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ISO 9972 AND CONSTRAINTS ON ZERO-FLOW PRESSURE DIFFERENCE

A comprehensive study on the influence of stack effects

AIVC Webinar – Airtightness tests for high-rise buildings – 26.01.2024

Benedikt Kölsch

ISO 9972: FAN PRESURIZATION METHOD

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN ISO 9972

September 2015

ICS: 91.120.10

Supersedes EN 13829:2000

English Version

Thermal performance of buildings —
Determination of air permeability of buildings —
Fan presurization method
(ISO 9972:2015)

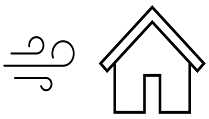
Performance thermique des bâtiments —
Détermination de la perméabilité à l'air des bâtiments —
Méthode de pressurisation par ventilateur
(ISO 9972:2015)

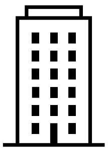
Wärmetechnisches Verhalten von Gebäuden —
Bestimmung der Luftdurchlässigkeit von Gebäuden —
Differenzdruckverfahren
(ISO 9972:2015)

ISO CONSTRAINTS

Zero-Flow Pressure Differences

- Δp_0 = Pressure difference between inside and outside when a building is not artificially pressurized
- ISO 9972 defines constraints to limit the influence of wind + temperatures
- Constraints for valid measurements:
  1. **$|\Delta p_0| < 5$ Pa**
  2. **Lowest Δp_{st} = 10 Pa** or **5 x $|\Delta p_0|$**





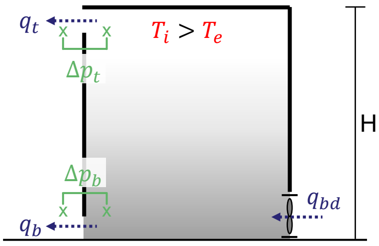
ISO CONSTRAINTS EXCLUDE MANY BUILDINGS FROM BEING TESTED!

Understanding airflow errors and effectiveness of ISO constraints:

- What is the **error of the measured airflow** induced by Δp_0?
- Which **parameters influence Δp_0** in detail?
- Does **pressure tap position** have an influence on Δp_0 ?
- Are there **alternative constraints** that could be applied when the ones in ISO 9972 are impossible to reach (e.g., for high-rise buildings)?

?

STACK EFFECT MODEL



Stack

UNDERSTANDING ZERO-FLOW PRESSURE

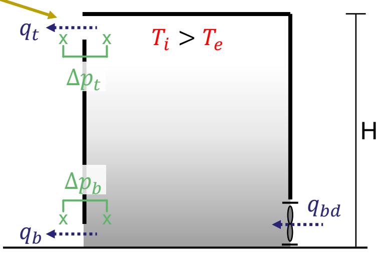
Stack measurement position of Δp_0

$$\Delta p_{0,s} = -\frac{p_s}{1 + 1/z_s^{1/n}}$$

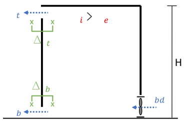
$$p_s \approx \frac{\rho_0}{T_0} g \, \Delta T \, H$$

$$z_s = \frac{C_t}{C_b}$$

- Always **negative**
- Depends on:
  - Temperature difference
  - Building height
  - Pressure exponent
  - Leakage distribution



ISO 9972 AIRFLOW ERROR



Calculation procedure and assumptions in ISO 9972:

Correction of the measured pressure station with Δp_0:

$$q_{est} = C_{est}(\Delta p_{st} - \Delta p_0)^n$$

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Contrary to the assumption in ISO 9972:

$$C_{est}(\Delta p_{st} - \Delta p_0)^n = C_b\, \Delta p_b^n + C_t(\Delta p_b - p_s)$$

$$C_{est} \neq C_{real} = C_b + C_t$$

Airflow error:

$$\frac{\delta q}{q} = \frac{C_{est} - C_{real}}{C_{real}} = \frac{C_{est}(\Delta p_{st} - \Delta p_0)^n}{C_{real}(\Delta p_{st} - \Delta p_0)^n} - 1 = \frac{C_b\, \Delta p_b^n + C_t(\Delta p_b - p_s)}{C_{real}(\Delta p_{st} - \Delta p_0)^n} - 1$$

