Feedback from the 43rd AIVC-11th TightVent & 9th venticool Conference: Summary of the airtightness track

On 4-5 October 2023, the AIVC – TightVent - venticool 2023 joint Conference "Ventilation, IEQ, and Health in Sustainable Buildings", was organized by the International Network on Ventilation and Energy Performance (INIVE) on behalf of the Air Infiltration and Ventilation Centre (AIVC), the Building and Ductwork Airtightness Platform (TightVent Europe), the international platform for ventilative cooling (venticool), and Aalborg University. It was a successful event, which drew over 200 participants - researchers, engineers & architects, policy makers or regulatory bodies, manufacturers & stakeholders and international organizations from 33 countries.

The conference programme featured three parallel tracks of structured sessions, with around 150 presentations that exploring the main conference themes: Smart Ventilation, Indoor Air Quality (IAQ) and Health, Building & Ductwork Airtightness, and Ventilative Cooling – Resilient Cooling. A special session known as: “90 seconds industry presentations” was specifically organized for the event's sponsors.

Furthermore, the conference served as a major discussion place for ongoing projects, such as the IEA EBC annex 78 "Supplementing Ventilation with Gas-phase Air Cleaning, Implementation, and Energy Implications", the IEA EBC Annex 80 "Resilient Cooling of Buildings", the IEA EBC Annex 86 "Energy Efficient IAQ Management in Residential Buildings" and the IEA EBC Annex 87 "Energy and Indoor Environmental Quality Performance of Personalized Environmental Control Systems."

In this article, we present the key trends, ideas, considerations, and conclusions that emerged during the two days of the conference, with a primary focus on the topic of building and ductwork airtightness. The "Airtightness" track at the AIVC 2023 conference featured a total of 15 presentations. For the purpose of this article, we have grouped the presentations into two main themes and five subthemes.

Airtightness, still a growing concern around the world

On the importance of airtightness

De Sola stressed the need to bridge the gap between mechanical and enclosure commissioning (de Sola & Fanning, 2023). Better incorporating building enclosure performance in mechanical design, could significantly reduce the global demand on energy.

Flamant et al. investigated the impact of the building airtightness and natural driving forces on the operation of a mechanical exhaust ventilation system in social housing in Chile (Flamant, Bustamante, Janssens, & Laverge, 2023). They highlighted the significant effect of the building airtightness and the natural driving forces, mainly the wind effect, on the performance of extract only ventilation system and emphasized the need for improving the level of airtightness for a better operation of the ventilation system to guarantee sufficient indoor air quality to the occupants.

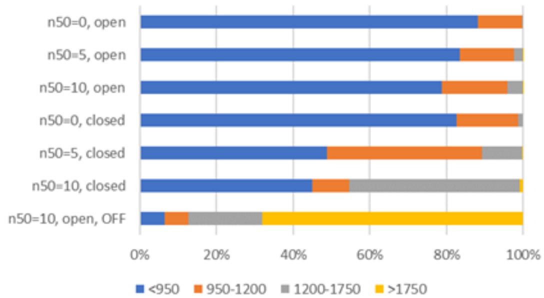

Figure 1: Percentage of time spent in four CO2 concentration (ppm) classes for the father (Flamant, Bustamante, Janssens, & Laverge, 2023)

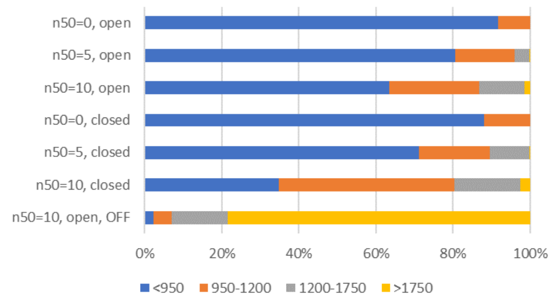

Figure 2: Percentage of time spent in four CO2 concentration (ppm) classes for the child (Flamant, Bustamante, Janssens, & Laverge, 2023)

Hurel et al. developed a simple calculation tool for building designers to estimate the financial impact of leaky ductwork in houses over their whole life (Hurel, Leprince, & Lightfoot, 2023). They evaluated the impact of ductwork airtightness on fan energy use, in an effort to help raise awareness and encourage the design and installation of airtight ventilation ductwork systems. The authors found significant financial benefits of installing airtight ventilation ductwork systems in all buildings.

