

INSTITUTION OF MECHANICAL ENGINEERS HONG KONG BRANCH
TECHNICAL VISIT TO GUANGZHOU CTF FINANCE CENTRE ON 28/1/2019



Modern high-rise buildings are equipped with trendy and fashionable entrances and high-speed lifts. However, every entrance and lift door has been carefully designed and configured in order to cope with the stack effect, or otherwise it may be too heavy to open and its purpose may be defeated. Though people may have taken for granted, the basic building features of entrances and lift doors in tall buildings are mechanical engineering principles, which Institution of Mechanical Engineers Hong Kong Branch (IMEchE-HKB) was privileged to appreciate in its technical visit to the 530 m tall from ground level Guangzhou CTF Finance Centre at the heart of the provincial capital of Guangdong Province in the mainland China, Guangzhou (CTF Tower), on 28/1/2019.

Nature of Stack Effect

Buildings in all heights, as long as there is indoor-outdoor temperature difference, are subject to stack effect. In winter, an upward buoyancy force is originated by the the outdoor cold air infiltrates into the building on the ground floor and, absorbing heat inside the building and becoming warm air, rises through the lift shaft and exfiltrates out of the building at the higher floors. In summer, in contract, a downward buoyancy force is generated in the reverse order of winter. Stack effect is not caused by the simple “hot air rises” principle, while its strength is proportional to the building height. The solutions for the summer stack effect are different to the winter stack effect, and the former effect is usually weaker than the latter one. Stack effect in northern China is stronger than southern China.

The 44 storey, 166 m tall 1999 N Broadway in Denver, Colorado, the U.S. is a reference building of stack effect. In winter, the indoor and outdoor temperature is 21

°C and -12 °C has generated a 250 Pa of stack effect driving force on the building. In Hong Kong, according to ASHRAE Handbook – Fundamentals, the lowest and highest outdoor temperature in a year is 9 °C in February and 33.2 °C in July respectively, which translate into the pressure equivalent to the Denver building of 85 Pa for winter and 60 Pa for summer. Likewise in Guangzhou, January at 5.7 °C is the coldest month of a year and July at 34.8 °C the hottest, corresponding to 110 Pa and 68 Pa of the Denver building in winter and summer respectively.

Problematic Stack Effect

Translating the above into CTF Tower, which is championed the fifth tallest building in the globe, the total pressure is approximately 350 Pa each at the top and bottom floor, or the total stack effect driving force is 700 Pa, which can compromise the CTF Tower comfort in various ways:-

- Whistling air flow through doors and cracks, which starts occurring at 100 litre per second;
- Difficulty in opening and closing of swing doors and lift doors at 130 Pa and 100 Pa respectively;
- Difficulty in temperature control of the floors with excessive infiltration;
- Increase in building energy costs due to uncontrolled air flow from outdoor;
- Ingress of odours from outdoor;
- Migration of indoor odours.

In most times, buildings are positively pressurised by the heating, ventilation and air-conditioning systems (HVAC), which means that there is a net air flow from outdoor to indoor (i.e. the quantity of fresh air entry is higher than indoor warmed air exhaust). In winter, the positive pressurisation offsets the negative stack effect pressure at the ground floor. On the other hand, the offset pressure at the ground floor is added to the higher floors, exacerbating the positive driving force of the stack effect there. The phenomenon in summer is the opposite of winter. Indoor pressurisation is a solution for one floor and simultaneously an exacerbation for another.

On the exacerbated floors, the pressure exerted on the swing doors and lift doors very often exceeds their respective threshold, causing them unable to open and operate. Also, HVAC finds itself difficult to maintain a uniform predefined ambient for the building. The temperature of certain floors may be too high, and others may be too low.

Live with Stack Effect

Stack effect compromises buildings indoor comfort. While it may be eliminated, it can be mitigated to reduce the frequency and severity of its undesirable effects and issues within the building, actively or passively. HVAC pressurisation with seasonal control is an effective active mitigation, while passive mitigation may be achieved by:-

- Adding vestibules doors or walls;
- Using revolving doors;
- Tightening the building envelopes, specific doors or vents.

Simple details on doors and accesses could have significant impact on the stack effect mitigation effectiveness. For instance, unshielded drip tray under revolving doors, unsealed gaps between doors and walls and floor as well as loosely installed building façades could induce free air flow into and out of a building, nullifying the mitigation efforts.

For a 530 m tall building in Guangzhou, without mitigation, 350 Pa of pressure at the ground is borne by the ground floor doors at 311 Pa and lift doors at 37 Pa respectively, exceeding their respective operable threshold of 130 Pa and 25 Pa respectively. Improving the façade would result in less air leakage across the floors, dropping the lift door pressure to 20 Pa. Simultaneously, though the lift doors are operable, the pressure acting on the ground floor doors is raised to 330 Pa, which even adding vestibules helps little with the pressure on each vestibule door of 165 Pa still exceeds the 130 Pa threshold.

If only the building ground floor is positively pressurised, the ground floor pressure would fall to about 139 Pa and each of the vestibule door, which is subject to 70 Pa, is operable. This, on the other hand, in turn would raise the lift door pressure to about 201 Pa. Instead, positively and moderately pressuring all floors in the building would suppress the lift door pressure to 15 Pa, whilst the pressure on the ground floor of 70 Pa would be maintained, achieving an optimised arrangement.

Designed to Stack Effect

CTF Tower accommodates offices, serviced apartments and a hotel on its lower, middle and top floors respectively. Its complex lift arrangement with multiple express shuttles and floor access lifts facilitates people movement the most effectively. Apart from the service lifts which stop at all floors, the office, serviced apartment and hotel floors are served by both lift types. In addition, it has operable windows and upper level terraces, and it is subject to summer and winter stack effect mode. As said, 350 Pa stack effect driving force is recorded on CTF Tower.

A 14 day site measurements in March 2017 reveal that between 0 m (L0) and 440 m (L95) from ground level:-

- Overall, L0 is hotter than L95 by 2 °C to 3 °C, except the morning hours until noon when L0 is cooler than L95 by less than 1.5 °C.
- In the coldest day when the outdoor temperature varies from 15 °C to 12 °C between L0 and L95 respectively, the temperature of various lift shafts is higher outdoor by 6 °C to 10 °C and the L0 temperature is higher than the L95 temperature by from 4 °C to 5 °C.
- In the hottest day when the outdoor temperature is about 24 °C across the height, the temperature of various lift shafts deviates from the outdoor temperature from 0 °C to 1 °C, and the temperature difference between L0 and L95 varies from 0 °C to 3 °C.
- In the coldest day, the measured pressure difference between L0 and L95 is about 150 Pa.
- In the hottest day, the measured pressure difference between L0 and L95 is about 60 Pa.

Based upon the above, whereby the temperature difference in winter is larger than summer, the winter stack effect is stronger than the summer stack effect for CTF Tower.

Building Services

The impressive height of 530 m of CTF Tower, which 40th floor is the refuge floor, has given building façade a challenge. The material must be very low in thermal expansion coefficient, or it may extend beyond its scope of coverage and turn a poor appearance for the building. CTF Tower uses Japan-made ceramic tiles, which extra low thermal expansion coefficient maintains the façade in shape in all ambient weather conditions.

CTF Tower is the first development in Guangzhou which uses district cooling. 70 % of the cooling demand for the office and retail floors, which latter may accommodate a daily 200,000 times of visit, is met by district cooling. They are backed-up by high pressure air-cooled chillers with their cooling towers located at the ground floor to provide a reserve of 50 % of the cooling demand.

The cooling demand of the floors for hotel and serviced apartment is met by four (4) 500 ton class / 1,758 kW Shanghai-made York chillers at “n+1” capacity located inside the plant room. The low temperature-containing installations are insulated by clad calcium silicate, in spite of elastomeric nitrile rubber material is principally used in China. Heat pump is utilised to supply hot water for these floors.

Bullet Lift

CTF Tower not only is the fifth tallest building in the world, its Hitachi-made specially designed lifts, which commute between the said lift shafts, can reach the world record of upward speed of 20 m/s, or 72 km/h.

The achievement of the world speed record is the simultaneous delivery of safety, comfort and operability in terms of traction and control.

Traction and Control

The advanced drive motor features extra high output of 330 kW, which is attained by large diameter, thin wall stator iron coil inside the drive motor. The very high power density permits the traction system to be confined to within 2,200 mm in the overall length and 1,800 kg of mass. The braking pads are made of high thermal resisting material, dissipating braking energy to over 300 °C, four (4) times more than the preceding highest performing braking pads in Hitachi product range. Also, with the longer travel distance and the minimised traction system size, the suspension ropes must reduce their self weight. Leveraging the refined grain size, the high performance suspension ropes enjoy strength-density ratio 30 % higher than the preceding Hitachi models.

Starting a 300 kW double winding drive motor demands 2,200 kVA peak power and 3 kA current; however a current transformer-converter-inverter (CNV/INV) can output

maximum 1,100 kVA. Utilising the proven technologies, two (2) CNV/INVs of existing type are configured in parallel with current differential control to attain the required peak power, while the current demand is satisfied by the dedicated 16 kVA transformers.

Safety

To limit the different ascending and descending speed at 20 m/s and 10 m/s respectively, the over-speed governor of less than 600 mm in breadth comprises of one-way ascendant and descendant governors. When the car descends, the one-way descendant governor clutches with and governs diversion sheaves in clockwise rotation, whereas the one-way ascendant governor disengages with the diversion sheaves. In reverse, however, when the car ascends, the one-way ascending governor clutches with and governs the diversion sheaves in anticlockwise rotation, while the one-way descendant governor disengages. The differential over-speed control is therefore achieved.

The progressive type safety gear requires bringing the descending car in 23 tons of mass at 26.2 m/s to still. The Hitachi proprietary ceramic-made gripping and counter wedges are able to dissipate 21 MJ of the descending energy at the highest temperature of 800 °C, 4.8 times of the preceding largest Hitachi model, two (2) consecutive times.

Comfort

The car ascending at 20 m/s inside the lift shaft inevitably generates high level noise and atmospheric pressure change, compromising ride comfort. Together with the cabin pressure regulator, the aerodynamic shrouds with the optimised geometries at the top and bottom of the car successfully suppress the car internal pressure variation by 50 % and noise by over 15 dB(a).

Also, to combat the undesired car motions of surge, sway, pitch and yaw when the car ascends at 20 m/s, Hitachi equips the cars with two (2) active vibration suppressors at the car top and two (2) at the bottom, effectively suppressing the unwanted motions by 60 %.

The traction systems and the control panels were individually shop tested, while the safety gear and the car and its accessories and installations were function tested at the top testing speed of 800 m/min, or 13.3 m/s, in the Hitachi in-house 184 m tall testing tower in Japan. The full system was tested in CTF satisfactorily, and raising the ascending speed to 21 m/s has been under active exploration.

Noise Control

Tall buildings of 60 m height or above are susceptible to the stack effect, whereby cold air from outside the building may pass through the landing doors and enter the lift shaft, and escape through openings in the motor room on the building top. Such air movement generates noise at the landing door gaps and turbulent inside the lift shaft. The effective solution is to reduce the air flow, by means of improving the air seal of

the landing doors and the use of the stack effect control measures mentioned above, plus the motor room should be air-conditioned rather than air extraction enabled.

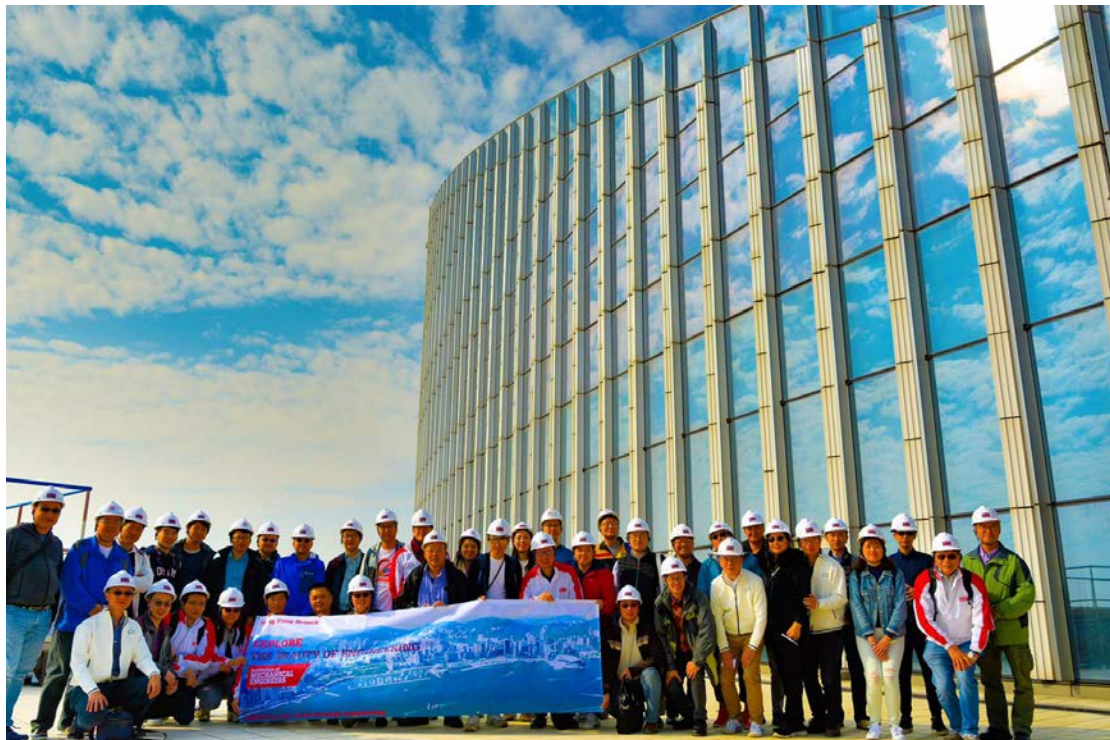
Furthermore, the air below the car is compressed by the descending motion of the car the car and the air compression generates noise. An effective method to mitigate the noise is to maintain a minimum clearance with the lift shaft in the following tabled order so that the air may divert from the car bottom, plus the lift shaft should have as little profile change as possible:-

Car Speed [m/min]	below 150	180	210	240	300/360	420/480
Dmin [mm]	standard	450	450	500	630	675
Wmin [mm]	standard	350	400	400	450	500

Besides, ventilation openings along the lift shaft help reducing the compression of air in the lift shaft, thus alleviating the noise during the car motion.

Remarks

As Hitachi has researched, the trend of building skyscrapers of 500 m to 600 m in height in predominately Asia and Middle East is extending, and China is championing the number of such new developments. Stack effect is worth the mechanical engineers to take into careful consideration in designing HVAC for them, while super or ultra high speed lifts are breaking the records and technical limits. CTF Tower has exhibited to the IMechE-HKB members in the visit the future of commercial towers in China and the Asia region, by which they have been much impressed.



IMechE-HKB thanks Dr. Duncan Philips, Mr. Greg Thompson and Xiang-Dong Du of Rowan Williams Davies & Irwin Inc., Mr. Yosuke Mawamura of Hitachi Elevator

(China) Co., Ltd. and Mr. Daniel Wong of New World China Land Ltd. and his colleagues for their presentation and hospitality.

The technical visit to CTF Tower was reported in Institution News dated 25/2/2019 which can be found on the IMechE website <https://www.imeche.org/news/news-article/technical-visit-to-guangzhou-ctf-centre-a-small-change-makes-a-big-difference> (see the extraction appended).

*** END ***

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WHT

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INSTITUTION NEWS

Technical Visit to Guangzhou CTF Centre: a small change makes a big difference

25 Feb 2019

World Bulletin Team



</images/default-source/oscar/Institution-News/feb-2019/ctf-photo-1-800.jpg?sfvrsn=2>

Hong Kong Branch at the CTF Centre

Tiffany Hiu-ching Chan reports on the Hong Kong Branch visit to Guangzhou's Chow Tai Fook Centre and the world's fastest lift

Adjacent to Hong Kong where Hong Kong Branch is based, Guangdong Province of China is a vibrant and thriving economy which contributes the largest share of gross domestic product of the People's Republic.

Its sheer economic development has compelled its provincial capital, Guangzhou, to pursue even greater building heights for satisfying the ever growing appetite for commercial spaces. Standing by the stream of the central Guangzhou Pearl River, and opposite the famous Canton Tower, the Guangzhou Chow Tai Fook Finance Centre (CTF Finance Centre) offers Guangzhou the much needed floors for premium offices, shopping arcade and hotel with its 530 m of height from the ground level, linked by the world's fastest lift supplied by Hitachi of Japan.

The impressive CTF Centre not only is the fifth tallest building in the world, but also well-known of the marvellous engineering design for minimising stack effect and operating the bullet-speed Hitachi lift at



20 m/s.

View across Guangzhou and the canton Tower from the CTF Finance Centre

Stack effect, which exists in all buildings, impedes elevator door operability and causes whistling. CTF Centre has optimised door arrangements and heating, ventilating and air-conditioning operating regime to alleviate the frequency and severity of the undesirable stack effect impacts. The Hitachi lift, endowed with state-of-the-art safety, energy and space efficient and passenger comfort features, enables high-speed traveling in skyscrapers, setting a new standard of lift travel.