UNDERSTANDING ZERO-FLOW PRESSURE

Stack measurement position of Δp_0

$$\Delta p_{0,s} = -\frac{p_s}{1 + 1/z_s^{1/n}}$$

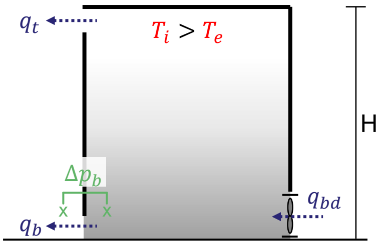
$$p_s \approx \frac{\rho_0}{T_0} g\, \Delta T\, H$$

$$z_s = \frac{C_t}{C_b}$$

Airflow error:

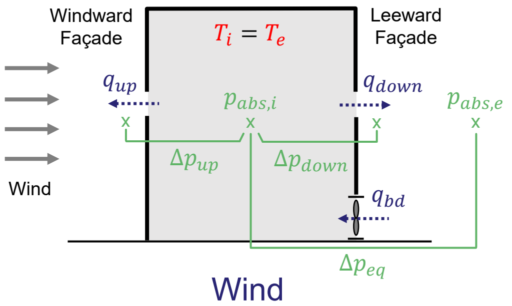
$$\frac{\delta q}{q}_s = \frac{C_b\, \Delta p_b^n + C_t(\Delta p_b - p_s)}{C_{real}(\Delta p_{st} - \Delta p_0)^n} - 1$$

$$x_s = \frac{p_s}{\Delta p_{st}}$$



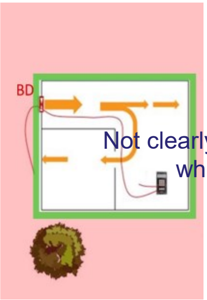
$$\frac{\delta q}{q}_s = \frac{1 + z_s(1 + x_s)^n}{(1 + z_s)\left(1 + \frac{x_s}{1 + 1/z_s^{1/n}}\right)^n} - 1 \qquad (\Delta p_b = \Delta p_{st})$$

WIND MODEL – PRESSURE TAP POSITIONS



Wind

Next to the building



Pressure difference across envelope

or

Not clearly defined in ISO 9972 which one to use!

Further away from the building

Equilibrium internal pressure

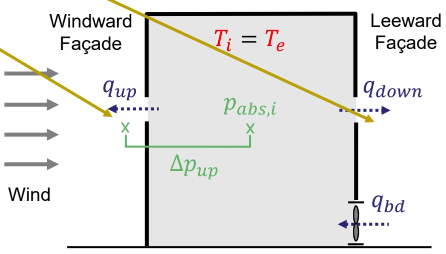
UNDERSTANDING ZERO-FLOW PRESSURE

Upwind measurement position of Δp_0

$$\Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}} \qquad z_w = \frac{C_{down}}{C_{up}}$$

- Always **negative**
- Depends on:
  - Upwind pressure
  - Downwind pressure
  - Pressure exponent
  - Leakage distribution

$$q = C\,\Delta p^n$$



$$p_{up} = C_{p,up}\frac{\rho_0}{2}u^2 \qquad p_{down} = C_{p,down}\frac{\rho_0}{2}u^2$$

UNDERSTANDING ZERO-FLOW PRESSURE

Upwind measurement position of Δp_0

$$\Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}}$$

$$z_w = \frac{C_{down}}{C_{up}}$$

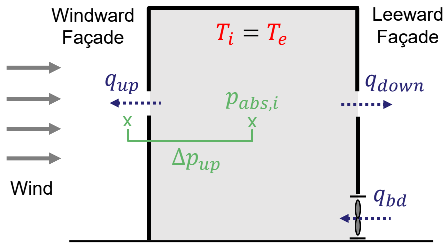
$$x_w = \frac{p_{up} - p_{down}}{\Delta p_{st}}$$

Airflow error:

$$\left.\frac{\delta q}{q}\right|_{w,up} = \frac{C_{est,w,up} - C_{real,w}}{C_{real,w}}$$

$$= \frac{1 + z_w(1 + x_w)^n}{(1 + z_w)\left(1 + \frac{x_w}{1 + 1/z_w^{1/n}}\right)^n} - 1$$

$$q = C\,\Delta p^n$$



$$p_{up} = C_{p,up}\frac{\rho_0}{2}u^2 \qquad p_{down} = C_{p,down}\frac{\rho_0}{2}u^2$$