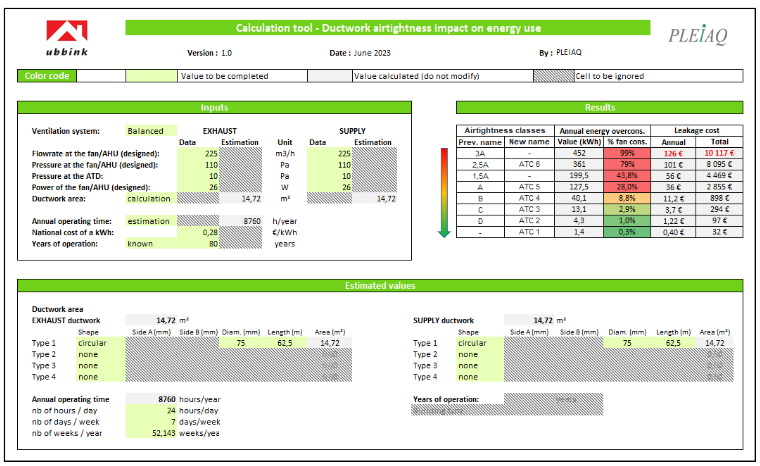

Figure 3: Calculation tool (Hurel, Leprince, & Lightfoot, 2023)

Updates on regulations on airtightness

During the topical session on: "Building and ductwork airtightness regulations in various countries" Nolwenn Hurel (PLEIAQ, France) presented the series of newly released AIVC Ventilation Information Papers on building and ductwork airtightness regulations. Following this introduction there were 5 presentations representing 5 European countries (Norway, Netherlands, Spain, Latvia & Montenegro) with the following key requirements in relation to building airtightness:

- In Norway (Aurlien, 2023):
  - All new buildings shall be tested
    - Probably much less than 100% is tested in practice
  - $n_{50} \leq 0.6$ /h for all dwellings
- In Netherlands (Bink, Dam, & Lightfoot, 2023):
  - Building Decree demands is based on building volume:
    - < 500 m^3: q_{v10} = 0.2m^3/s (200 l/s) as q_{v10} value
    - > 500 m^3: q_{v10} kar = qv10 (500/Vb)

        - q_{v10} should be measured according to NEN 2686 standard (similar to EN ISO 9972)
- In Spain (Hoek, Poza-Casado, & Melgosa, 2023) :
    - There is a window permeability regulation since 1975 (RD 1490/1975)
    - For the envelope, there is a requirement only for dwellings >120m^2
        - n_{50}<6 (for V/A<=2) and n_{50}<3 for V/A>=4
    - There are 2 options for justification: measurement or calculations
- In Latvia (Nitijevskis, Keviss, & Hurel, 2023)
    - Mandatory airtightness requirements (in q_{50}) for all new buildings
    - No mandatory testing
- In Montenegro (Tombarević, Vušanović, & Krivokapić, 2023)
    - Airtightness requirement:
        - without mechanical ventilation ACH50=3 h^{-1}
        - with mechanical ventilation ACH50=1.5 h^{-1}
    - No mandatory testing

How to evaluate airtightness?

Blowerdoor test according to ISO 9972

During the topical session "Revision of ISO 9972: Improvements in the reliability of airtightness measurements", Valérie Leprince (Cerema, France) made an introduction on ISO 9972:2015 "Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method" which describes the measurement procedure and calculation methods for determining airtightness. According to the presenter, to obtain comparable and credible results, the standard needs to be reliable and valid for different kinds of buildings; reproducible under challenging environmental conditions; applicable in any conditions; and consistent with other standards. Recent scientific studies and increased experience in field testing have shown that part of the standard could be improved. The standard is now under revision since September 28th, 2023, when ISO TC163/ SC1 Committee agreed to launch its revision.

Prignon investigated the integration of two new aspects in the fan pressurization measurement procedure: an uncertainty source related to the inhomogeneity of pressure difference along building envelope, and the autocorrelation of successive pressure difference measurement due to wind fluctuations (Prignon, 2023). Results showed the relatively low impact of those additions to the determination of building characteristics (n, $Cenv$ and q50) and their large impact on both results variability and uncertainty assessment. This work highlighted the fact that uncertainties are still not well quantified for fan pressurization test but bring the scientific community one step further in the uncertainty analysis for fan pressurization measurements.

