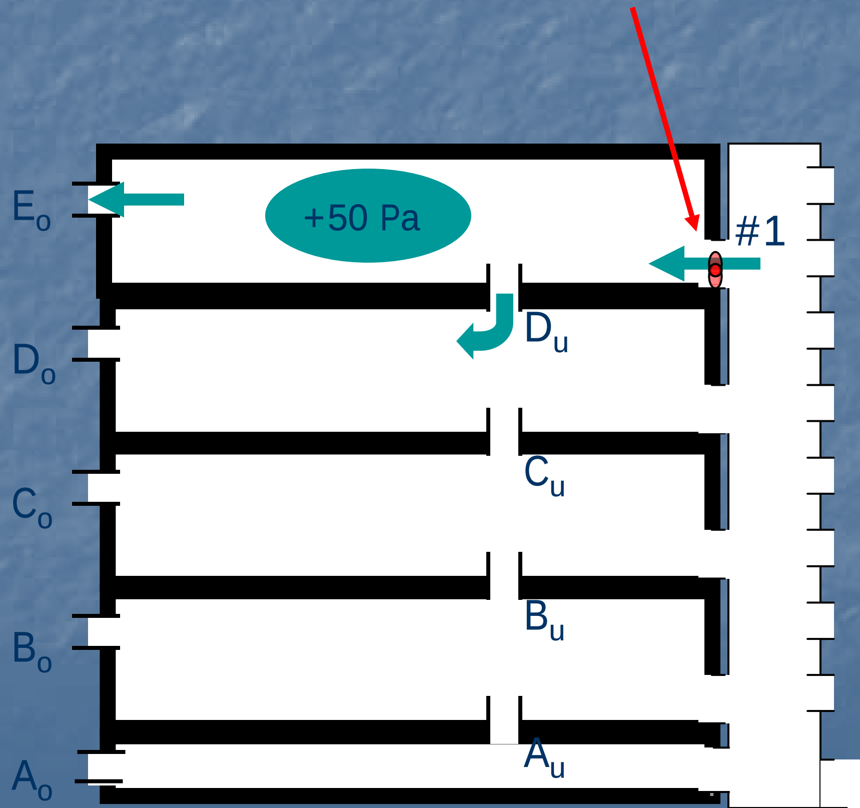
Where $E_o = E_s + E_d + E_w$



Step 1a

Measure Individual Floor Leakage

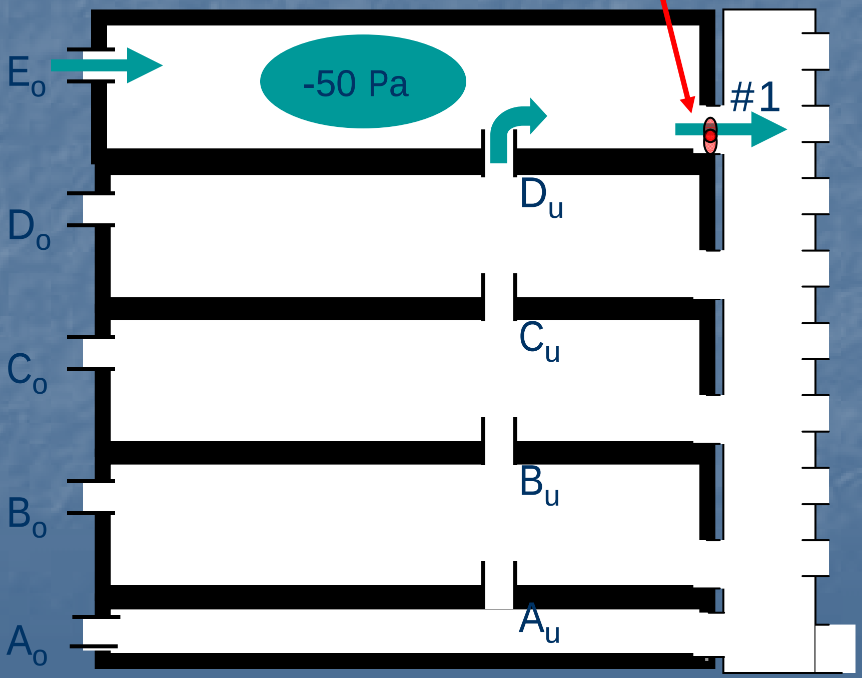
- Door-Fan Blower #1 pressurizes top floor