UNDERSTANDING ZERO-FLOW PRESSURE

Downwind measurement position of Δp_0

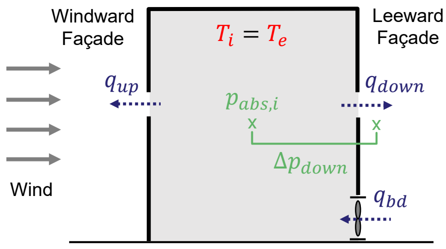
$$\Delta p_{0,down} = \frac{p_{up} - p_{down}}{1 + z_w^{1/n}} \qquad \Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}}$$

- Always **positive**

Airflow error:

$$\left.\frac{\delta q}{q}\right|_{w,down} = \frac{z_w + (1 - x_w)^n}{(1 + z_w)\left(1 - \frac{x_w}{1 + z_w^{1/n}}\right)^n} - 1$$

$$q = C\,\Delta p^n$$

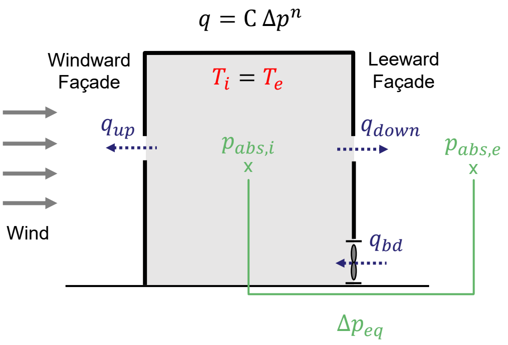


UNDERSTANDING ZERO-FLOW PRESSURE

Equilibrium measurement position of Δp_0

$$\Delta p_{0,w,eq} = \frac{p_{up} + z_w^{1/n} p_{down}}{1 + z_w^{1/n}} \qquad z_w = \frac{C_{down}}{C_{up}}$$

- Can be **positive** or **negative** depending on the **leakage distribution!**



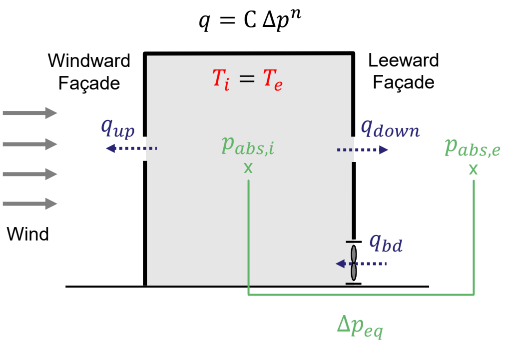
UNDERSTANDING ZERO-FLOW PRESSURE

Equilibrium measurement position of Δp_0

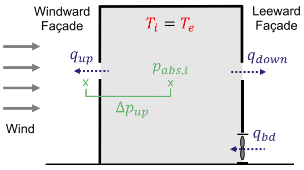
$$\Delta p_{0,w,eq} = \frac{p_{up} + z_w^{1/n} p_{down}}{1 + z_w^{1/n}}$$

Airflow error:

$$\frac{\delta q}{q}_{w,eq} = \frac{\left(1 - x_{w,up}\right)^n + z_w\left(1 - x_{w,down}\right)^n}{\left(1 + z_w\right)\left(1 - \frac{x_{w,up} + z_w^{1/n} x_{w,down}}{1 + z_w^{1/n}}\right)^n} - 1$$