Exploring the engineering

Mr. Aaron Wong, China Sub-Committee Chairman of Hong Kong Branch who championed the eye-opening cross-boundary visit, remarked,

“Our visit to CTF Centre is the fruit of the kindness and convenience rendered by the host, who is our fellow IMechE member. He once joined one of our technical visits and was impressed by the inspirations of such activities brought to the participants. Leveraging his position in the CTF Centre project, he proactively offered a technical visit to us. We are grateful to him for his hospitality, and this is how all fellow IMechE members can help each other even with small help of ‘open house’. A tip of favour could benefit many.”

We would like to express our sincere gratitude to New World China for inviting RWDI and Hitachi to conduct the inspiring seminars and arranging the memorable site visit and tour.

Read more related articles

[Construction and Building Services \(/news?topic=construction-and-building-services\)](/news?topic=construction-and-building-services)

Technical Visit and Seminar The Institution of Mechanical Engineers

Guangzhou CTF Finance Centre
(K11 Art Mall & Office and Rosewood Hotel)

27 January 2019



HITACHI
Inspire the Next

Background: About RWDI

**We are
specialty
consultants**

Large Range of Projects

- All continents,
- All climates,
- All building types

~500+ employees,
Established in 1972

Large sustainability practice

- 2% of the world's LEED buildings.

We do:

- Air, heat and energy building physics

buildings ↔ environment

- All climate related impacts:
 - Rain, snow, ice
 - Wind
 - Pollutants
 - Sun – Daylighting / Glare
 - Energy demand
 - Noise

Where We are and Where We've Worked



Facilities

Four wind tunnels

Water tunnel / flume

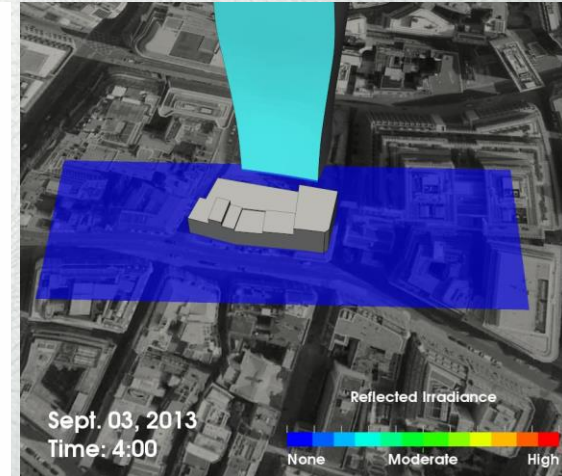
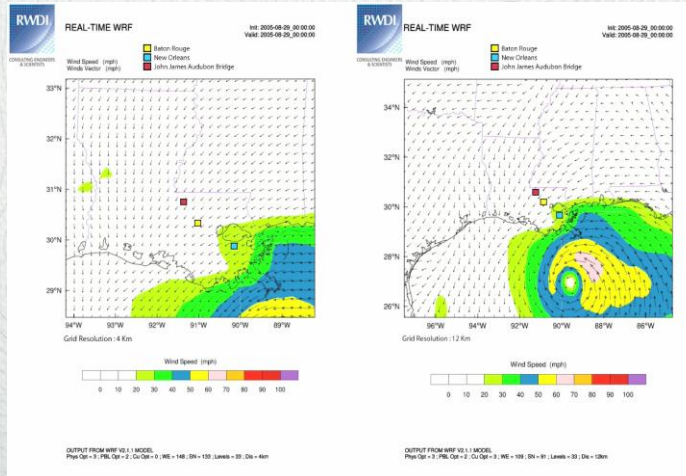
**High Performance
Computing**

Instrumentation

- AQ, noise, thermal comfort, winds, etc.

**Large climate
database**

Custom tools



Studies & Mitigation Assessments Conducted

The lists below are samples – there are others

Cold climates

Boston, USA
New York, USA
Quebec City, CA
Montreal, CA
Toronto, CA
Chicago, USA
Seattle, USA
Seoul, KO
Harbin, CN
Shanghai, CN
Beijing, CN
Guangzhou / Shenzhen, CN
Kuala Lumpur, MY
Dubai, UAE
Moscow, RU
London, UK

Hot climates

Boston, USA
New York, USA
Quebec City, CA
Montreal, CA
Toronto, CA
Chicago, USA
Seattle, USA
Seoul, KO
Harbin, CN
Shanghai, CN
Beijing, CN
Guangzhou / Shenzhen, CN
Kuala Lumpur, MY
Dubai, UAE
Moscow, RU
London, UK

Existing Buildings

Boston, USA
New York, USA
Montreal, CA
Toronto, CA
Chicago, USA
Edmonton, CA
Seattle, USA
Los Angeles, USA
Shanghai, CN
Guangzhou, CN
Astana, KZ
Dubai, UAE
London, UK



Redefining possible.

STACK EFFECT IN TALL BUILDINGS

Duncan Phillips, Ph.D., P.Eng, Principal

Greg Thompson, M.A.Sc., Principal

Xiangdong Du, Ph.D., P.Eng, Principal

Best Practice

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Acknowledgements/Credits

The work presented here represents the efforts and contributions of many bright and committed people at RWDI.

Outline

What is stack effect?

- The stack effect driving force
- Stack effect impacts & issues in buildings

The neutral plane

Effects of building pressurization

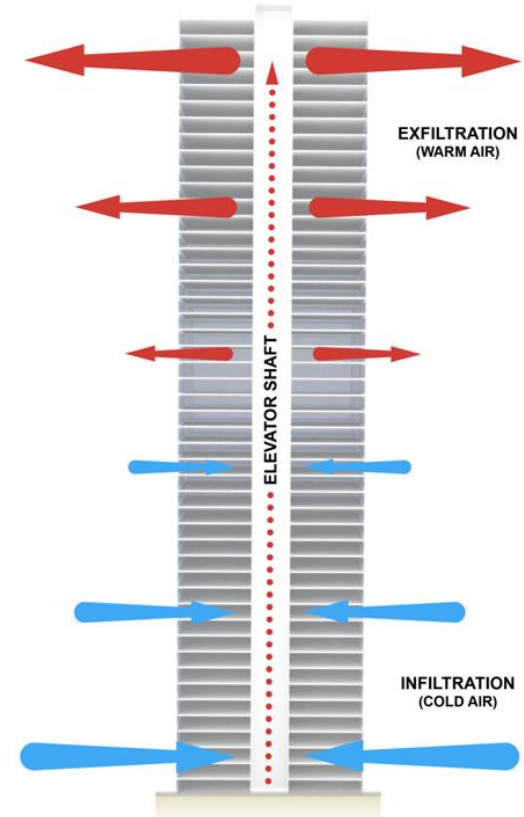
Managing stack effect in buildings

What is Stack Effect?

It does not happen because ~~“hot air rises”~~

Stack effect is a phenomenon that can exist in **all buildings** and is induced by the buoyancy force originating from indoor-outdoor temperature differences.

Winter Stack-Effect
Driven Airflow



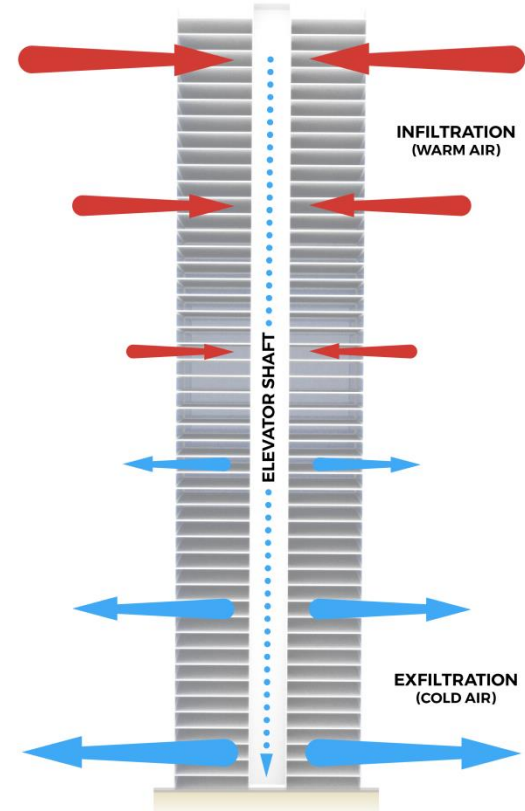
What is Stack Effect?

It does not happen because ~~“hot air rises”~~

Stack effect is a phenomenon that can exist in **all buildings** and is induced by the buoyancy force originating from indoor-outdoor temperature differences.

- The solutions for summer stack effect are different from winter stack effect.
- Typically the summer driving forces are weaker.

Summer Stack-Effect
Driven Airflow



What is Stack Effect?

1999 N Broadway

Denver, Colorado

- 44 stories
- Height: 166m / 548 ft
- Outdoor Temperature: -12°C / 10°F
- Indoor Temperature: 21°C / 70°F
- Moderately Tall
- Cold Winter Day (not extreme)
- Building has a ~ 250 Pa ($\sim 1''$) stack effect driving force.



Visualizing Stack Effect in a Tall Building

**Stack effect
can play a
strong role in
smoke
transport**

**Remember a
~250 Pa (~1")
stack effect
driving force.**

Approximately
125 Pa on this
door.



Hong Kong

Winter 99.6 = 9.0°C

Summer 0.4% = 33.2°C

Pressures for equivalent
Denver building

- Winter = 85 Pa
- Summer = 60 Pa

Design conditions for HONG KONG INTL ARPT, China

Station Information												
Station name	WMO#	Lat	Long	Elev	SDP	Hours ± UTC	Time zone code	Period				
HONG KONG INTL ARPT	450070	22.33N	114.18E	24	101.04	8.00	CHN	8200				
Annual Heating and Humidification Design Conditions												
Cooling month	Heating DB	Humidification DB/MCDB and WB				Coolest month WBMCDR				MCWB/POWB to 99.6% DB		
2	99.6%	99%	DP	WB	MCDB	DP	WB	MCDB	WB	MCDB	WB	POWB
2	9.0	10.8	-3.1	2.9	14.0	0.1	3.8	15.0	10.2	16.1	9.4	15.5
330												
Annual Cooling, Dehumidification, and Entropy Design Conditions												
Hottest month	Hottest DB range	Cooling DB/MCDB				Evaporation WB/MCDB				MCWB/POWB to 0.4% DB		
7	8	0.4%	DB	MCWB	DB	WB	MCDB	WB	MCDB	WB	MCDB	POWB
7	4.5	33.2	26.3	32.9	26.3	32.1	28.2	27.6	30.6	27.3	30.3	27.0
30.2												
Extreme Annual Design Conditions												
Extreme Annual WB				Extreme Annual DB				n-Year Return Period Values of Extreme DB				
Max	Mean	Standard deviation	n=5 years	n=10 years	n=20 years	n=50 years	n=100 years	n=200 years	n=500 years	n=1000 years	n=2000 years	n=5000 years
33.2	26.3	3.2	26.3	28.2	27.6	30.6	27.3	30.3	27.0	30.2	27.0	30.2
27.0	22.7	29.8	26.2	21.7	29.4	26.1	21.6	29.4	27.9	31.2	28.5	30.9
85.3												
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures												
%	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
0.4%	25.0	19.2	25.1	21.0	27.8	23.1	30.8	24.6	32.2	26.0	33.2	26.6
1%	24.1	18.6	24.2	19.8	27.0	22.6	29.9	24.7	32.0	26.0	33.0	26.5
2%	23.1	18.1	23.8	19.2	26.2	22.4	29.1	24.4	31.2	25.9	32.4	26.4
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures												
%	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
0.4%	20.5	23.1	22.2	23.8	24.1	26.1	26.0	28.6	27.1	29.9	28.0	30.5
1%	19.9	22.5	21.2	23.1	23.8	25.7	25.6	28.3	26.8	29.7	27.7	30.3
2%	19.4	22.0	20.6	22.5	23.6	25.5	25.3	28.0	26.6	29.5	27.5	30.2
Monthly Mean Daily Temperature Range												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
5.1	4.5	4.7	4.5	4.4	4.1	4.5	4.6	4.6	4.6	5.3	5.8	
WMO#	World Meteorological Organization number				Lat	Latitude, °				Long	Longitude, °	
Elev	Elevation, m				SDP	Standard pressure at station elevation, kPa				WB	Wet bulb temperature, °C	
DB	Dry bulb temperature, °C				DP	Dew point temperature, °C				WB	Wet bulb temperature, °C	
WS	Wind speed, m/s				Enthalpy	Enthalpy, kJ/kg				WB	Wet bulb temperature, °C	
MCDB	Mean coincident dry bulb temperature, °C				MCDB	Mean coincident dew point temperature, °C				MCWB	Mean coincident wet bulb temperature, °C	
MCWB	Mean coincident wet bulb temperature, °C				POWB	Prevailing wind direction, °; 0 = North, 90 = East				POWB	Prevailing wind direction, °; 0 = North, 90 = East	

Guangzhou

Winter 99.6 = 5.7°C

Summer 0.4% = 34.8°C

Pressures for equivalent
Denver building

- Winter = 110 Pa
- Summer = 68 Pa

Design conditions for GUANGZHOU/BAIYUN, China

Station Information															
Station name	WMO#	Lat	Long	Elev	SDP	Hours ± UTC	Time zone code	Period							
GUANGZHOU/BAIYUN	592870	23.13N	113.32E	8	101.23	8.00	CHN	8201							
Annual Heating and Humidification Design Conditions															
Cooling month	Heating DB	Humidification DB/MCDB and WB						Coolest month WB/MCDB				MCWB/POWB to 99.6% DB			
2	99.6%	99%	DP	WB	MCDB	DP	WB	MCDB	WB	MCDB	WB	MCDB	POWB	POWB	
1	5.7	6.9	-5.6	2.4	11.6	-3.0	2.9	11.8	7.7	12.1	6.7	11.8	3.0	0	
Annual Cooling, Dehumidification, and Entropy Design Conditions															
Hottest month	Hottest DB range	Cooling DB/MCDB						Evaporation WB/MCDB				MCWB/POWB to 0.4% DB			
7	8	0.4%	DB	MCWB	DB	WB	MCDB	DB	WB	MCDB	WB	MCDB	POWB	POWB	
7	6.7	34.8	26.5	34.0	26.4	33.1	28.2	27.7	31.5	27.4	31.1	27.1	30.7	2.5	0
Extreme Annual Design Conditions															
Extreme Annual WB				Extreme Annual DB				n-Year Return Period Values of Extreme DB							
DB	WB	DB	WB	DB	WB	DB	WB	n=10 years	n=20 years	n=50 years	n=100 years	n=100 years	n=100 years	n=100 years	
26.9	22.6	29.5	26.4	21.9	29.2	26.2	21.6	29.0	89.1	32.1	87.4	31.3	86.0	31.2	
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures															
%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	
0.4%	25.1	19.2	26.1	19.3	28.2	22.7	31.2	24.9	33.2	26.0	34.9	26.7			
1%	24.2	18.6	25.2	19.0	27.4	22.3	30.7	24.9	32.9	25.9	34.1	26.6			
2%	23.4	18.0	24.2	18.7	26.8	22.0	29.9	24.4	32.1	25.6	33.8	26.5			
%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	
0.4%	36.0	26.8	36.1	26.4	34.9	25.8	32.6	24.3	29.5	21.8	26.8	19.8			
1%	35.2	26.8	35.2	26.4	34.1	25.6	31.9	24.1	28.9	21.7	25.8	19.1			
2%	34.7	26.7	34.7	26.4	33.7	25.6	31.2	23.8	28.1	21.0	24.7	18.4			
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures															
%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	
0.4%	20.4	23.2	21.3	24.1	23.9	26.7	26.2	29.8	27.4	30.8	28.2	31.9			
1%	19.7	22.5	20.7	23.6	23.5	26.0	25.7	29.1	27.1	30.4	27.9	31.4			
2%	19.2	22.2	20.3	22.7	23.1	25.3	25.2	28.2	26.7	29.5	27.6	31.1			
%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	DB	WB	
0.4%	28.2	32.1	28.1	32.3	27.5	31.8	26.1	30.1	23.7	27.4	22.2	23.8			
1%	28.0	32.0	27.8	31.8	27.2	31.1	25.7	29.6	23.2	26.5	20.8	24.1			
2%	27.7	31.6	27.6	31.5	26.9	30.7	25.4	29.1	22.7	25.8	20.0	23.3			
Monthly Mean Daily Temperature Range															
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec				
7.2	6.1	5.8	5.7	6.2	6.1	6.7	6.8	6.9	7.5	8.1	8.4				
WMO#	World Meteorological Organization number				Lat	Latitude, °				Long	Longitude, °				
Elev	Elevation, m				SDP	Standard pressure at station elevation, kPa				WB	Wet bulb temperature, °C				
DB	Dry bulb temperature, °C				DP	Dew point temperature, °C				WB	Wet bulb temperature, °C				
WS	Wind speed, m/s				Enthalpy	Enthalpy, kJ/kg				WB	Humidity ratio, grams of moisture per kilogram of dry air				
MCDB	Mean coincident dry bulb temperature, °C				MCDB	Mean coincident dew point temperature, °C				MCWB	Mean coincident wet bulb temperature, °C				
MCWS	Mean coincident wind speed, m/s				POWD	Prevailing coincident wind direction, °, 0 = North, 90 = East									

Potential Stack Effect Impacts

There are many potential impacts

- Whistling airflow through doors and cracks
- Difficulty opening and closing of doors
- Difficulty controlling temperatures on some floors with excessive infiltration
 - Cold at the bottom
 - Hot (humid) at the top
- Elevator door operability issues & whistling
- Increased building energy costs due to uncontrolled airflow from outdoors
- Ingress of odors from outdoors &
- Migration of odours indoors
Often from unit to unit in residential

How Does Stack Effect Get Setup

Imagine two tubes: one filled with air and one filled with water.