Pressurize E_o + D_u=	.66

Measure Individual Floor Leakage

- Door-Fan Blower #1 depressurizes top floor



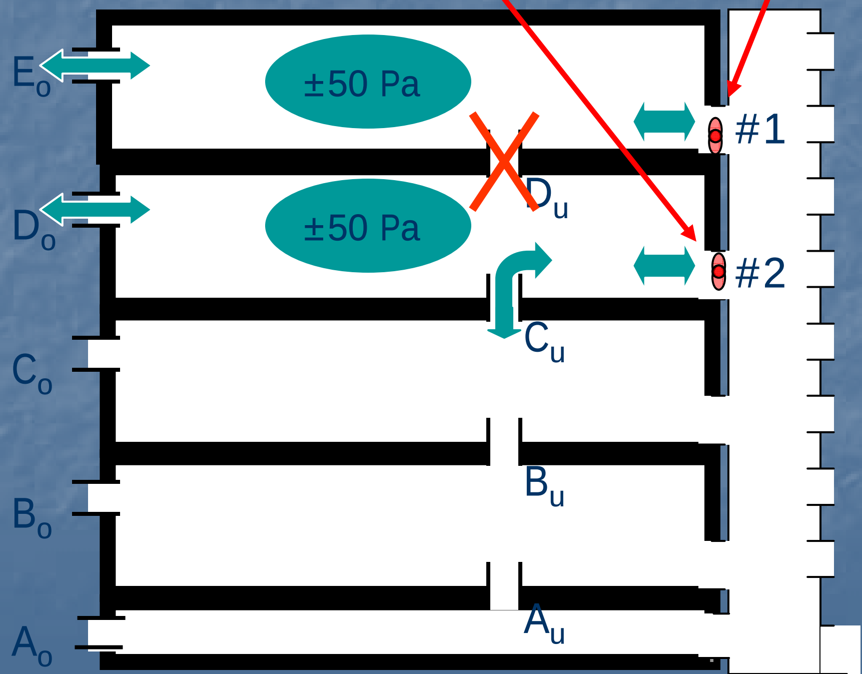
Pressurize E_o + D_u=	.66
Depressurize E_o + D_u=	.44
Average (Eo + Du) / 2 =	**.55**

Step 2

Neutralize D_u Slab

- Blower #2 added to neutralize flow through Du
- Blower #1 only measures E_o

E_o= 0.42

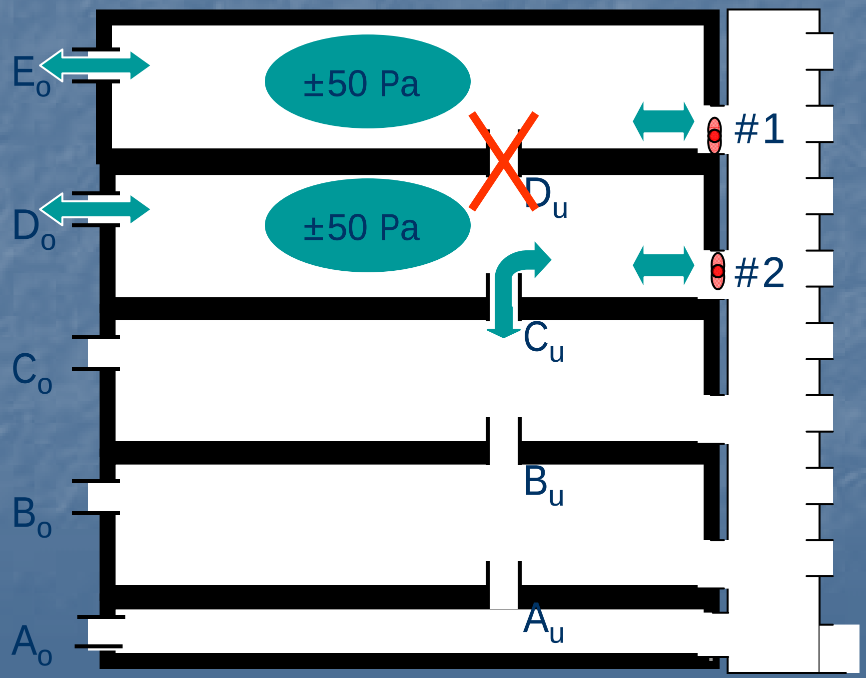


from step 1b: $E_o + D_u$=	.55
From Blower #1, E_o=	.42
∴ **BY SUBTRACTION** D_u=	.13