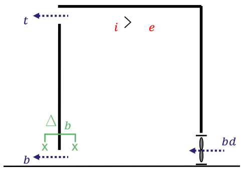
UNDERSTANDING ZERO-FLOW PRESSURE



Wind

$$\frac{\delta q}{q} = \frac{1 + z(1+x)^n}{(1+z)\left(1 + \frac{x}{1+1/z^{1/n}}\right)^n} - 1$$

$$\Delta p_{zf} = -\frac{p_{force}}{1+1/z^{1/n}}$$



Stack

$$p_{force,w,up} = p_{up} - p_{down}$$

$$x_w = \frac{p_{force,w}}{\Delta p_{st}}$$

$$z_w = \frac{C_{down}}{C_{up}}$$

$$p_{force,s} = p_s \approx \frac{\rho_0}{T_0} g\, \Delta T\, H$$

$$x_s = \frac{p_{force,s}}{\Delta p_{st}}$$

$$z_s = \frac{C_t}{C_b}$$

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SIMULATION OF VARIOUS BUILDING SCENARIOS

Range of parameters

Input variable	Min. value	Max. value	Distribution characteristics
n	0.5	0.9	Linear distribution in steps of 0.1
$\Delta p_{st,pres/depres}$	± 10 Pa	± 100 Pa	Linear distribution in steps of 10 Pa
u	0 m/s	10 m/s	Linear distribution in steps of 0.1 m/s
z	$1/99$	99	Logarithmic distribution with 100 values
ΔT	1 K	20 K	Linear distribution in steps of 1 K (always $T_i > T_e$)
H	4 m	100 m	Linear distribution in steps of 1 m
$C_{p,down}$	–	–	$[-0.3, -0.5, -0.7]$
$C_{p,up}$	–	–	$[0.05, 0.25, 0.5]$

3 million wind and 7 million stack pressure scenarios!

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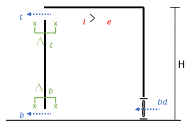
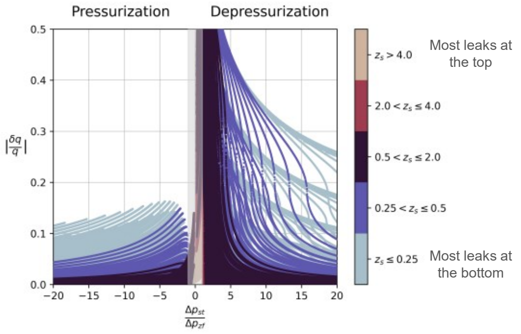
KEY FINDINGS

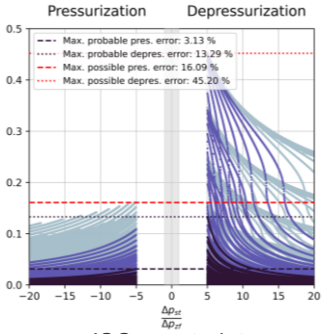
$$z_w = \frac{C_t}{C_b}$$



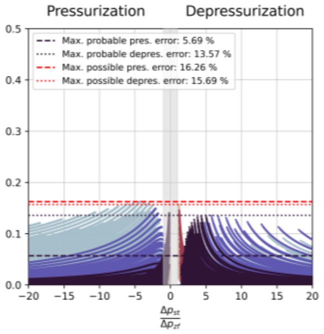
Stack measurement position of Δp_0



Full dataset



ISO constraints



Alternative

→ Fully pres/depres building with a margin of 10 Pa!

$|\Delta p_0| < 5$ Pa

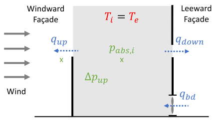
$|\Delta p_{st,low}| > 5 \times |\Delta p_0|$