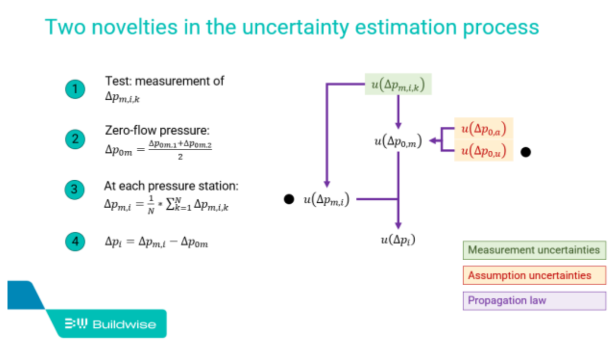

Figure 4: Two novelties in the uncertainty estimation process (Prignon, 2023)

Cerema started a project and set up a working group of international experts to improve and revise the ISO 9972 standard. A presentation by Benedikt Kölsch presented the suggested improvements to the standard to improve its reliability and validity for airtightness tests in buildings (Kölsch, Leprince, & Mélois, 2023). The proposed recommendations address key areas including the definition and symbolism of terms, measurements of air temperature and wind speed, regression analysis, and airflow corrections. Significant alterations include a weighted line of organic correlation (WLOC) to improve the predictability of airflows. Their findings also shed light on the significance of the zero-flow pressure difference and the requirements of measurement equipment. Additionally, the presentation proposed alternative constraints (from those of ISO 9972) to perform test in high-rise buildings.

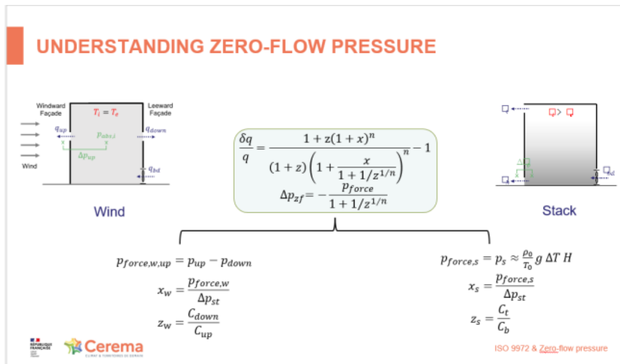

Figure 5: Understanding Zero-Flow Pressure (Kölsch, Leprince, & Mélois, 2023)

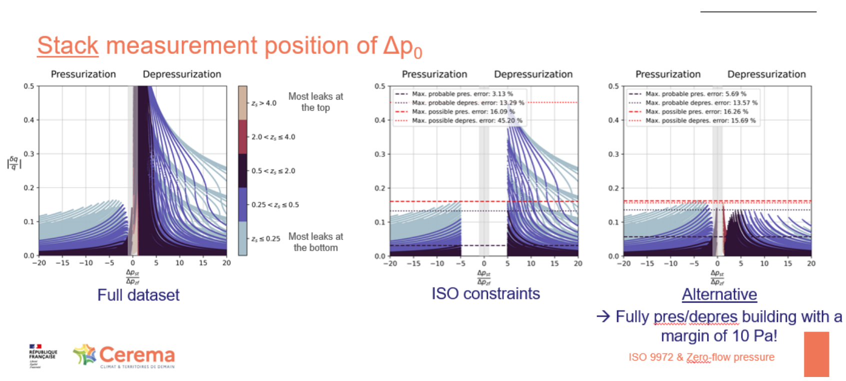

Figure 6: Stack measurement position of Δp₀ (pressure difference between inside and outside when a building is not artificially pressurized) (Kölsch, Leprince, & Mélois, 2023)

Moujalled et al. compared air permeability indicators in five European countries (France, Germany, Belgium, UK, Netherlands) and calculated the correlations between five indicators (specific air leakage rates q_{E4} / q_{E10} / q_{E50} and air change rates n_{10} / n_{50}) according to the building type and compactness (Moujalled, Kölsch, Mélois, & Leprince, 2023). According to their findings, the most common air permeability indicators include the specific air leakage rate per envelope area and the air change rate; reference pressure differences are 50 Pa in the majority of countries with lower values in some countries (e.g., 4 Pa in France, 10 Pa in Netherlands). Furthermore, their results showed strong linear correlations between the different indicators with correlation coefficients between 0.80 and 0.99; correlations between specific leakage rate and air change rate depend on the building type and geometry.