D_u= 0.13

Neutralize D_u Slab

- Blower #2 also measures $D_o + C_u$
- (D_u is neutralized)

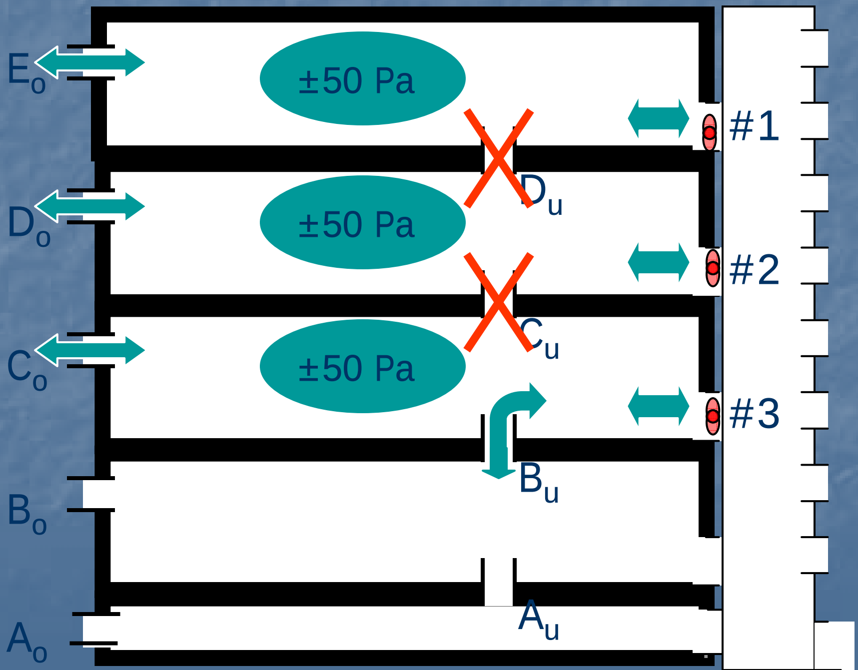


E_o = .42	D_u = .13

From Blower #2: $D_o + C_u$=	.53

Neutralize C_u Slab

- Blower #3 added
- Blower #2 now only measures D_o



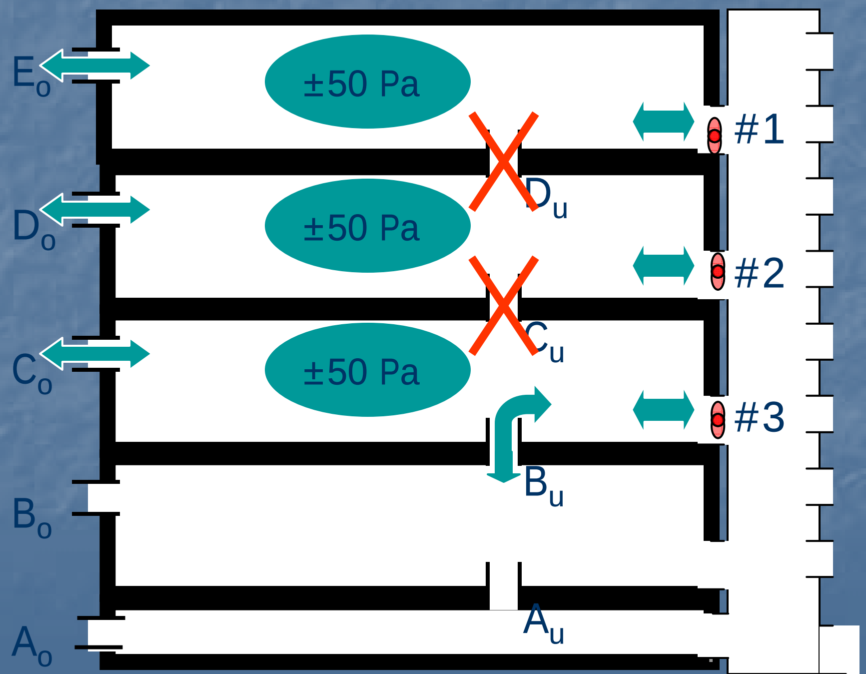
E_o = .42	D_u = .13

$D_o + C_u =$	.53
$D_o =$	.37
$\therefore\ C_u =$	.16

Step 3

Neutralize C_u Slab

- Blower #3 measures $C_o + B_u$

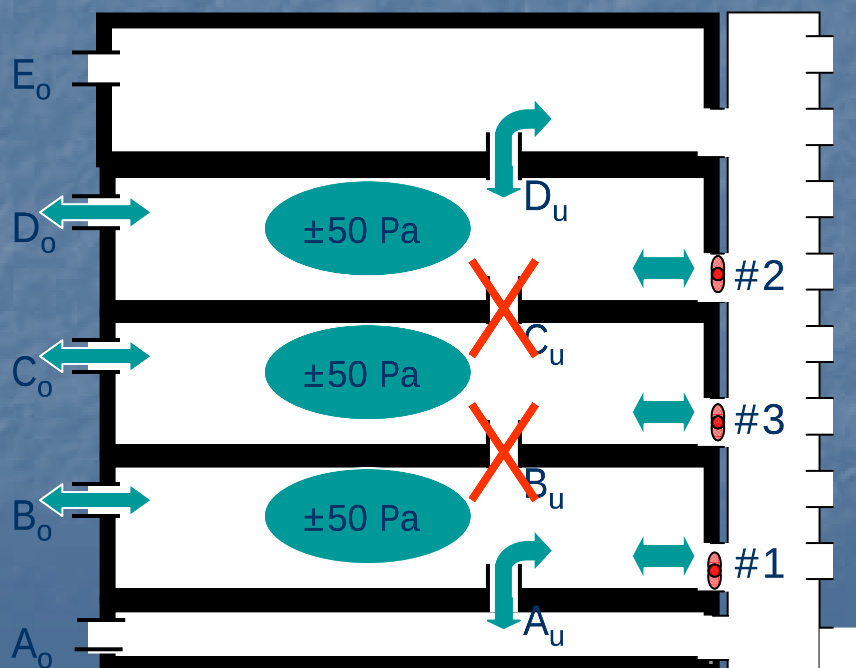