The weight of the air in the column is less than the weight of the column of water.

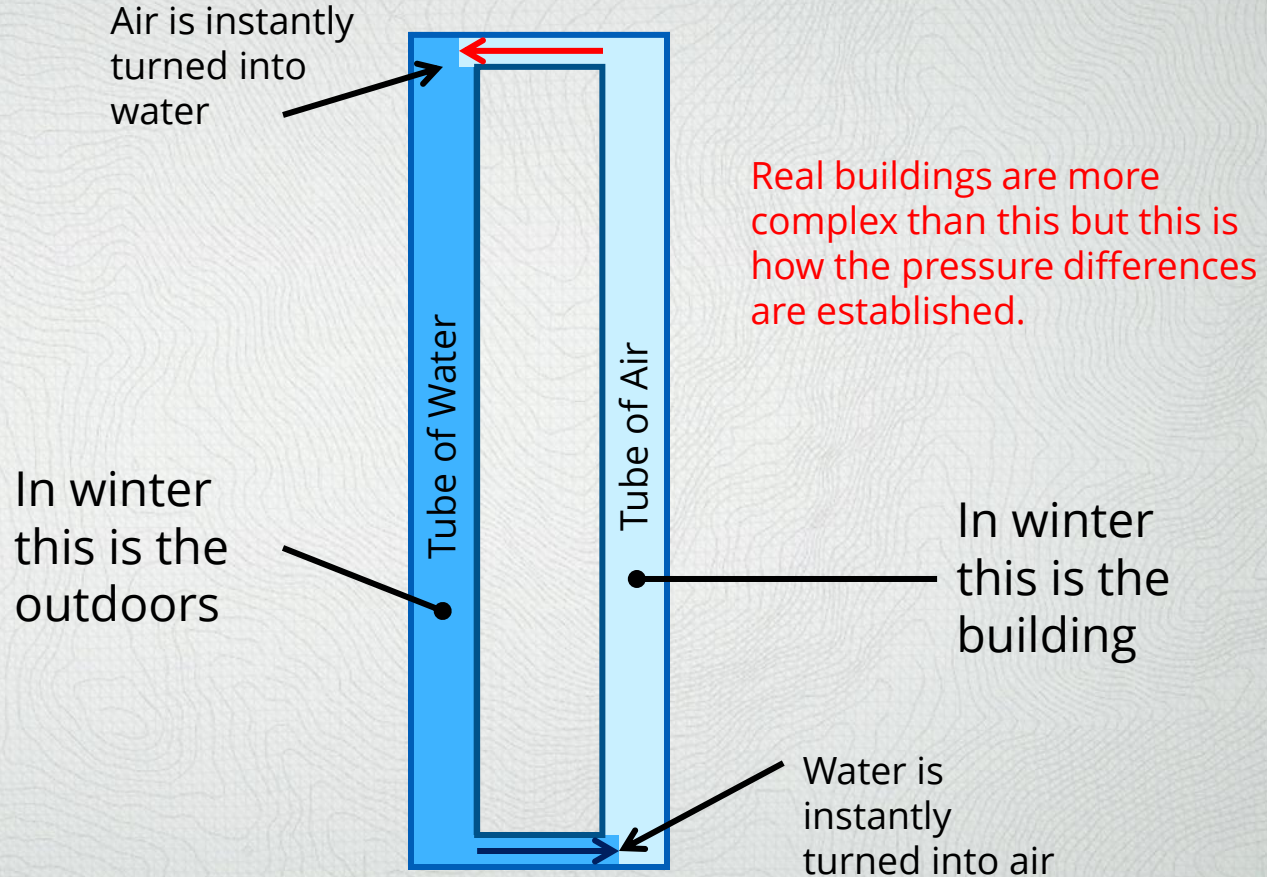


How Does Stack Effect Get Setup

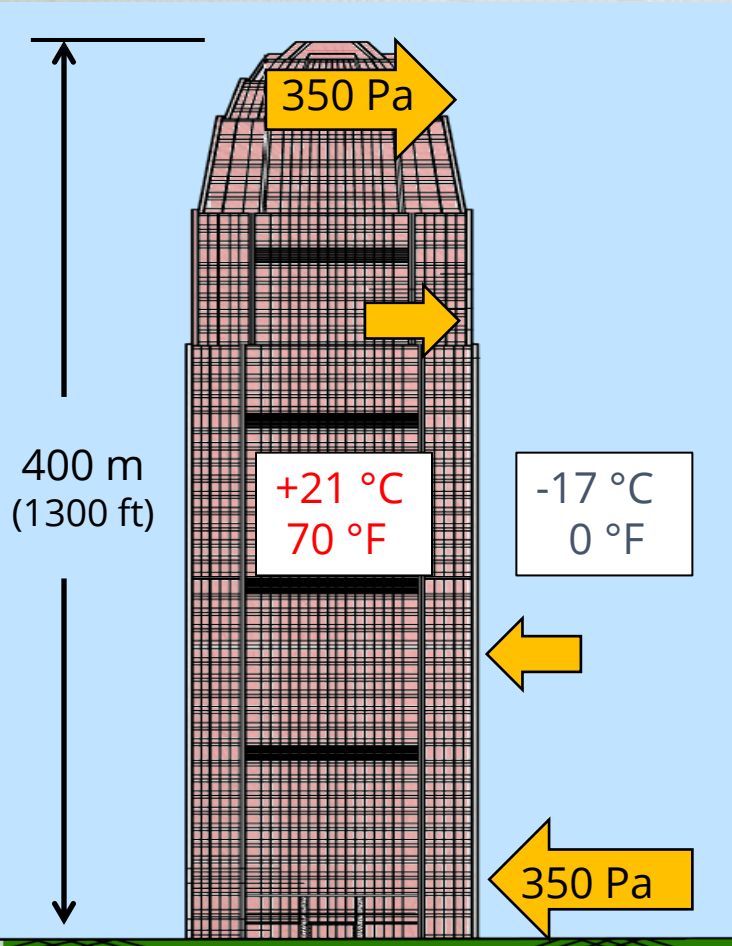
Imagine two tubes: one filled with air and one filled with water.

Now connect them at the top and bottom.

And add a little magic.



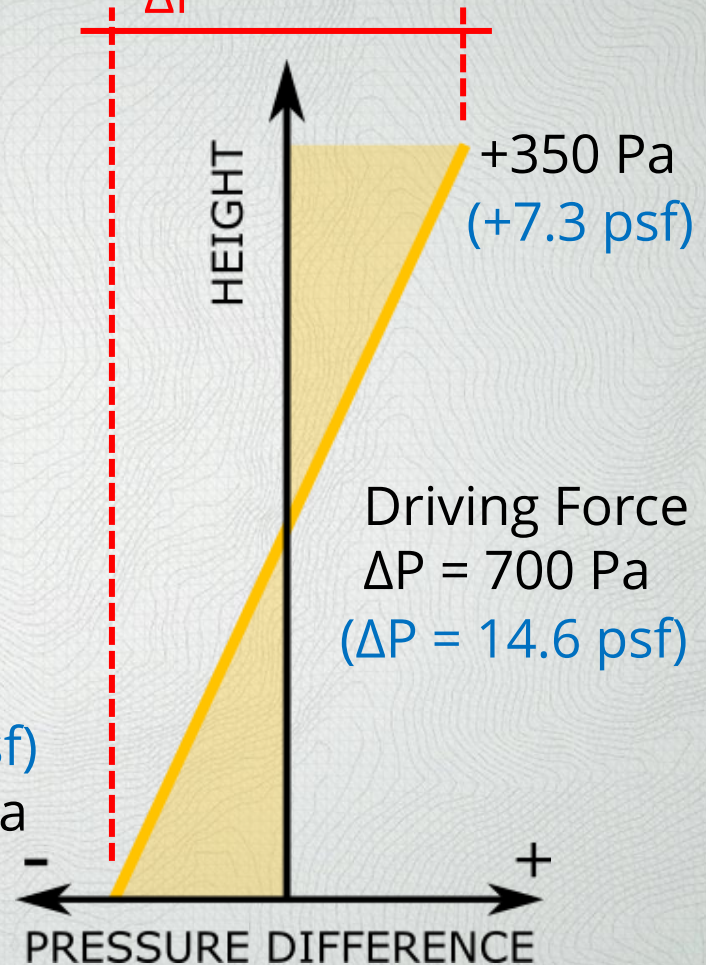
Stack Effect Pressures



The CTF Tower Pressures are approximately 350 Pa total.

That would be ~175 Pa at the top and bottom.

Remember the video? That was 250 Pa.



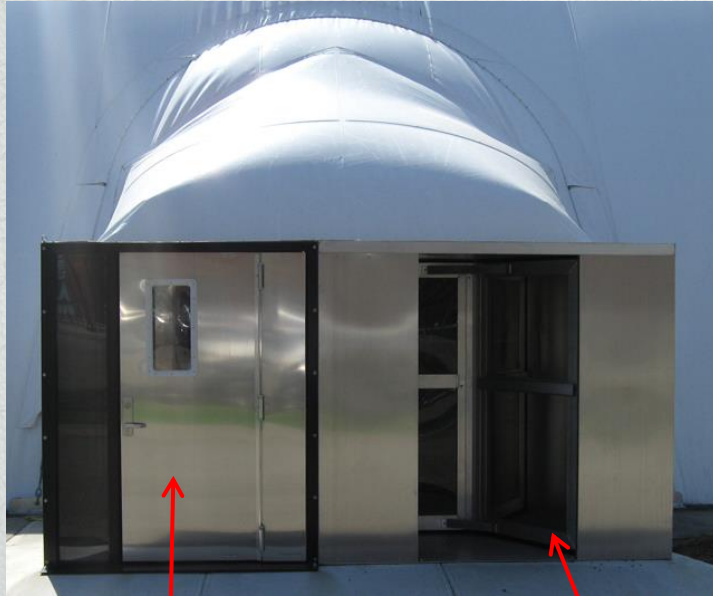
Stack Effect Driving Force



Pressure Difference (Interior to Exterior):

1 – 3 inches water
250 – 750 Pa
5.2 – 15.7 psf

Stack Effect Pressure Issues



Motorized swing door
with airlock (two sets
of doors)

Revolving Door



1 set of frameless glass doors - 350 Pa on doors
= approximately 80 lb force to open each door

Criteria

How do we judge 'problematic'

Criteria for Determining Acceptability

Difficulty opening and closing of swing doors

Operability threshold = 30 lb force to set in motion
= 130 Pa (2.8 psf)

Elevator door operability issues

Operability threshold = 25 Pa (0.5 psf)

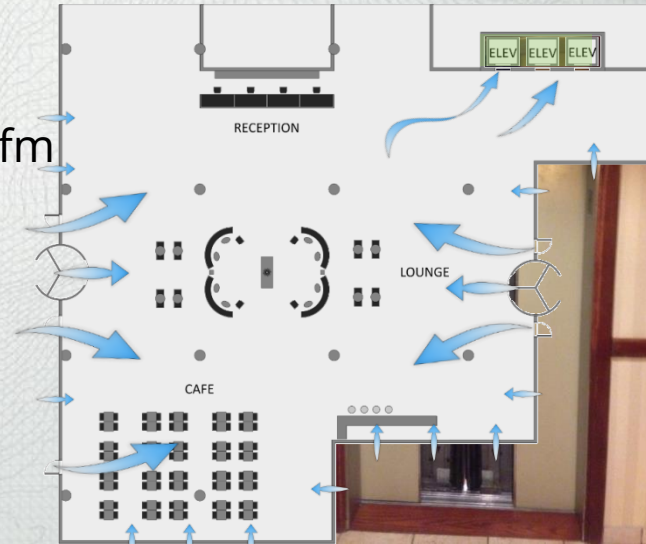
This is difficult to define precisely as sometimes 100 Pa is ok

Whistling through doors

We define a threshold at 100 L/s = 200 cfm

The HVAC system cannot keep up:

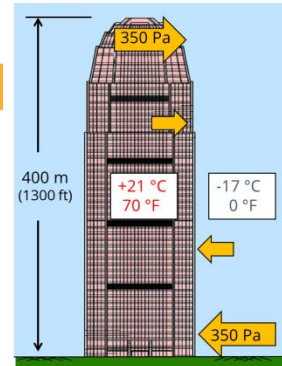
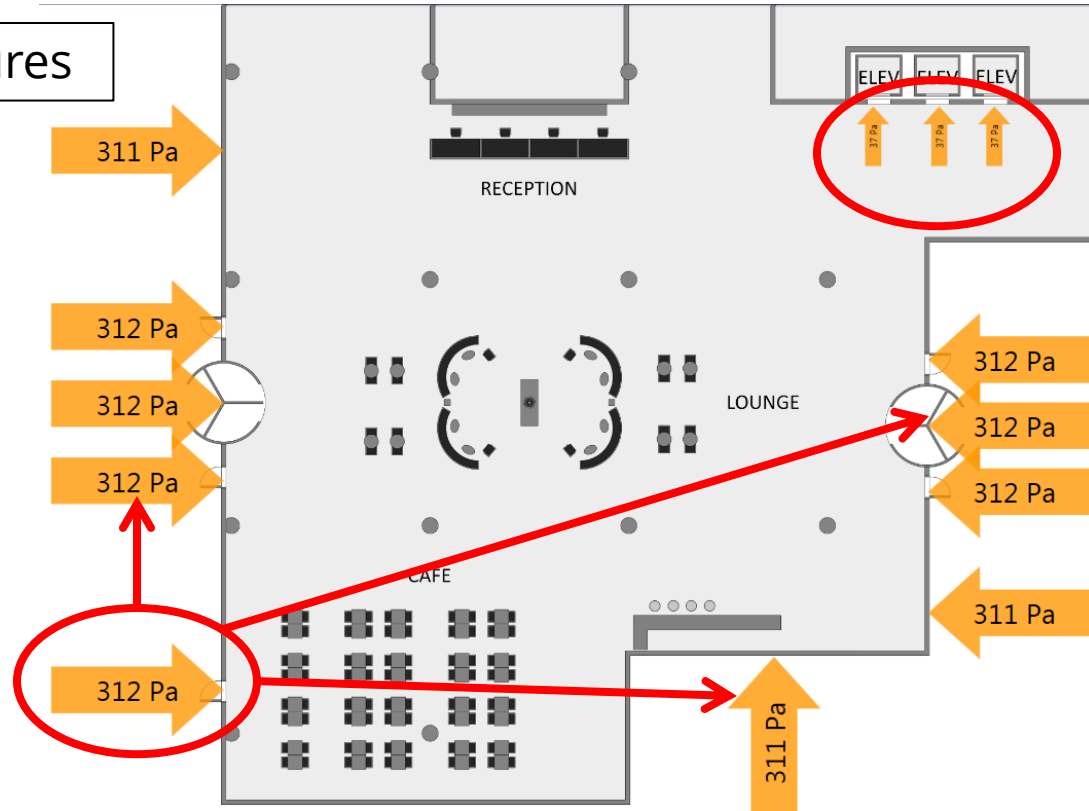
- Some areas are too hot;
- Some areas are too cold; and
- Balancing the HVAC system is a problem.