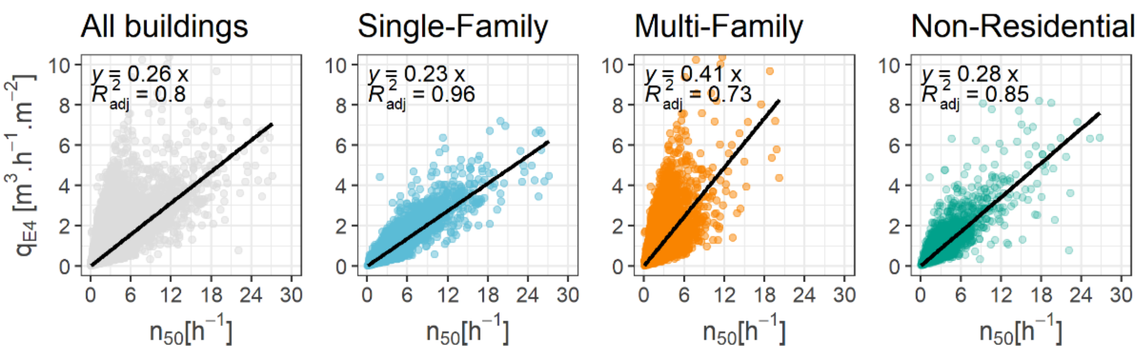

Figure 7: Correlations between air permeability indicators (Moujalled, Kölsch, Mélois, & Leprince, 2023)

Correlation	Building type	Correlation depending on building type and building compactness			Correlation depending on building type		General correlation	
		Compact.	Reg. coef.	Conf. Int. 95%	Reg. coef.	Conf. Int. 95%	Reg. coef.	Conf. Int. 95%
q_{E4} = Coef * n_{50}	Single-Family houses	(0.07,0.78]	0.264 (r^2=0.965)	[0.264,0.265]	0.228 (r^2=0.964)	[0.228,0.228]	0.26 (r^2=0.801)	[0.26,0.261]
		(0.78,0.83]	0.23 (r^2=0.983)	[0.23,0.231]				
		(0.83,0.88]	0.219 (r^2=0.984)	[0.218,0.219]				
		(0.88,2]	0.2 (r^2=0.977)	[0.2,0.2]				
	Multi-Family apartments	(0.02,0.29]	0.91 (r^2=0.929)	[0.906,0.914]	0.409 (r^2=0.728)	[0.407,0.41]		
		(0.29,0.46]	0.517 (r^2=0.958)	[0.516,0.519]				
		(0.46,0.70]	0.33 (r^2=0.966)	[0.329,0.331]				
		(0.70,1.94]	0.237 (r^2=0.964)	[0.236,0.238]				
	Non-Residential buildings	(0.08,0.64]	0.418 (r^2=0.9)	[0.412,0.423]	0.284 (r^2=0.851)	[0.282,0.287]		
		(0.64,0.78]	0.276 (r^2=0.971)	[0.274,0.278]				
		(0.78,0.85]	0.233 (r^2=0.973)	[0.231,0.234]				
		(0.85,6.52]	0.192 (r^2=0.936)	[0.19,0.194]				

Figure 8: Correlations between q_{E4} and n_{50} depending on building type and building compactness (Moujalled, Kölsch, Mélois, & Leprince, 2023)

Choi & Jo analysed airtightness measurement data in multi-unit residential buildings to look into the correlation between ACH50 and air permeability according to the building characteristics (Choi & Jo, 2023). 274 units were measured and classified into small, medium, and large types according to floor area and found the average Surface-area-to-Volume ratio (S/V) ratio for small equal to 1.11, for medium 1.05, and for large 1.02, with ratios closer to 1 as the floor area increases. They concluded that it is more reasonable to evaluate the airtightness by air permeability (q_{E50}), which has a smoother change in airtightness value and can consider the effect of leakage rate through the envelope.