E_o = .42	D_u = .13
D_o = .37	C_u = .16
$C_o + B_u$=	.42

Step 4

Neutralize B_u Slab

- Blower #1 moved to B floor
- Blower #3 now only measures C_o



E_o = .42 D_u = .13

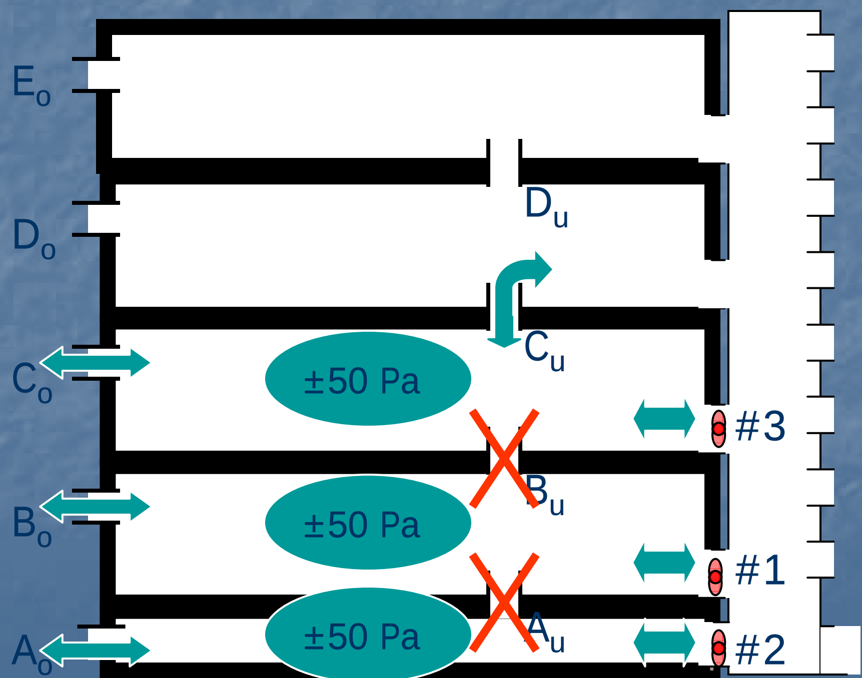
D_o = .37 C_u = .16

$C_o + B_u =$	.42
$C_o =$	.31
$\therefore B_u =$	.11

Step 5

Neutralize A_u Slab

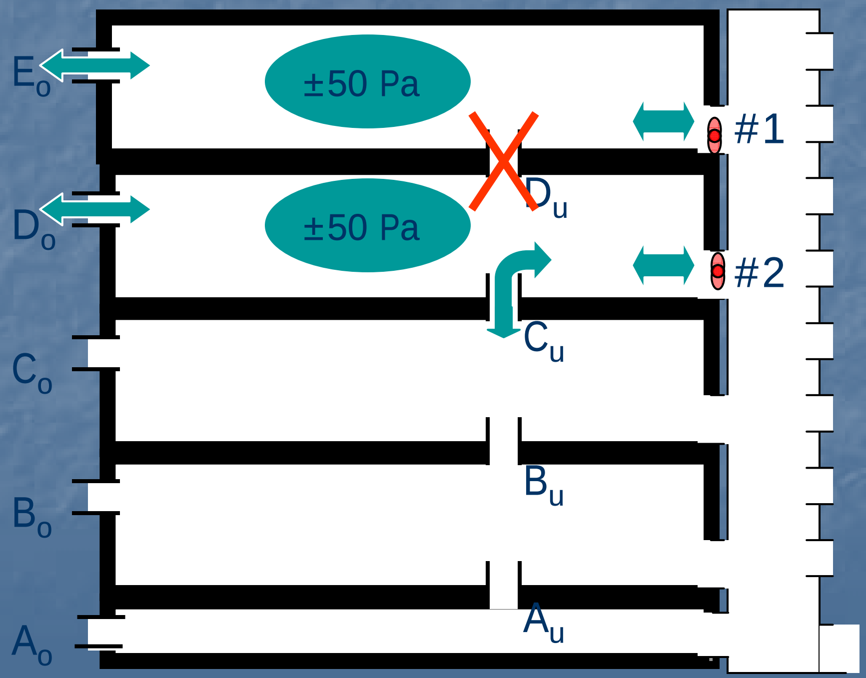
- Blower #2 moved to lobby



E_o = .42	D_u = .13
D_o = .37	C_u = .16
C_o = .31	B_u = .11
B_o = .30	A_u = .10
A_o = 1.1	

Another example:

Similar Outdoor leakage but very tight slab



E_o = .47 D_u = .015

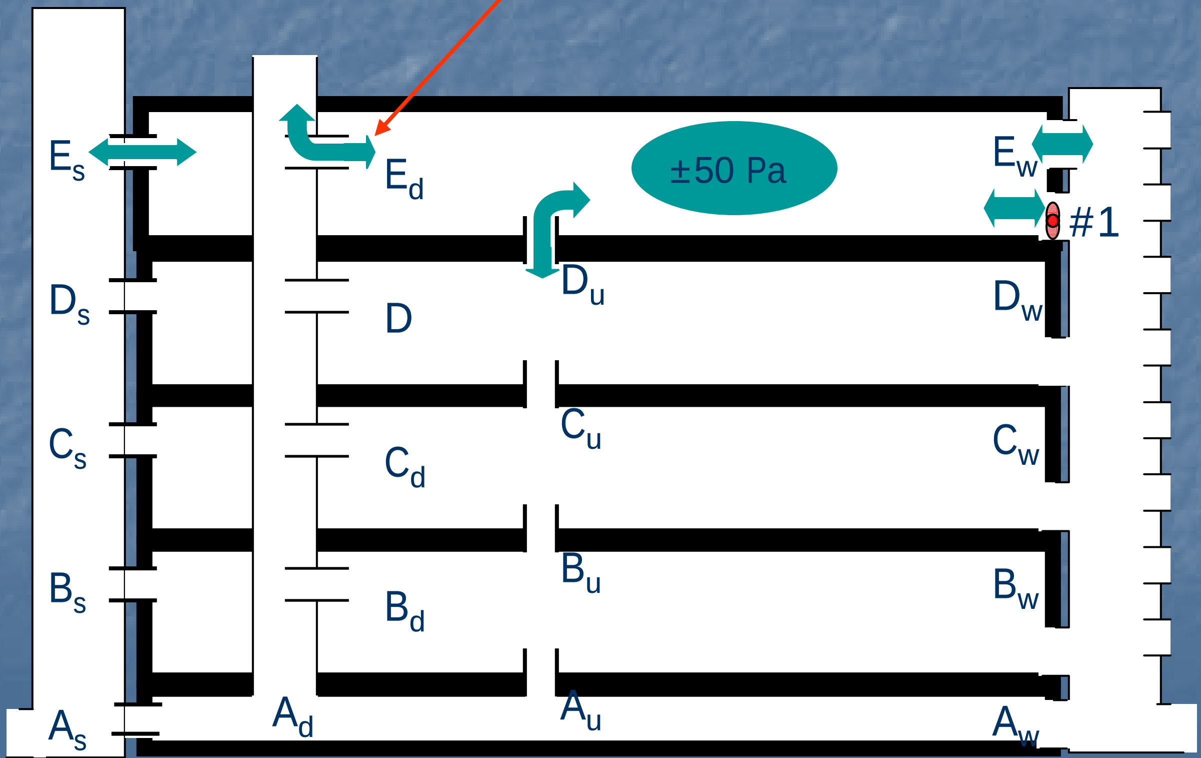
The previous example's results were

E_o = .42 D_u = .13

Leakage to outdoors surprisingly similar but leakage to floor below very different.