Criteria

Ground Floor Pressures

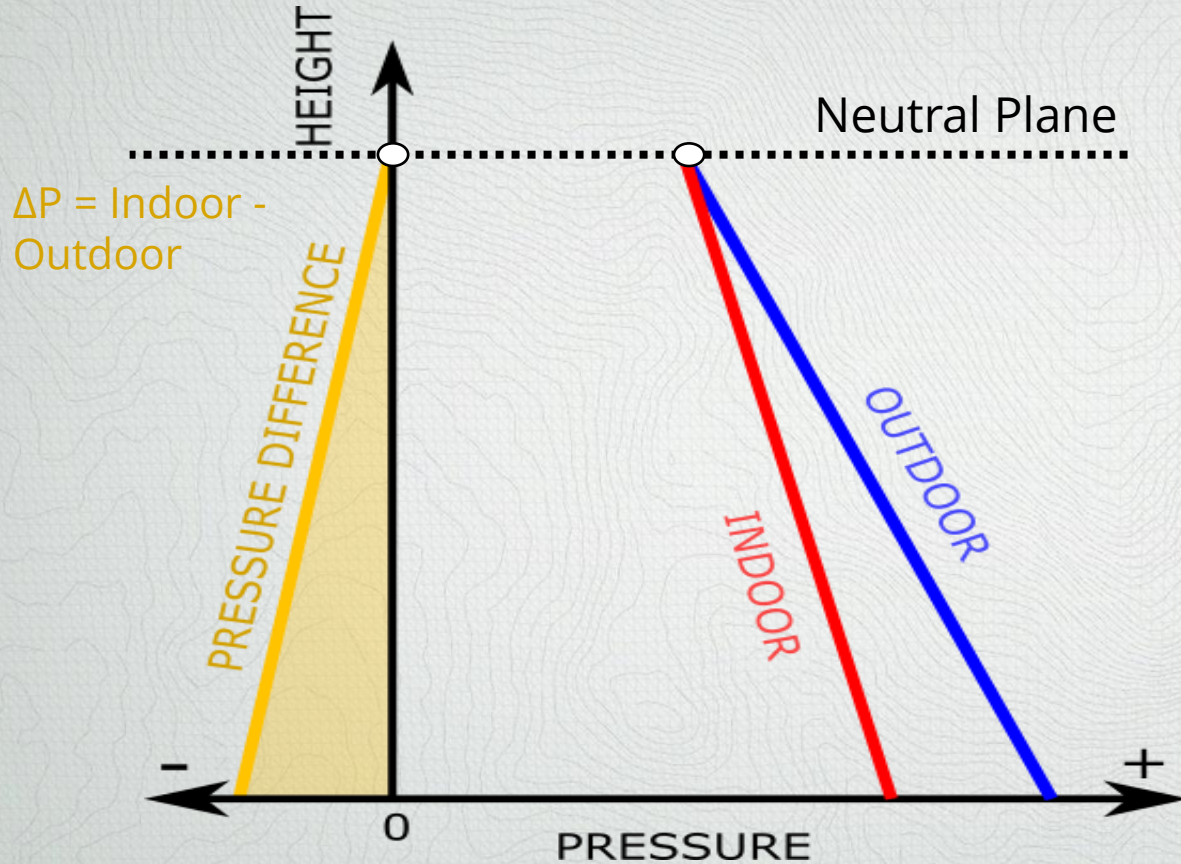
In this case, there are both elevator operability problems and door pressure issues.



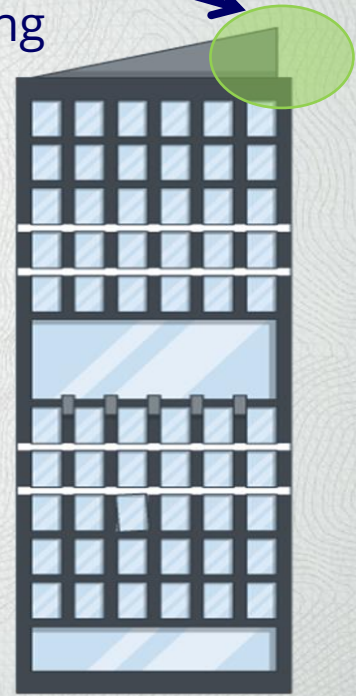


Where and what is the Neutral Plane

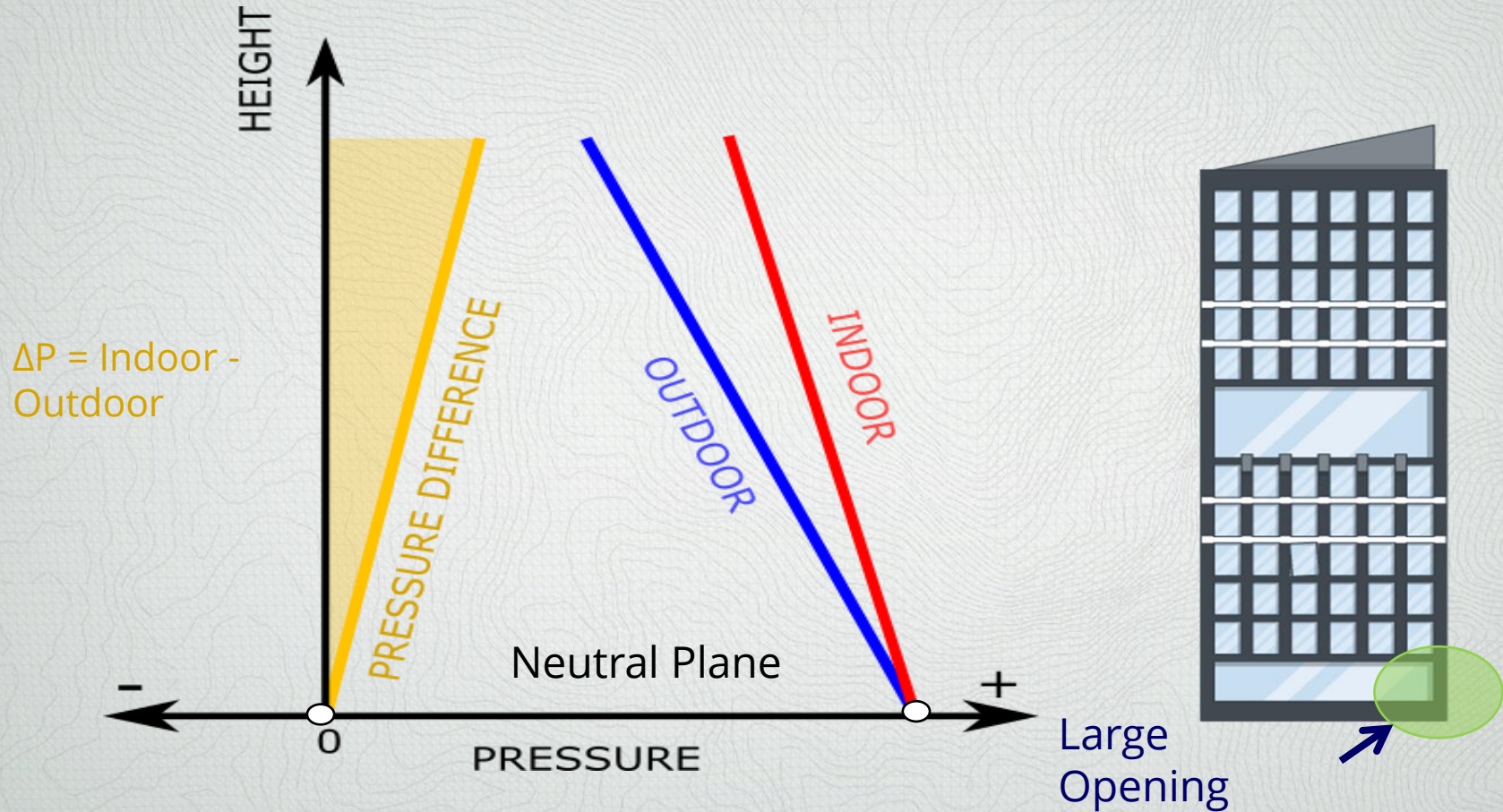
Winter: Large Opening @ Top



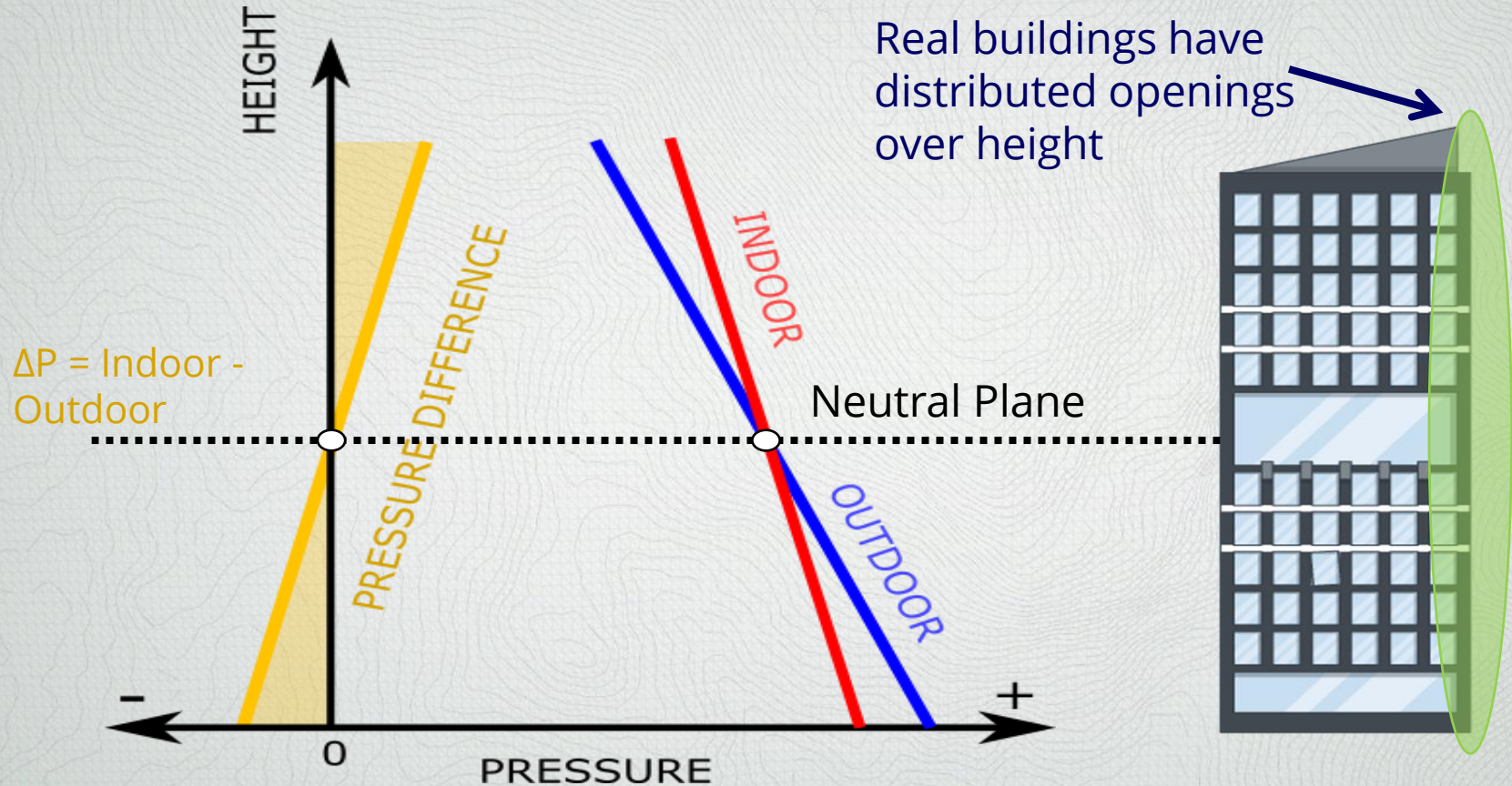
Large Opening



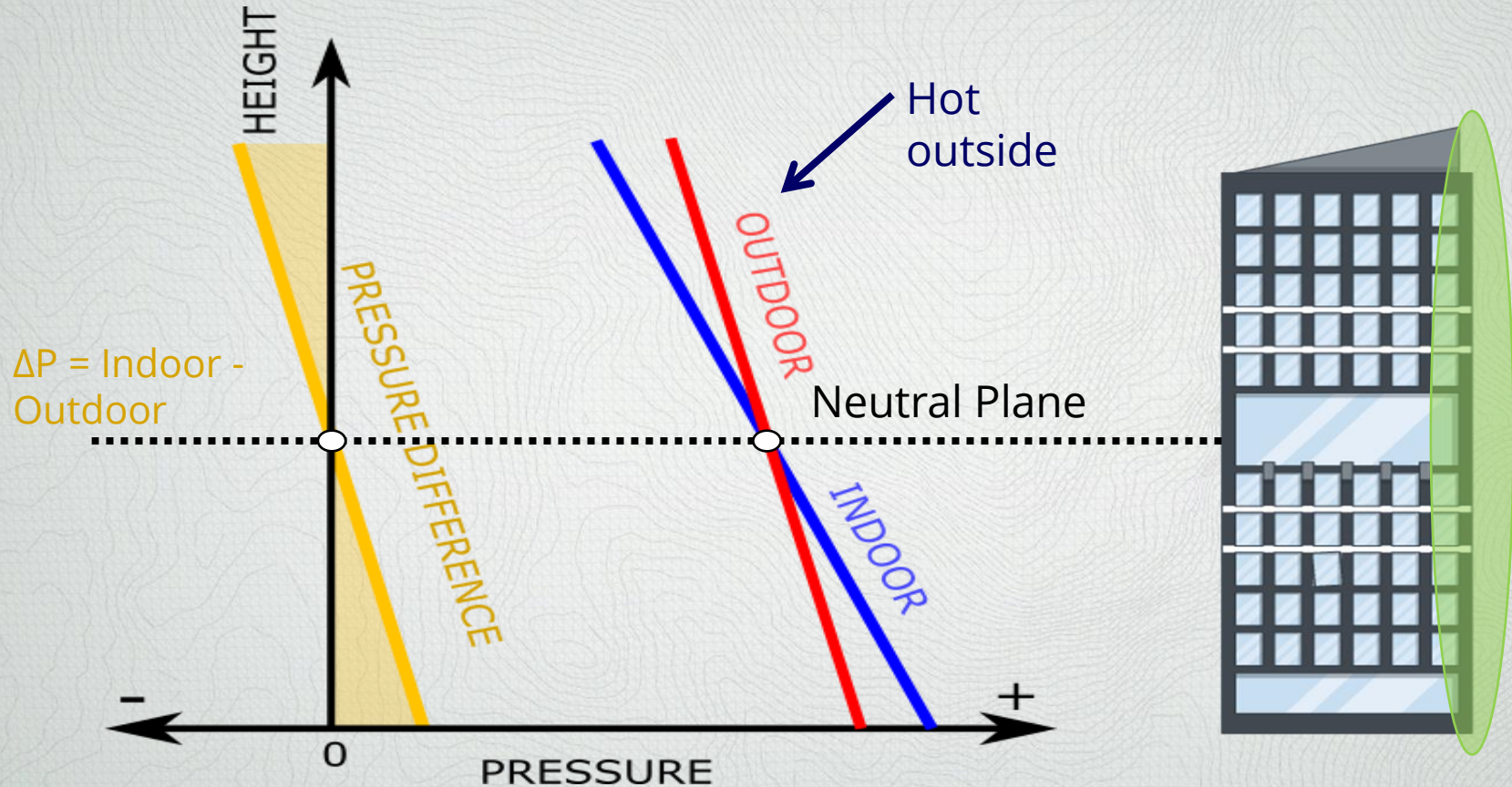
Winter: Large Opening @ Bottom



Winter: Distributed Openings



Summer: Distributed Openings



Effect of Building Pressurization

Building Pressurization

Fresh Air
(from outdoors)

Return

Exhaust
(to outdoors)

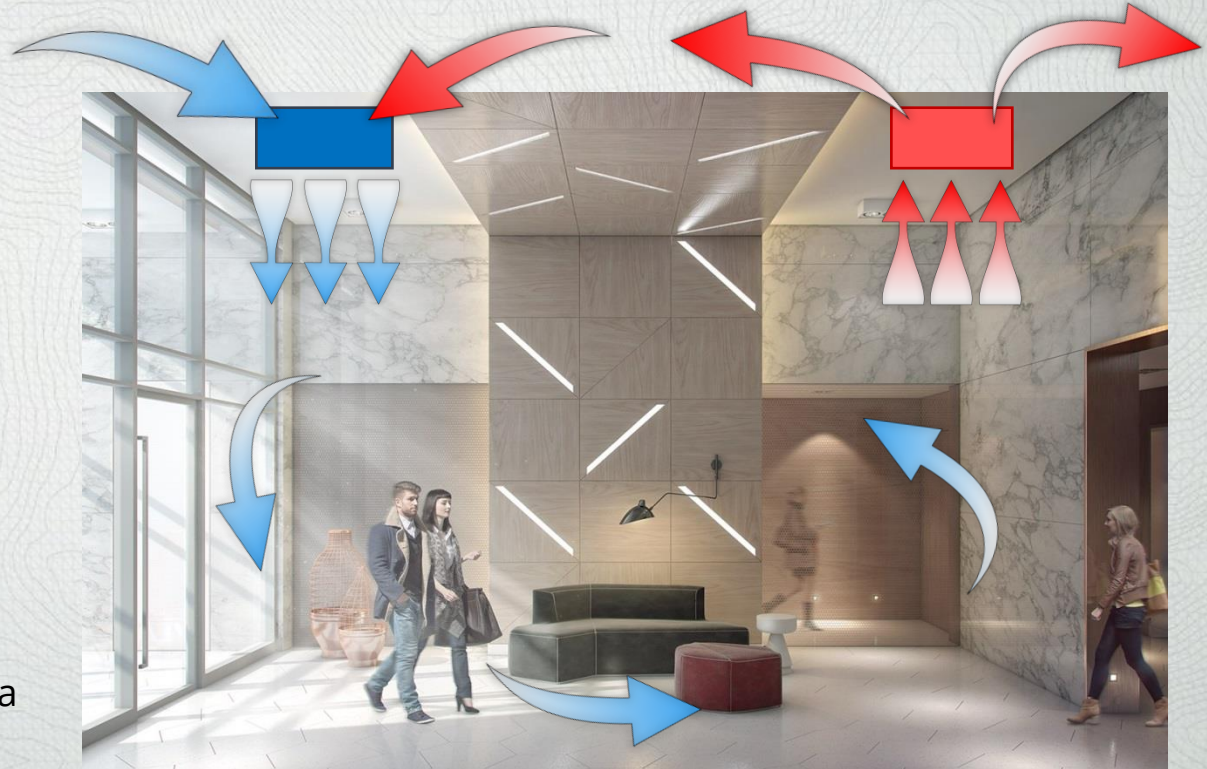
**Building Pressurization
through HVAC:**