Cerema CLIMAT & TERRITOIRES DE DEMAIN

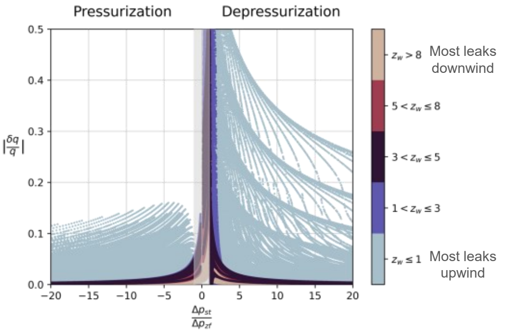
ISO 9972 & Zero-flow pressure

KEY FINDINGS

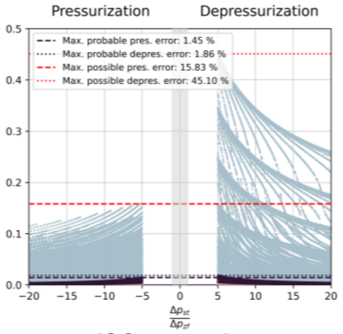
$$z_w = \frac{C_{down}}{C_{up}}$$



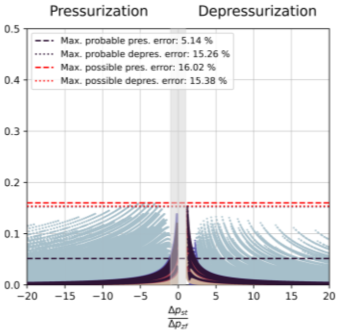
Upwind measurement position of Δp_0



Full dataset



ISO constraints



Alternative

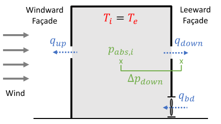
→ Fully pres/depres building with a margin of 10 Pa!

Cerema CLIMAT & TERRITOIRES DE DEMAIN

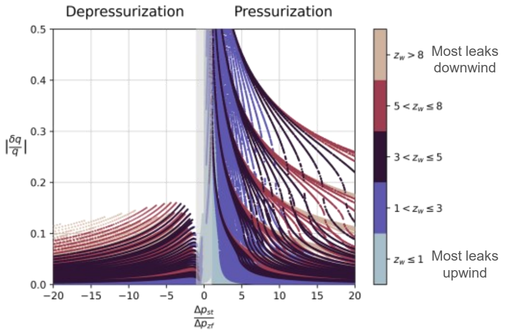
ISO 9972 & Zero-flow pressure

KEY FINDINGS

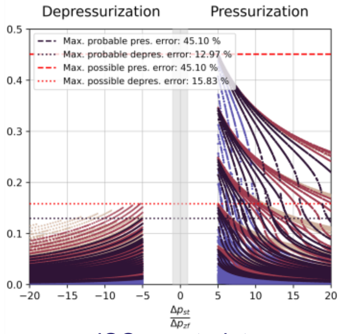
$$z_w = \frac{C_{down}}{C_{up}}$$



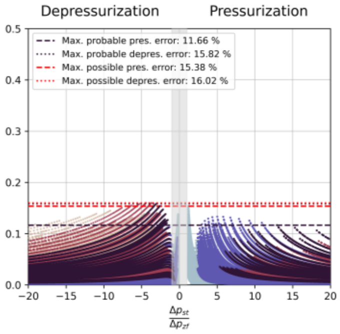
Downwind measurement position of Δp_0



Full dataset



ISO constraints



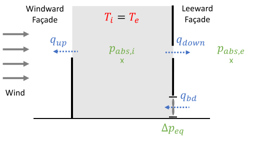
Alternative

→ Fully pres/depres building with a margin of 10 Pa!

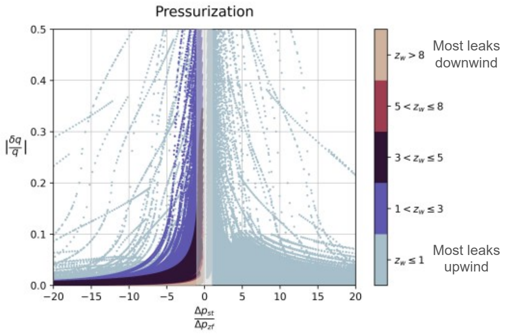
RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