Measure Ductwork Leakage

- Duct Flow (E_d) included in E_o : $E_o[.42] = E_s + E_d + E_w$



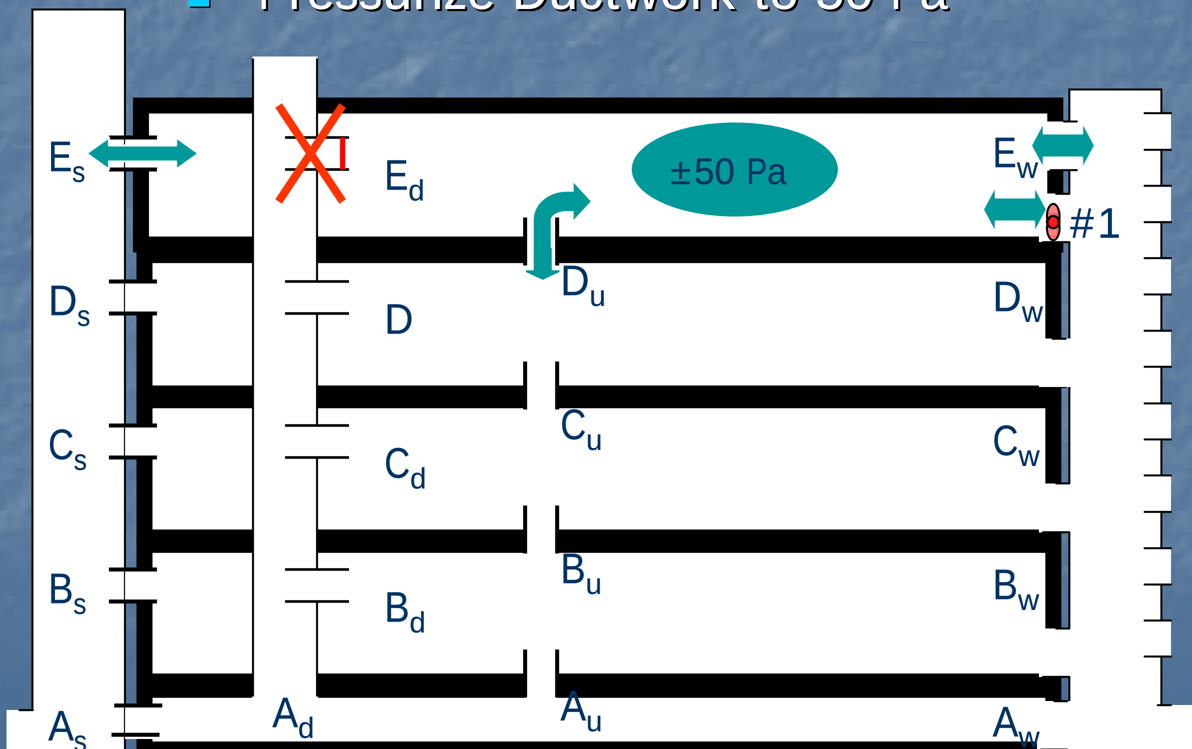
E_o = .42	D_u = .13
D_o = .37	C_u = .16
C_o = .31	B_u = .11
B_o = .30	A_u = .10
A_o = 1.1	