**Net Airflow Rate =
Fresh Air - Exhaust**

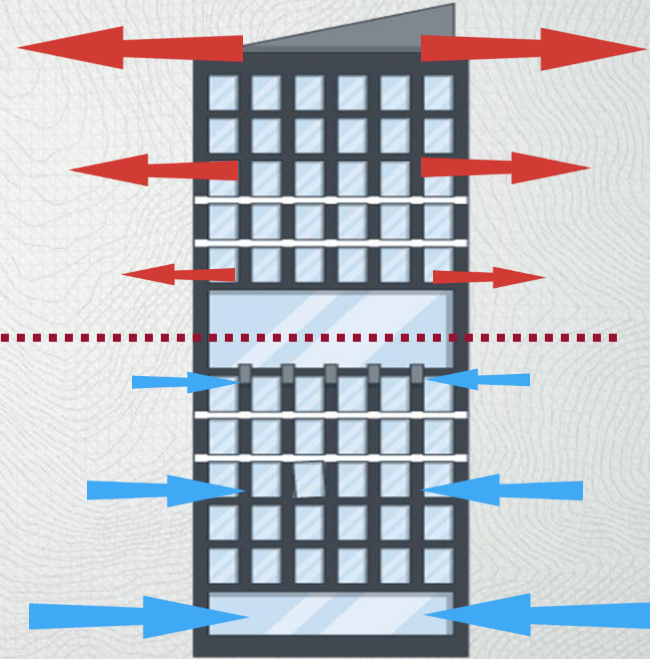
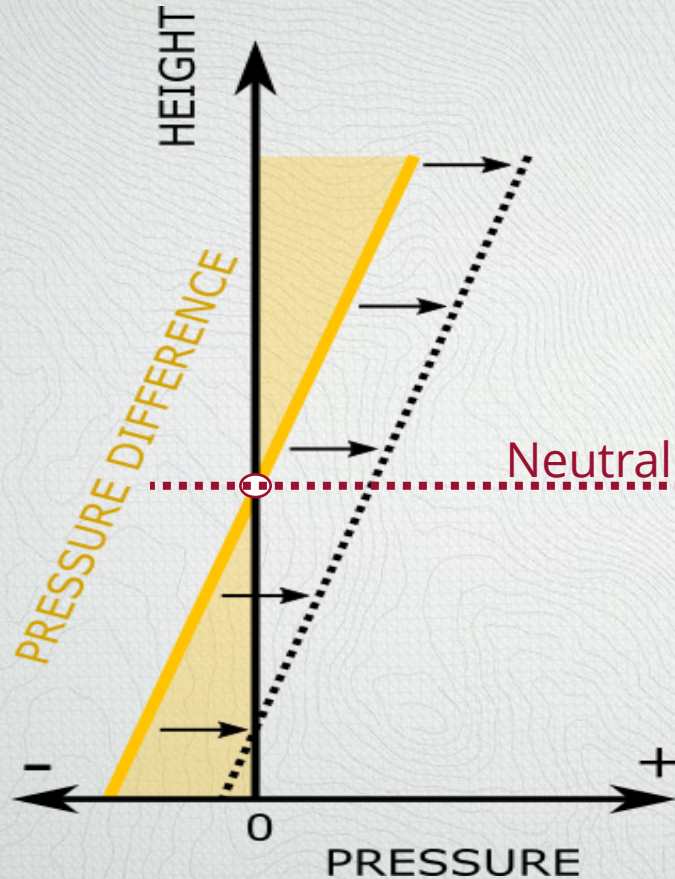
**Most buildings are
positive.**

Some are negative

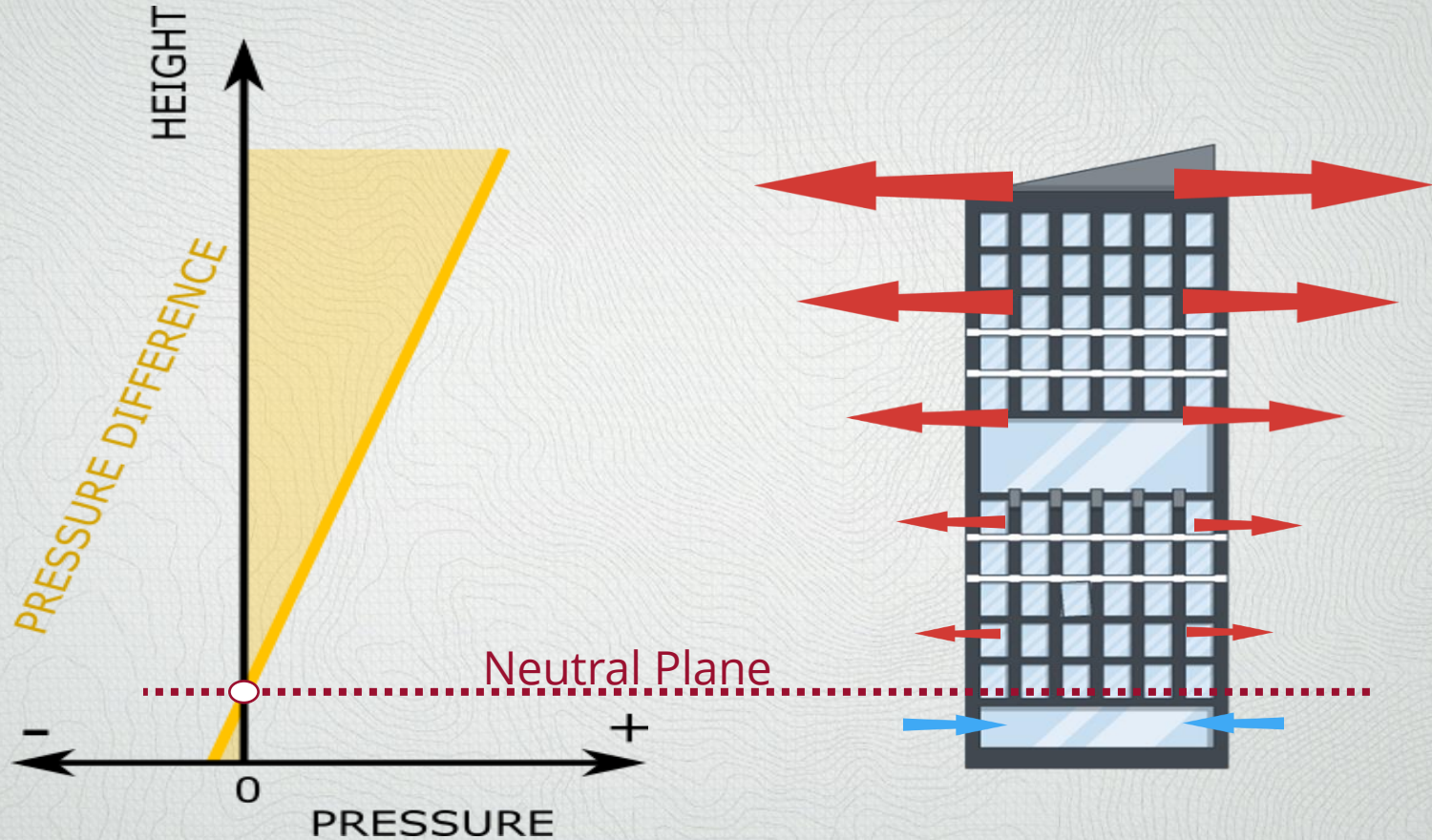
↖
This can be a
problem!



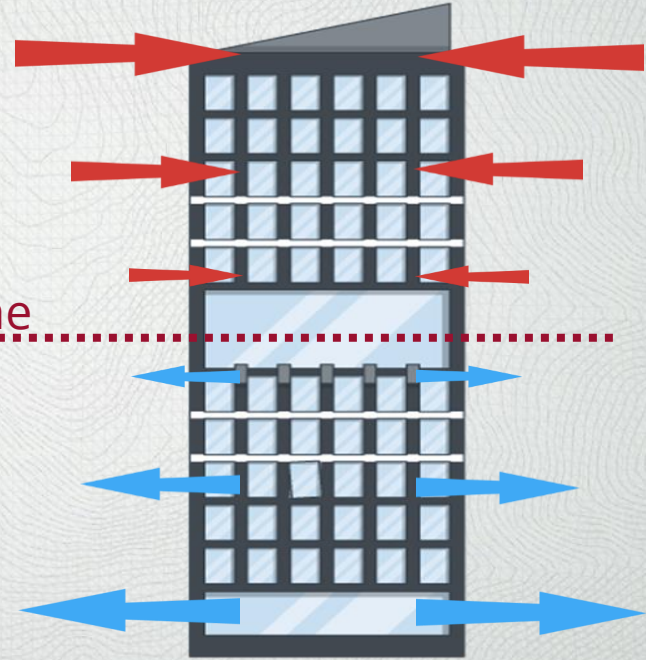
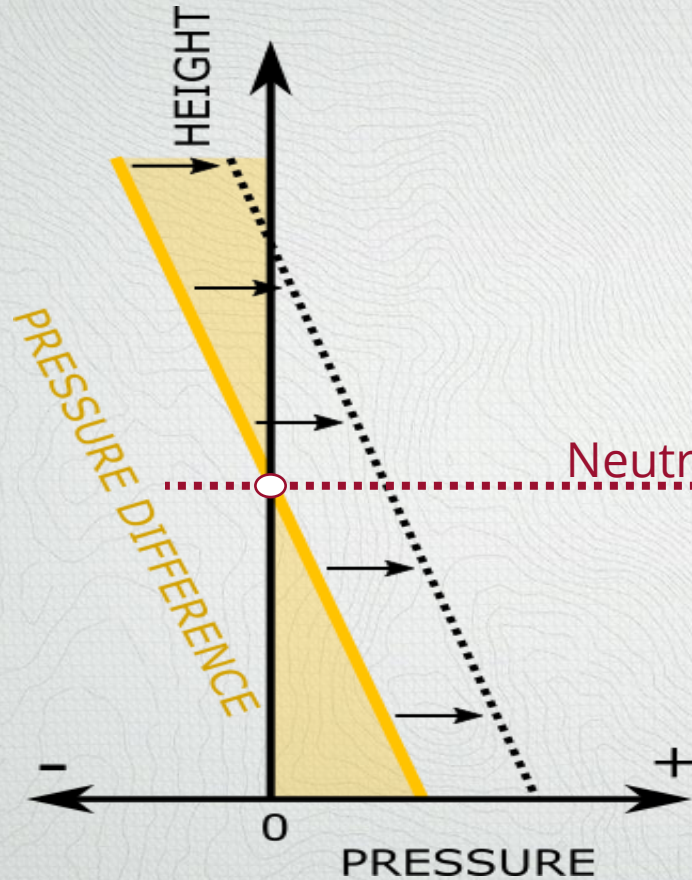
Winter: HVAC Positive Pressurization .



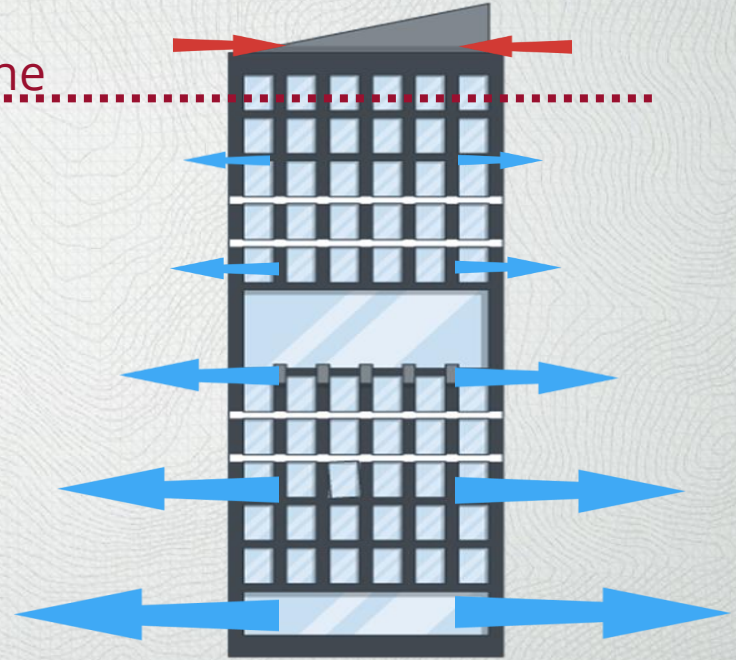
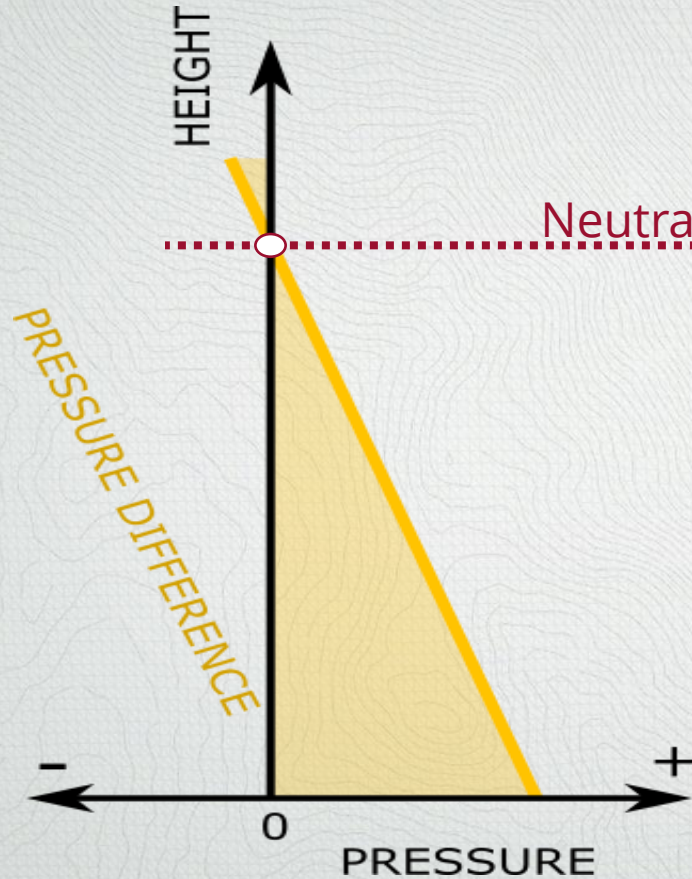
Winter: HVAC Positive Pressurization .



Summer: HVAC Positive Pressurization



Summer: HVAC Positive Pressurization



Managing Stack Effect

Managing Stack Effect

What is the Design Goal?

The goal is to “reduce the frequency and severity of undesirable stack effect impacts and issues within the building”

It is not to “get rid of stack effect”

- It is possible to get rid of stack effect – that is a different discussion

Example Problem

Managing Stack Effect – 80 Storey Building

- **Winter ground floor lobby**
- **Similar to an outdoor deck at the top of a building in summer**

Managing Stack Effect

Two main options for mitigation:

Passive Mitigation:

- Tightening the building envelope, specific doors, or vents.
- Adding vestibule doors or walls
- Using revolving doors

Active Mitigation:

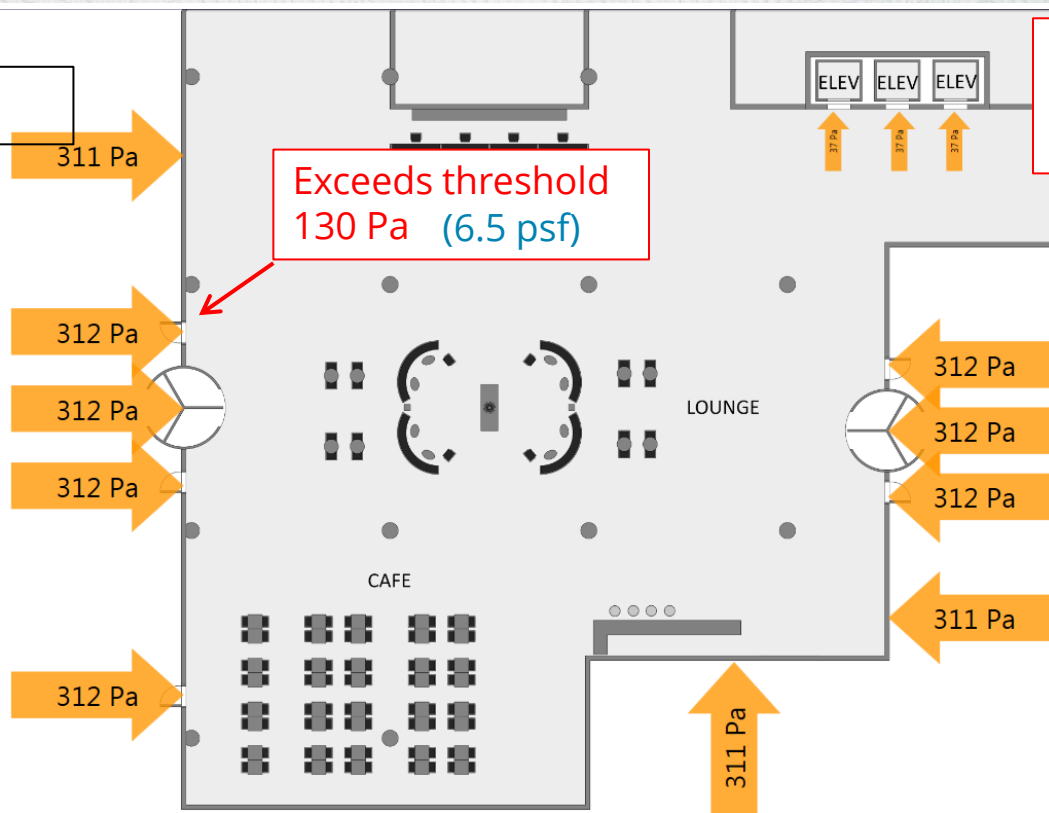
- HVAC pressurization
Including seasonal control

Mitigation Example

No Mitigation

The total pressure at the ground floor is 350 Pa.