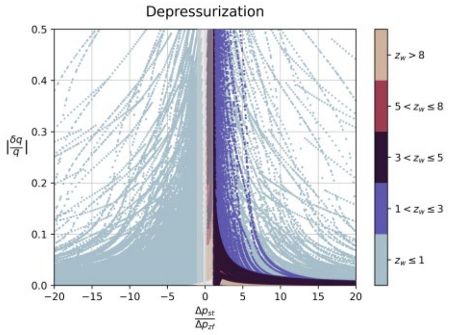
KEY FINDINGS

$$z_w = \frac{C_{down}}{C_{up}}$$



Equilibrium measurement position of Δp_0





RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

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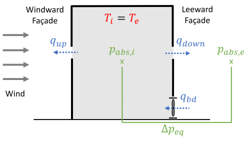
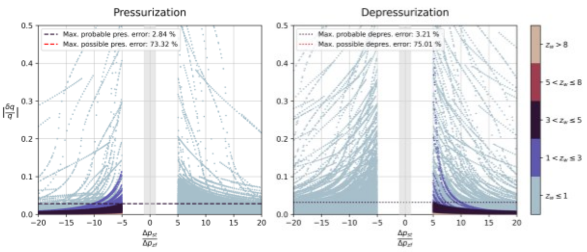
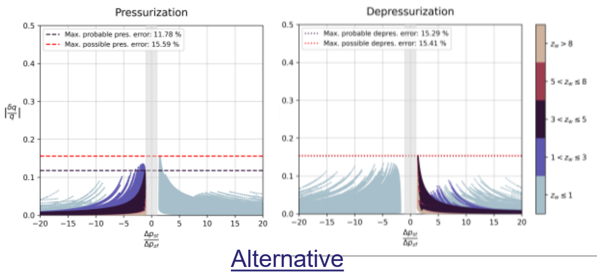


Equilibrium measurement position of Δp_0



ISO constraints



Alternative

→ Fully pres/depres building with a margin of 10 Pa!

SUMMARY AND CONCLUSION

- ISO 9972 constraints reduce significant flow errors
- High-rise buildings or buildings in windy locations are often impossible to test

SUMMARY AND CONCLUSION

Alternative: Pressurizing or depressurizing the entire building with a margin of 10 Pa would → same range of error!

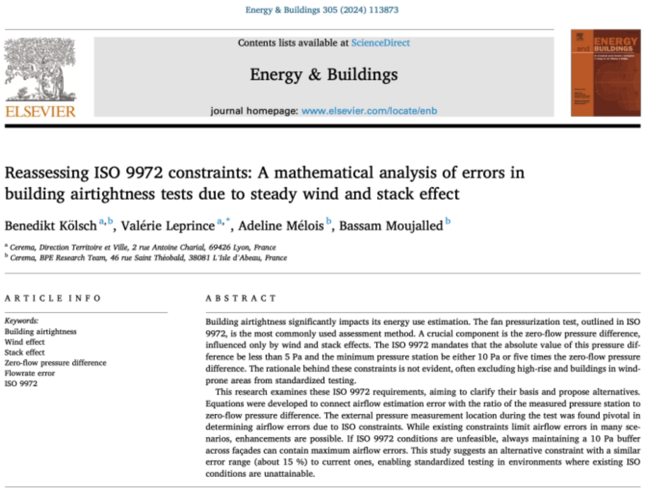
Max. probable error:

	Pressurization				Depressurization			
	Downwind	Upwind	Equilibirum	Stack	Downwind	Upwind	Equilibirum	Stack
ISO constraint	45%	1%	3%	3%	13%	2%	3%	13%
New constraint	12%	5%	12%	6%	16%	15%	15%	14%

Max. possible error:

	Pressurization				Depressurization			
	Downwind	Upwind	Equilibirum	Stack	Downwind	Upwind	Equilibirum	Stack
ISO constraint	45%	16%	73%	16%	16%	45%	75%	45%
New constraint	15%	16%	16%	16%	16%	15%	15%	16%

PUBLICATION



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Reassessing ISO 9972 constraints: A mathematical analysis of errors in building airtightness tests due to steady wind and stack effect

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ABSTRACT

Building airtightness significantly impacts its energy use estimation. The fan pressurization test, outlined in ISO 9972, is the most commonly used assessment method. A crucial component is the zero-flow pressure difference, influenced only by wind and stack effects. The ISO 9972 mandates that the absolute value of this pressure difference be less than 5 Pa and the minimum pressure station be either 10 Pa or five times the zero-flow pressure difference. The rationale behind these constraints is not evident, often excluding high-rise and buildings in wind-prone areas from standardized testing.

This research examines these ISO 9972 requirements, aiming to clarify their basis and propose alternatives. Equations were developed to connect airflow estimation error with the ratio of the measured pressure station to zero-flow pressure difference. The external pressure measurement location during the test was found pivotal in determining airflow errors due to ISO constraints. While existing constraints limit airflow errors in many scenarios, enhancements are possible. If ISO 9972 conditions are unfeasible, always maintaining a 10 Pa buffer across façades can contain maximum airflow errors. This study suggests an alternative constraint with a similar error range (about 15 %) to current ones, enabling standardized testing in environments where existing ISO conditions are unattainable.

QUESTIONS?

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