Step 6

Measure Ductwork Leakage

Measure Ductwork Leakage

- Use Temporary Sealing to Neutralize Duct Flow, or
- Pressurize Ductwork to 50 Pa



$$E_o = E_d + E_s + E_w = .42$$

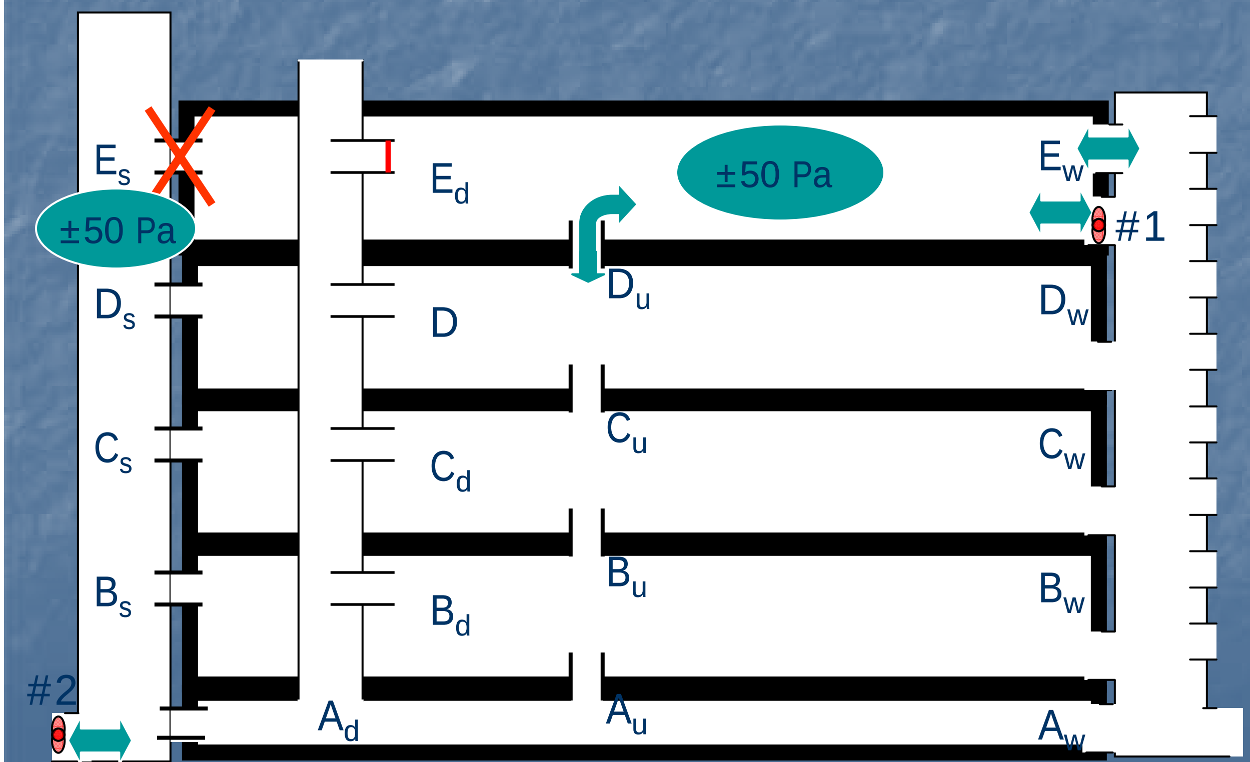
$$E_s + E_w = .34$$

$$E_d = .08$$

$E_o = .42$	$D_u = .13$
$D_o = .37$	$C_u = .16$
$C_o = .31$	$B_u = .11$
$B_o = .30$	$A_u = .10$
$A_o = 1.1$	

Measure Stairwell Leakage

- Use Second Blower to Neutralize E_s



$E_o = E_d + E_s + E_w = .42$

$E_w = .31$

$E_S = .03$

$E_d = .08$

$E_o = .42$	$D_u = .13$
$D_o = .37$	$C_u = .16$
$C_o = .31$	$B_u = .11$
$B_o = .30$	$A_u = .10$
$A_o = 1.1$	

Measure whole building

- Now look at comparative results of other buildings.