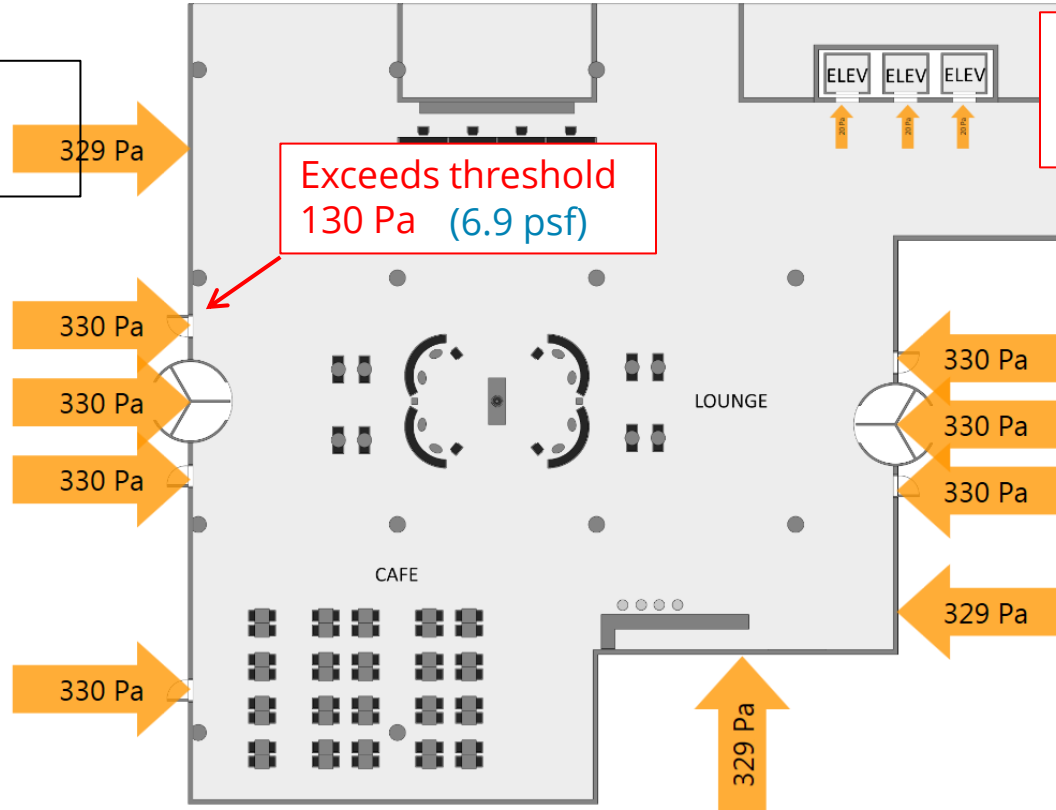
The total pressure at the ground floor for a 530m building in Guangzhou is 175 Pa.



37 Pa across
elevator doors
> 25 Pa (0.8 psf)

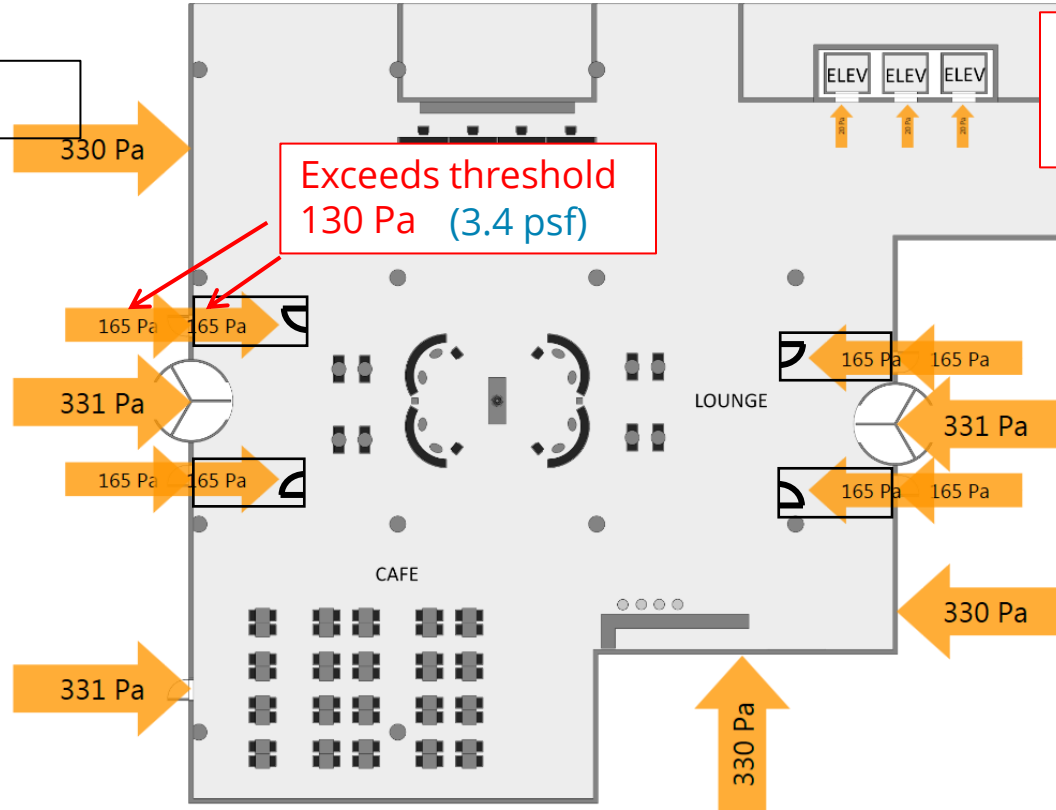
Mitigation Example

Improve Façade Air Leakage Specification



Mitigation Example

Adding Vestibules

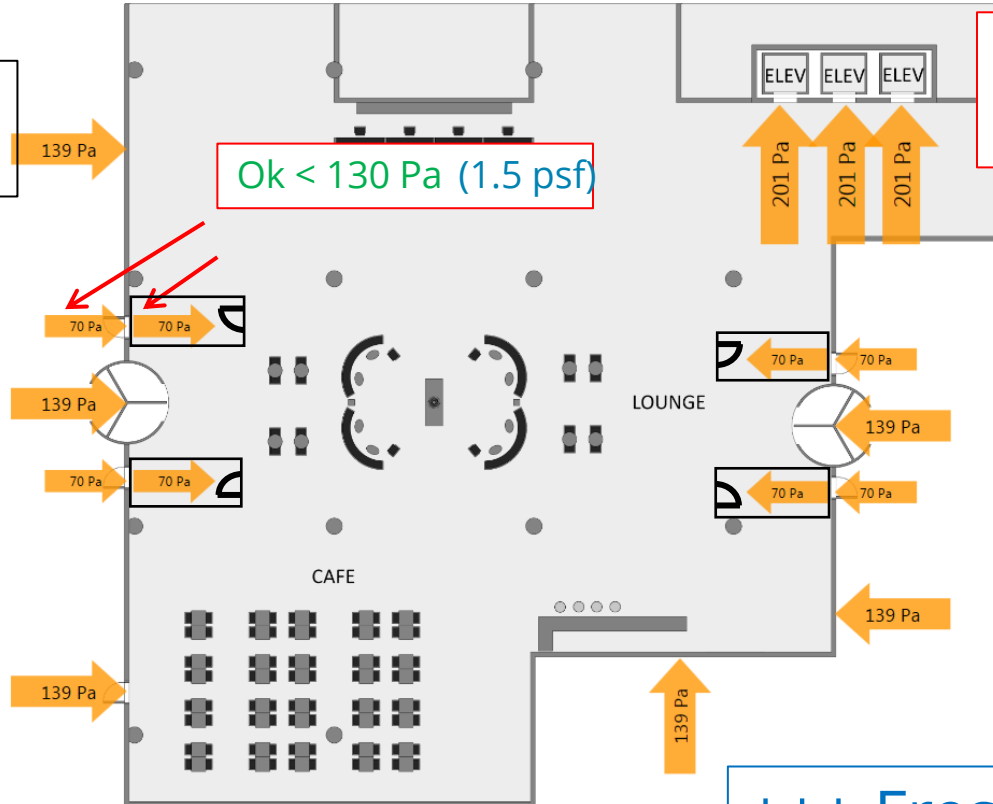


Exceeds threshold
130 Pa (3.4 psf)

20 Pa across
elevator doors
< 25 Pa (0.4 psf)

Mitigation Example

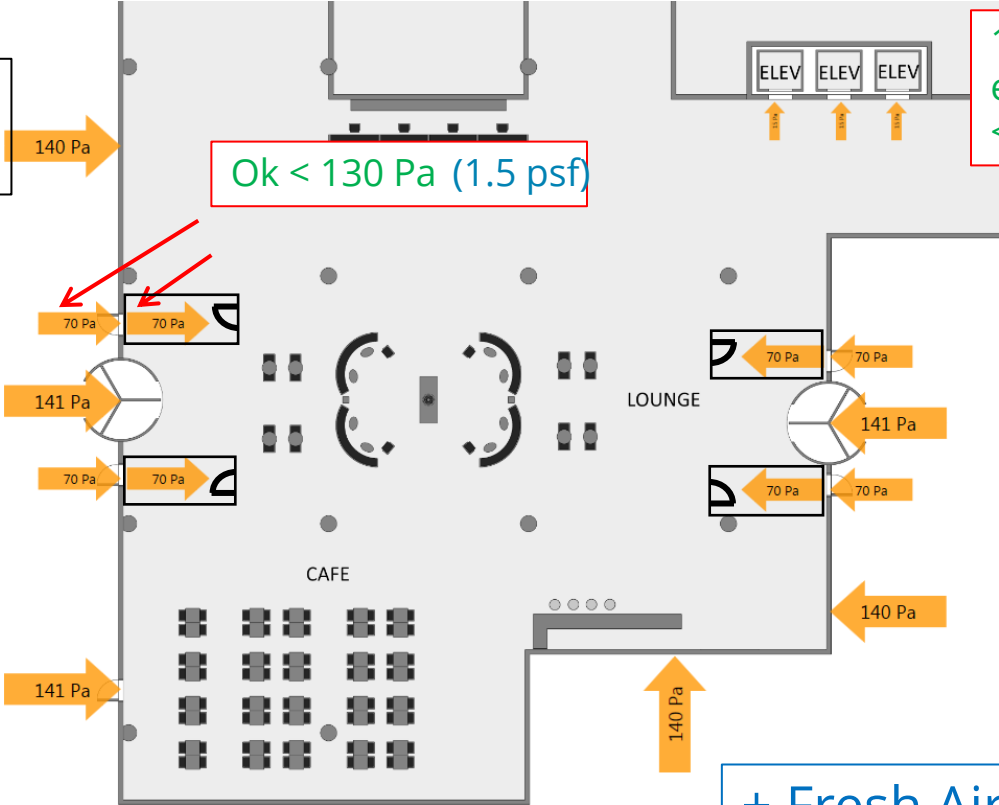
Positively Pressurizing
the Ground Floor only



201 Pa across
elevator doors
>> 25 Pa (4.2 psf)

+++ Fresh Air

Positively Pressurizing all floors



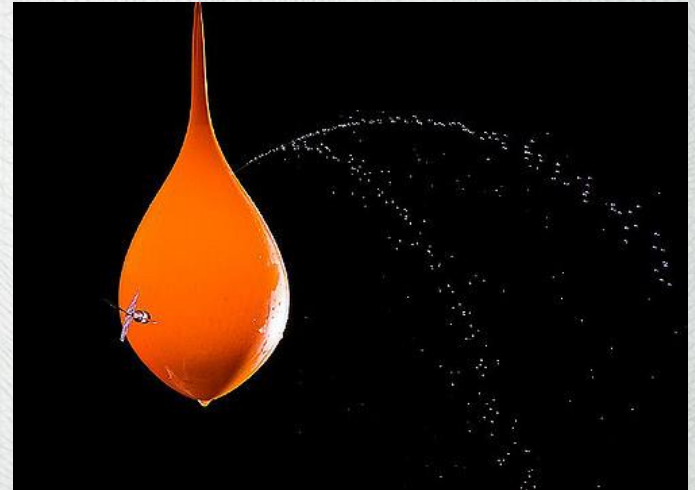
15 Pa across
elevator doors
< 25 Pa (0.3 psf)

+ Fresh Air

Challenges with Mitigation

It is like trying to plug a leaky dam

- Solving one stack effect issue can result in the creation of a new issue somewhere else in the building.
- It is important to understand pressures and air leakage through the whole building, not just individual floors.
- Different types of buildings require different types of solutions (e.g. residential, commercial, hotel).



Example Mitigation

Airlock Doors Used



Shanghai World Financial Center



Revolving Door – Attention to Details

The drip tray under this revolving door was not partitioned.

Air can flow freely underneath the door.

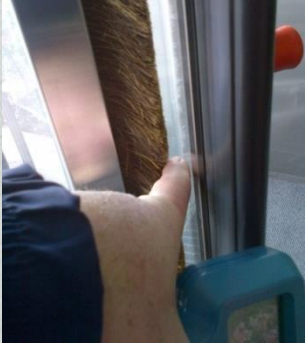
Sometimes the doors and enclosures have cracks / gaps.



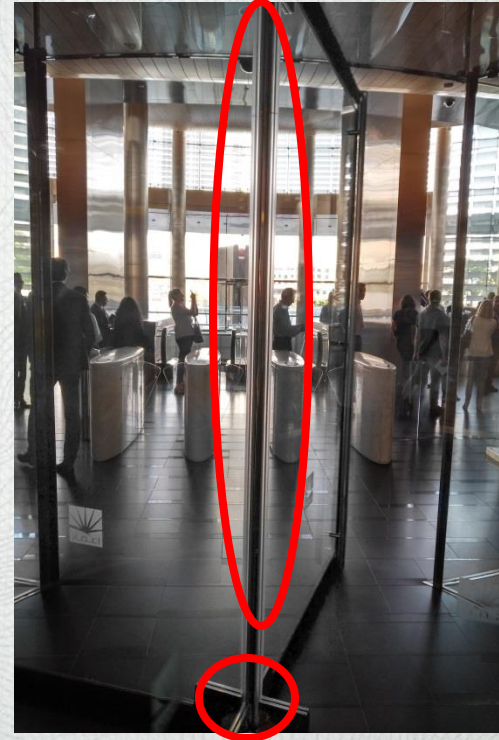
A Famous Building had Gaps in Rotating Doors

Before – large gaps

We have seen rotating doors where the leafs do not touch the outer shroud.