Type	Description	*Ht.*	*Envelope area*	*Vol.*	*Leakage Area*	*SLA*	*Driving Force*	*Min Egress Time*
		(m)	(m^2)	(m^3)	(cm^2)	(cm^2/m^2)	(Pa)	(Min)
Hydro Dam	Stairwell	60	1015	800	1738	1.71	75	0.23
Hydro Dam	Stairwell	80	915	800	2361	2.58	100	0.14
Hydro Dam	Stairwell	80	1412	800	5270	3.73	100	0.06
Apartment	Stairwell	27	360	270	140	0.39	.50	1.16
Hydro Dam	Elevator shaft	60	1003	800	12110	12.07	75	0.03
Hydro Dam	Elevator shaft	80	1210	1000	5483	4.53	100	0.08
Office Tower 2nd floor	Elevator lobby	4	480	576	4305	8.97	10	0.18
Office Tower 2nd floor	Elevator doors	30	4	180	145	36.25	25	1.05
Computer floor	Lower slab and walls	5	7000	11000	4164	0.59	15	2.89
Computer floor	one partition wall	5	300	11000	300	0.59	15	40.1
Apartment	8+9th floor, lower slab	6	1656	3024	1300	0.79	4	4.9
Apartment	6+7th floor, lower slab	6	1656	3024	1600	0.97	4	4.0
Office Tower 2nd floor	Slab between 1st & 2nd floor	4	1800	7200	152	0.08	2.5	126.9
Apartment	4+5th floor, lower slab	6	1656	3024	1100	0.66	4	5.8
Office Tower 2nd floor	Slab between 1st & 2nd floor	4	1800	7200	81	0.05	2.5	238.2
Apartment	2+3rd floor, lower slab	6	1656	3024	1000	0.60	4	6.4
UBC 905 standard	Floors and roofs	4	2500	4000	12500	5.00	2.5	0.90

Examples of Tightness Standards

Type	Description	*Ht.*	*Envelope area*	*Vol.*	*Leakage Area*	*SLA*	*Driving Force*	*Min Egress Time*
		(m)	(m^2)	(m^3)	(cm^2)	(cm^2/m^2)	(Pa)	(Min)
UBC 905 standard	Walls	4	2500	4000	25000	10.00	2.5	2.50
UBC 905 standard	Exit enclosures	4	2500	4000	8750	3.50	10	0.61
UBC 905 standard	Other shafts	4	2500	4000	37500	15.00	10	0.14
UBC 905 standard	Floors and roofs	4	2500	4000	12500	5.00	2.5	0.90
Energy Efficient House	R-2000 maximum	3	725	900	225	0.31	10	5.10
NFPA2001	FM200 protected zone	4	2500	4000	10000	4.00	10	0.54

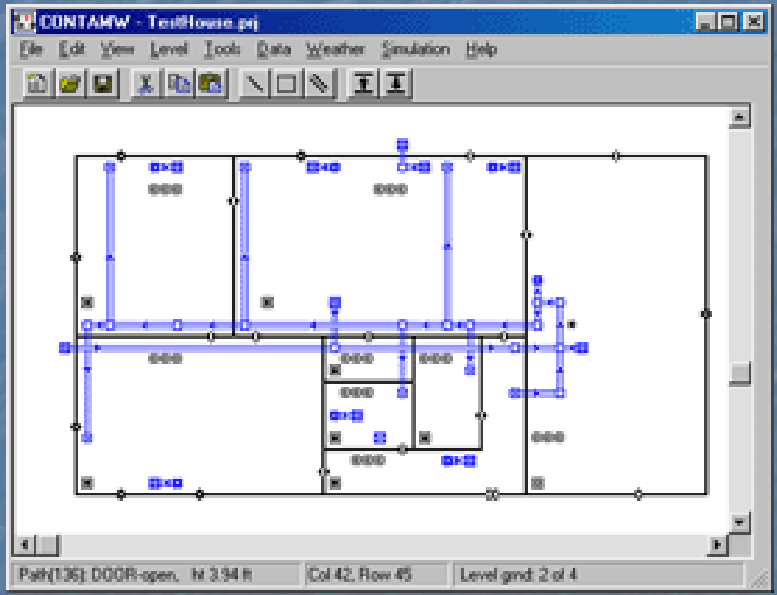
- Existing standards allow far too much leakage.

Conclusions

10 to 100 times more
Smoke movement !

Conclusions

Smoke simulation programs work better with real data?



CONTAMW recommends door-fan testing

Conclusions

Hole are Easily Measured @
1-hour per floor

Inspections = surprises

Conclusions

Correct design +
Proper materials =
Smoke tight buildings

END
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