After – gaps sealed



Basement Entrances are Important

**Very large gap under doors
between underground
parking and service
elevator lobby**

**We tend to assume the
basement garage is
outdoor space**



Case Study - Shanghai

Existing Building

Building 1

Temperature
in the city
drops to -2.0
 $^{\circ}\text{C}$ ($\sim 28^{\circ}\text{F}$) –
ASHRAE 99.6

Building is a 40 story office
building

- Operable windows
- Three lift cores (L, M, H)
- Access to outside on upper levels

Issue is that the high rise lifts
shuttle would not operate
under semi-cold conditions

- Would fail at $\sim 5^{\circ}\text{C}$ ($\sim 40^{\circ}\text{F}$)
- Building operations keeps two
H-lifts open on lobby floor to
enable operations



Building is Not Tall

Forty (40) storey building

Nothing particularly strange about the building

3 Lift banks

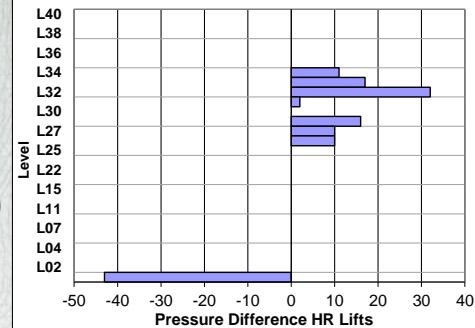
- low rise, mid-rise, high-rise

Lifts to highest floors do not work on “cold” days

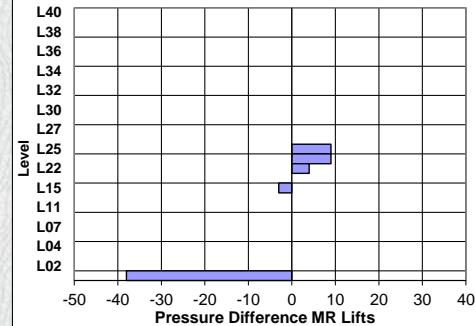
- Building operations puts two (2) lifts out of the five (5) on hold-open in order to get the others to work

Pressure Across the Lift Doors

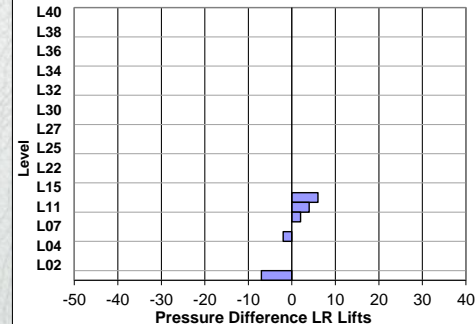
High Rise



Mid-Rise



Low Rise



Some Component Problems

The doors did not seal well.

- The façade took up ~25 Pa
- The lift doors took up ~40 – 70 Pa



L1 – Gap in Rotating Door



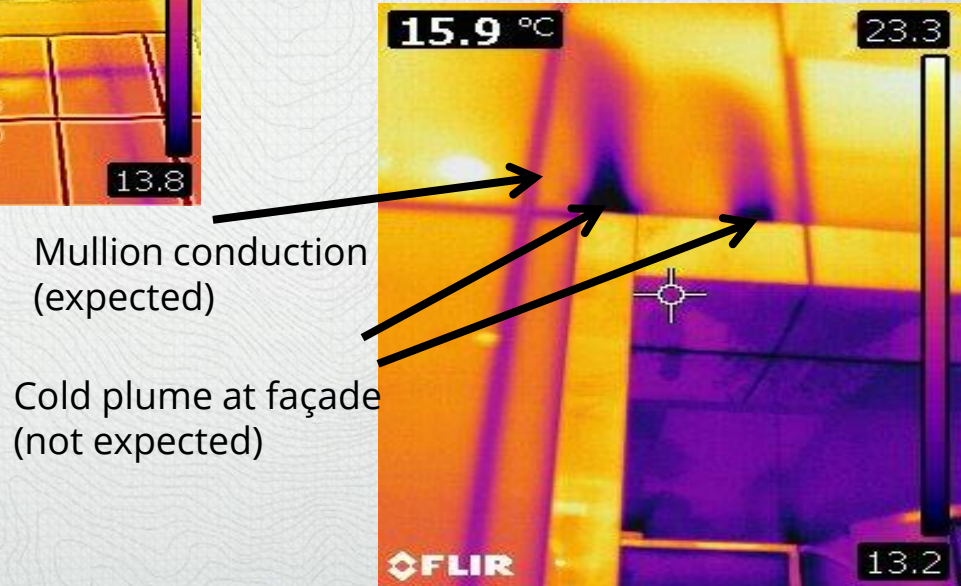
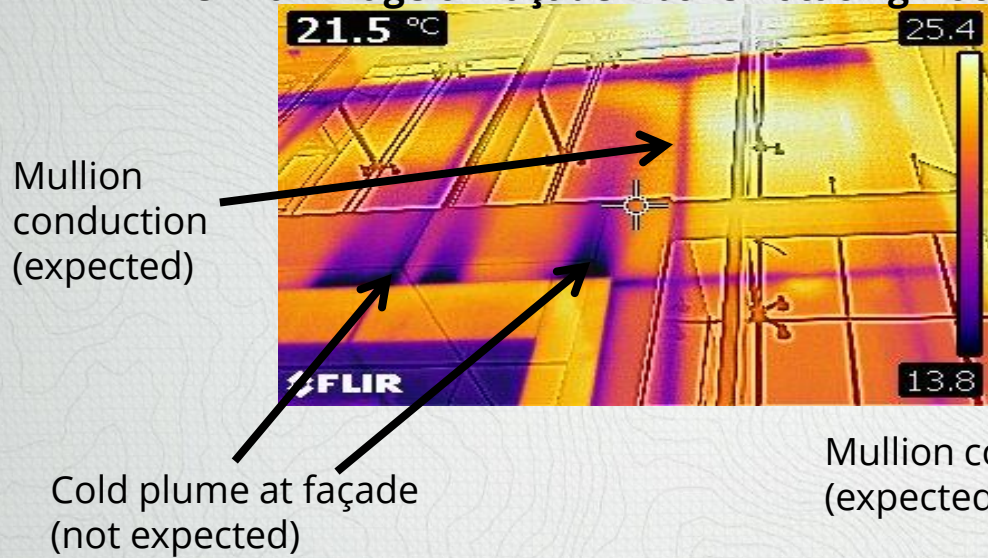
**L1 – Exterior Door Leak :
Partial Seal**



L1 – Exterior Door Leak

Some Construction Problems

L1 - Thermal Image of Façade Above Rotating Door



L1 - Thermal Image of Façade Above Rotating Door

Obvious Solutions

Seal the façade

- How do you seal a façade where you do not have access to all of the surfaces?

Create a vestibule for the HR Lifts

- Does this move the problem?

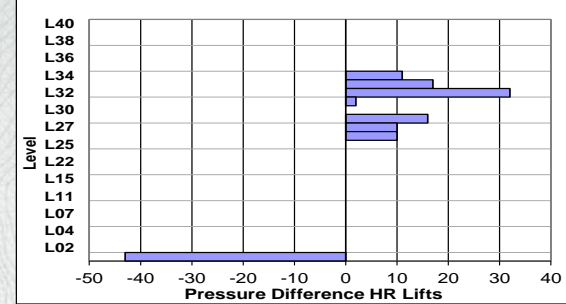


A Vestibule for Some Lifts Moves the Problem

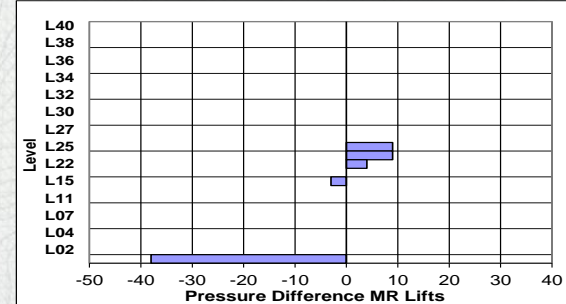
- Putting a rotating door / vestibule for the high-rise lifts would solve that problem
- The consequence is the pressure on the mid-rise lift doors would increase
- The mid-rise lifts would stop working
- Therefore, two sets of vestibules are required.

Pressure Across the Lift Doors

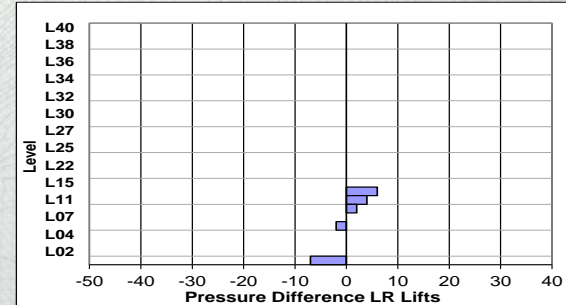
High Rise



Mid-Rise



Low Rise



Solutions

Seal the façade

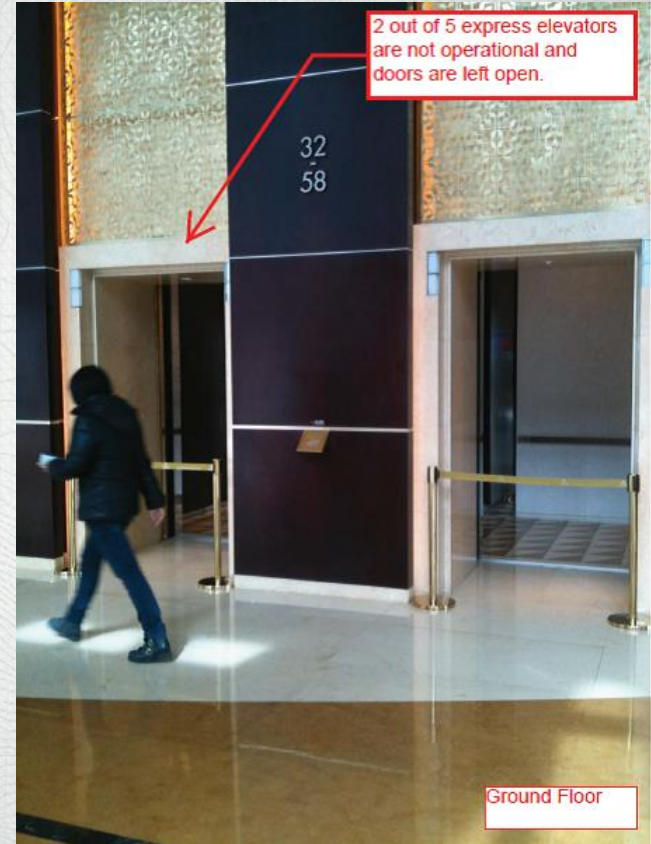
- A clear problem, but not a definitive solution

Create a vestibule for the HR Lifts

- Solves the problem for the HR lifts
- Creates a new one for the MR lifts

Make a hole in the HR lift shaft wall

- A non-standard approach, but resolves the operational problem
- Likely would have some code issues to resolve in some places

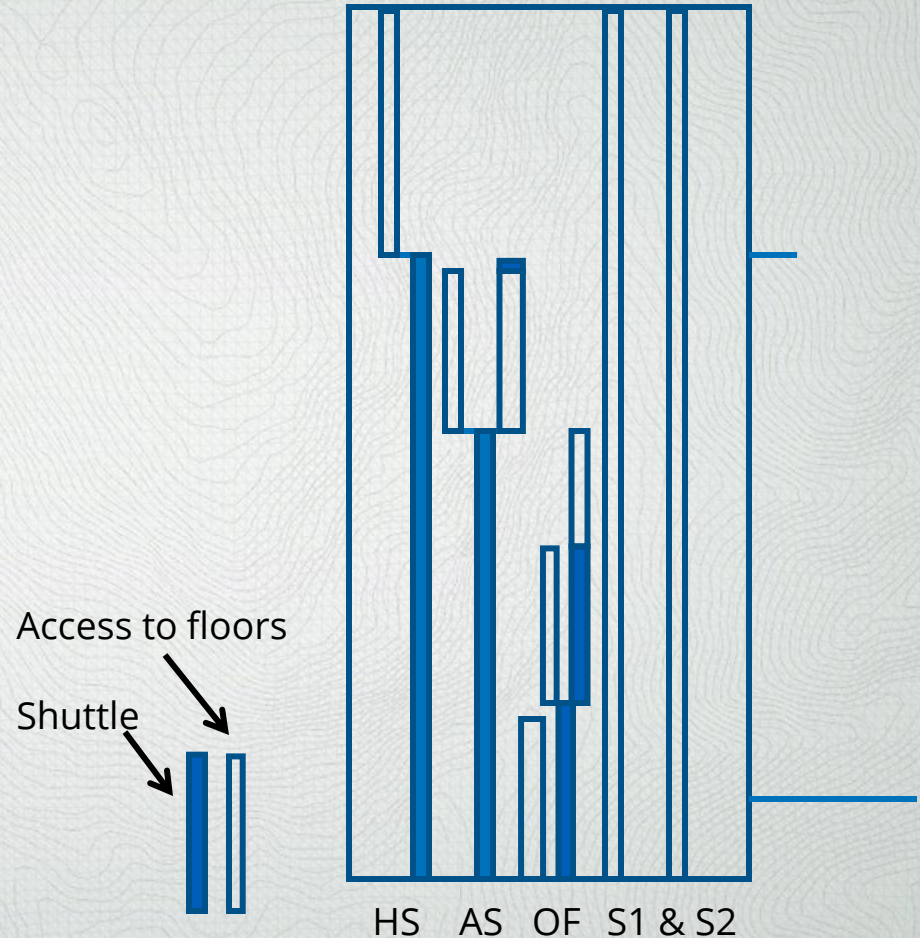


CTF Tower

Existing Building

CTF is a Super Tall Building in Moderate Climate

- Building is ~530m
- Has multiple express shuttles and complex lift arrangement
- Operable windows and upper level terraces
- Experiences summer and winter stack effect mode
- Pressures on lift doors high
- Lower part of building heated / cooled once floors occupied
- The design stack effect driving force is ~350 Pa

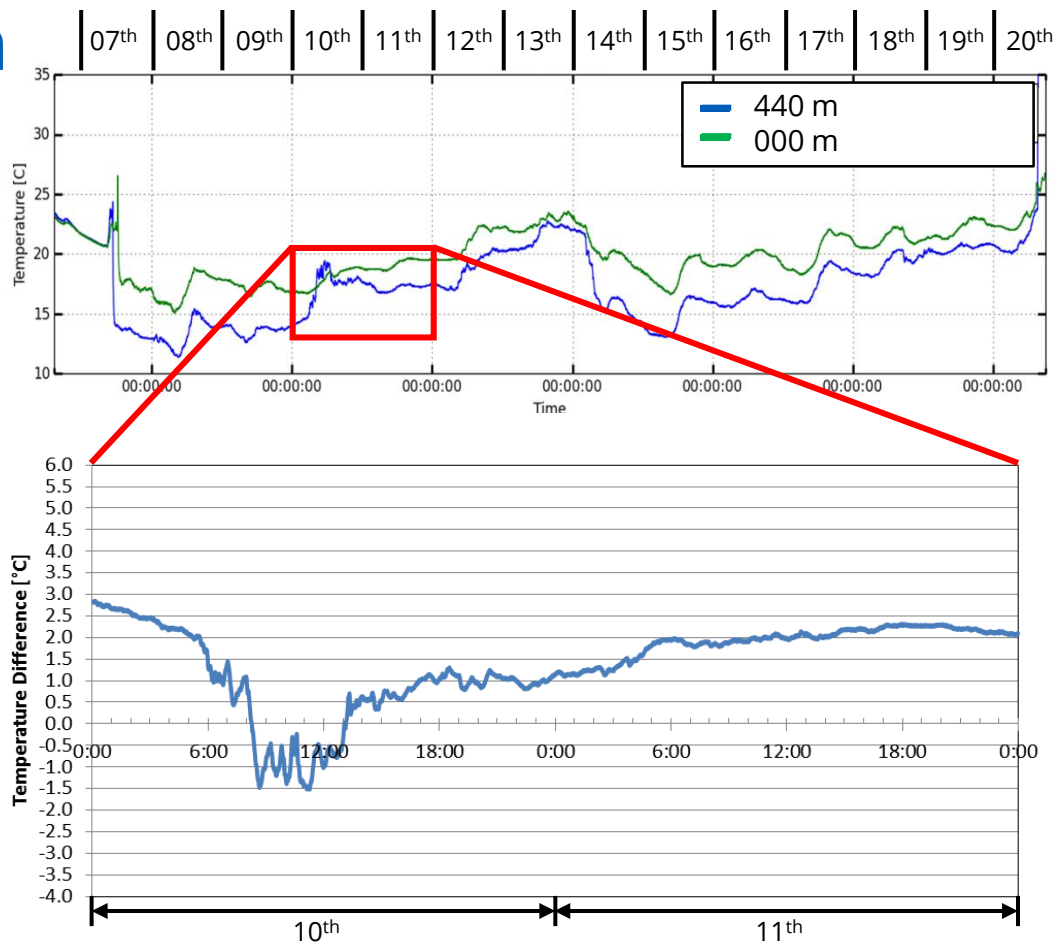


Temperature Conditions Top and Bottom

March 2017

The image to the right shows outside temperature at the top and bottom of the building.

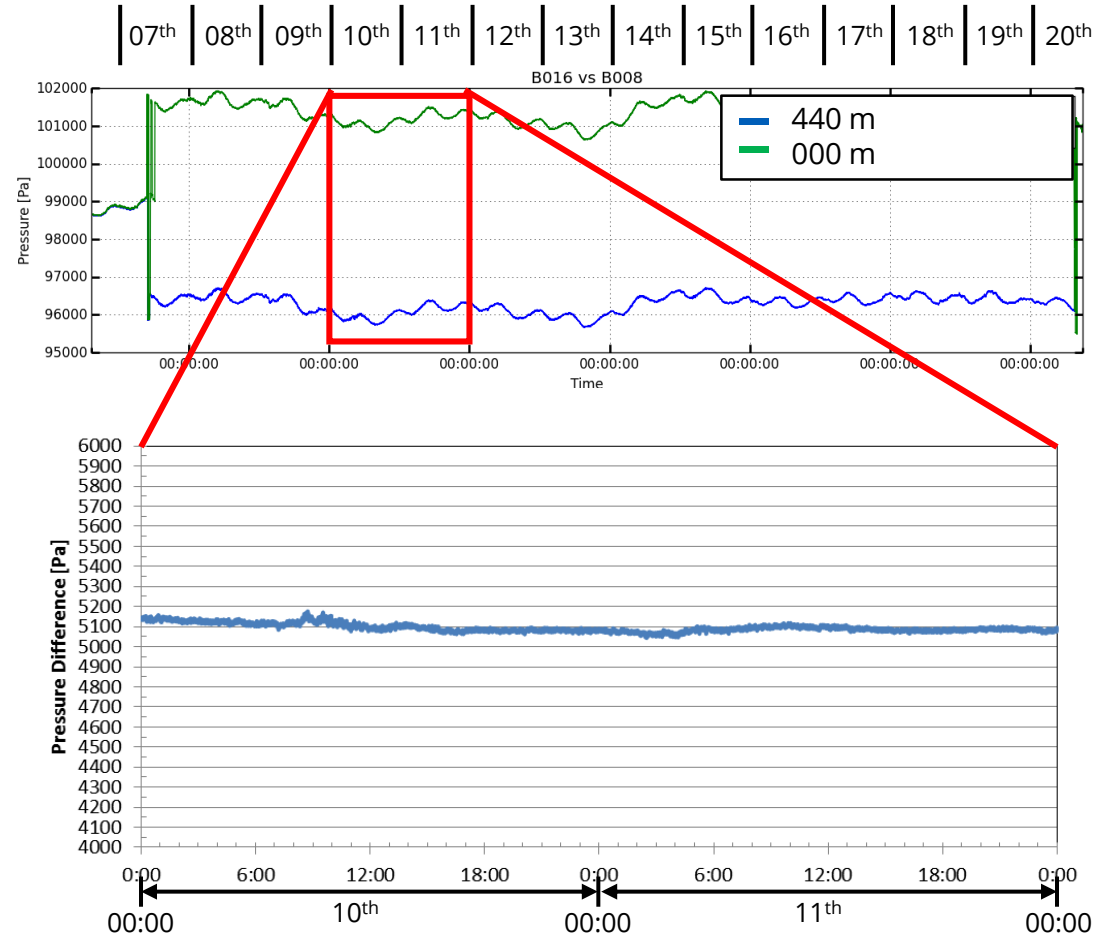
The lower image shows the temperature difference.



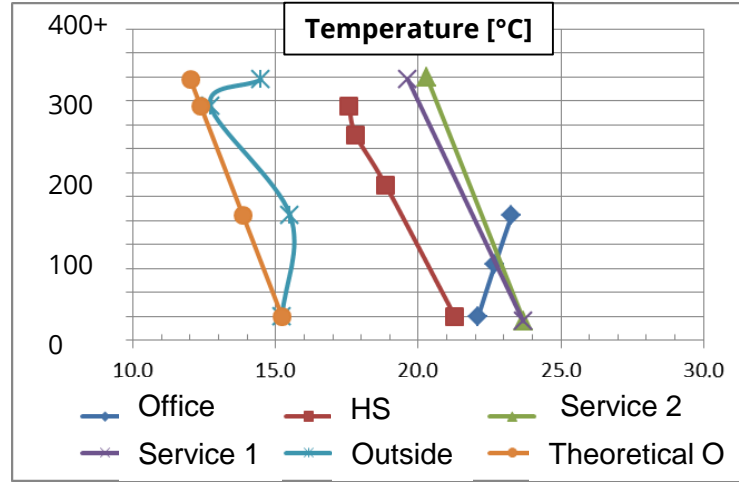
Pressure Difference Due to Height

March 2017

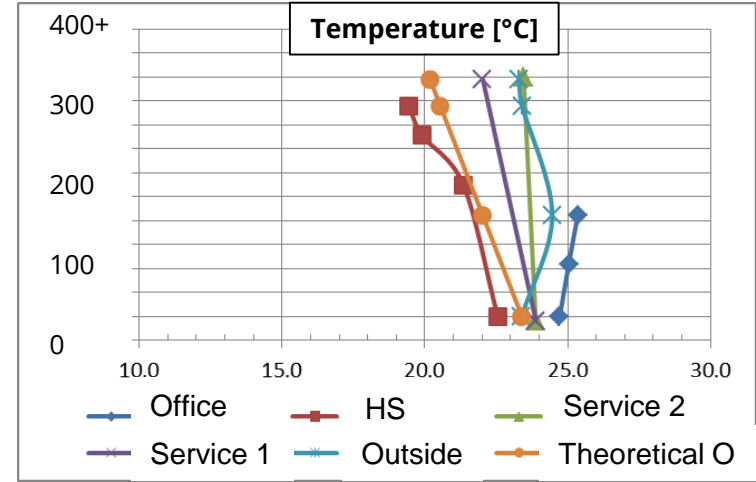
The upper image shows the pressures measured at the top and bottom of the building.



Measured Lift Shaft Temperatures

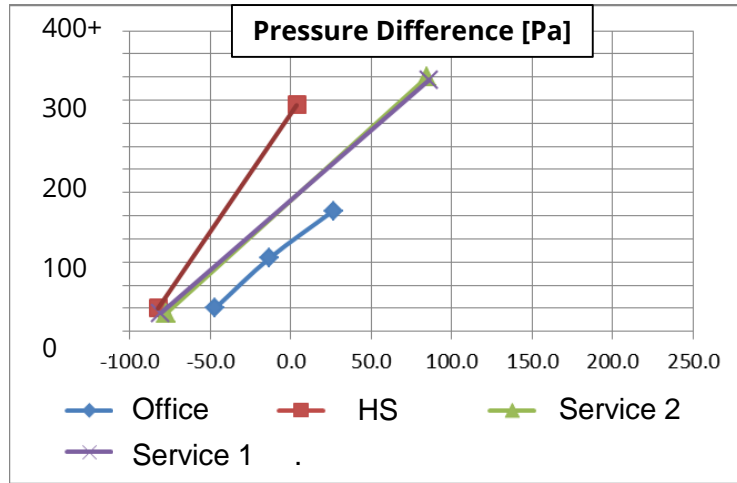


Coldest Day

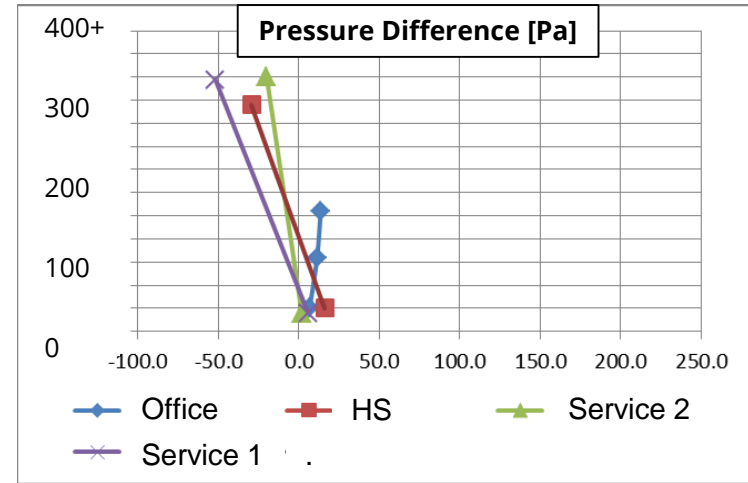


Hottest Day

Pressure Differences



Coldest Day



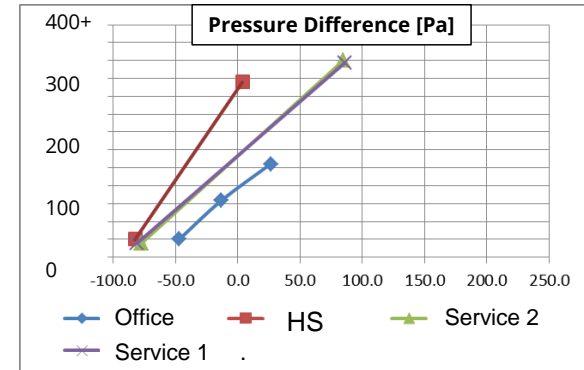
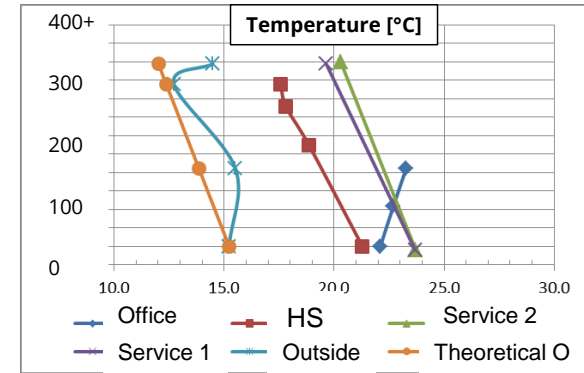
Hottest Day

Outside Temperature = 15°C
Pressure should be 130 Pa total

23°C
60 Pa

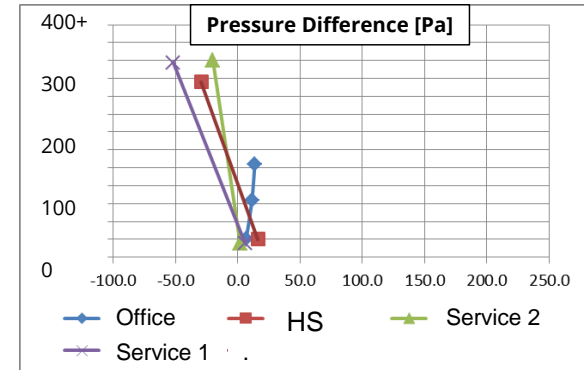
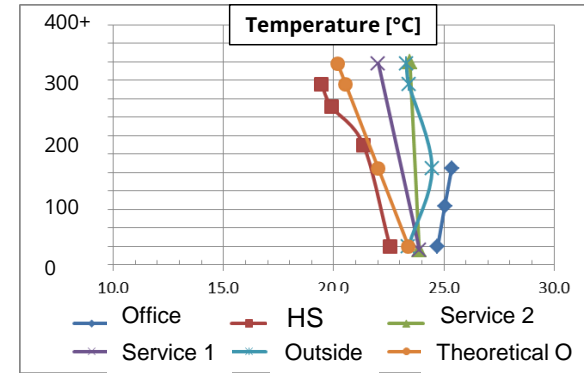
Coldest Point in Time: One Morning

- The outside temperature profile is coldest.
- The temperatures in all shafts drop with altitude except the office-lifts
- The temperature differences from the shafts to outdoors shows that the HE lift shaft is the coolest.
 - Slope of the HE-pressure difference is the steepest
 - Lowest temperature difference



Hottest Point in Time: Was in Evening

- All shafts are cooler than outdoors except the office lift.
- All shafts show 'reverse' / summer stack effect mode except the office lift.
 - The normal mode office shaft stack effect is weak (almost a vertical line)
 - The temperature difference between this shaft and outdoors is low.



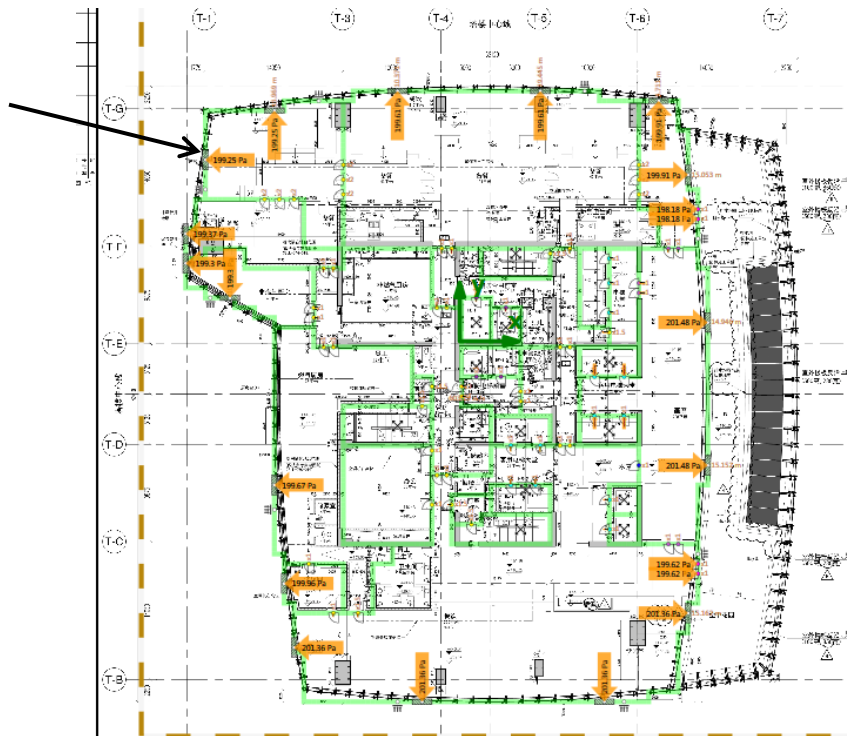
Typical Pressures at the Lobby Level

80 Pa

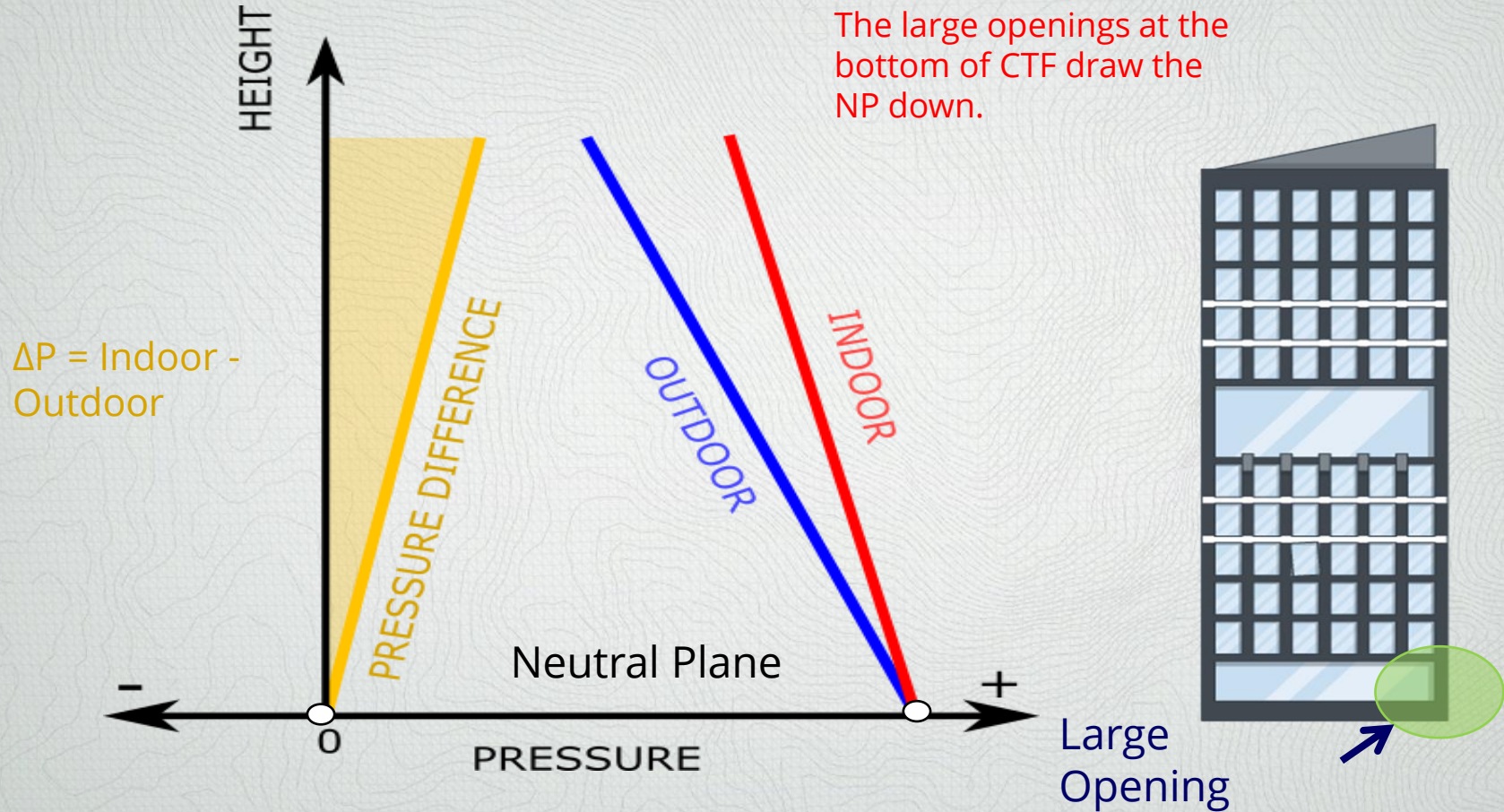


Typical Pressures at the Top Level

200 Pa



Winter: Large Opening @ Bottom



Conclusions

Conclusions

Stack effect can exist in all buildings

The driving force (strength of stack effect) depends on

Building height

Temperature difference

We can't totally get rid of the driving force but we can reduce negative impacts through design



Thank you for your time
and attention.

Duncan Phillips, Ph.D., P.Eng
Building Performance Group
Duncan.Phillips@rwdi.com