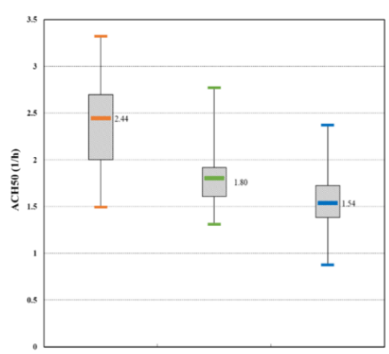

Figure 9: ACH50 by floor area (Choi & Jo, 2023)

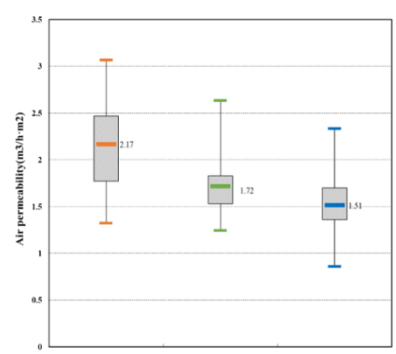

Figure 10: Air permeability by floor area (Choi & Jo, 2023)

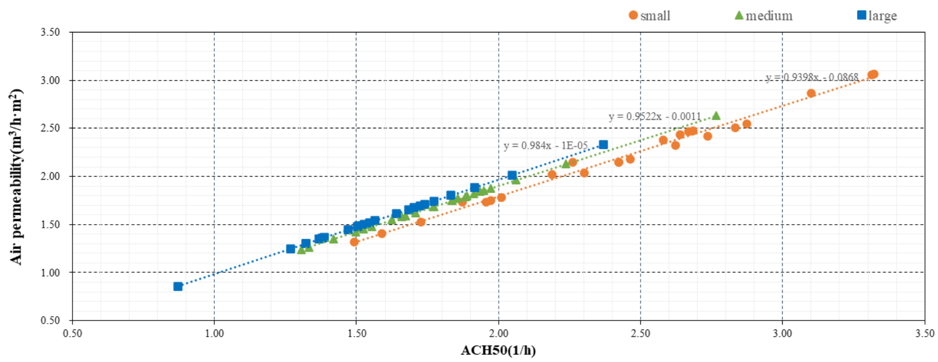

Figure 11: Correlation of ACH50 and air permeability (Choi & Jo, 2023)

Alternative methods

Are they reliable and implementable on site?

As an alternative to the conventional steady fan pressurisation method to measure building airtightness, the pulse technique releases compressed air from an air tank into the building over a short period of time and simultaneously measures the building and tank pressure responses to achieve the same purpose but at low pressures (Zheng, Smith, & Wood, 2023). Zheng et al. used this novel Pulse technique to measure the airtightness of 11 Passivhaus standard properties to understand its feasibility in measuring highly airtight buildings (alongside the steady method). Based on the results, the average difference between the two methods at 4Pa was 0.0003 $m^3/h/m^2$ @4Pa (11%) and 0.12 $m^3/h/m^2$ @50Pa (18%) at 50Pa when using the Power Law as a means of extrapolation. Even though it can be challenging to achieve a like-for-like comparison between the two methods due to the different way of testing, Pulse can measure very airtight dwellings just as reliably as the steady fan technique.

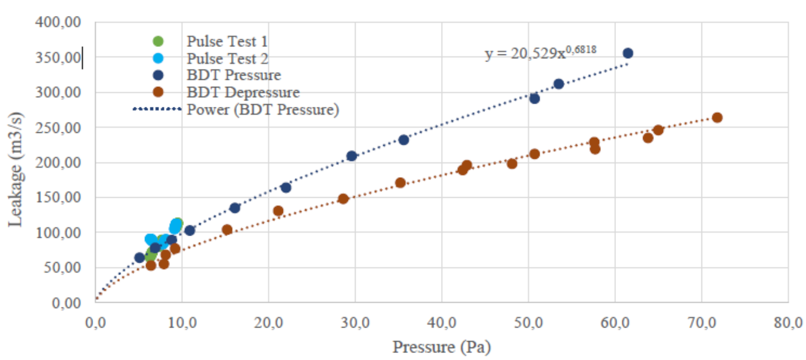

Figure 12: Property 004 blower door fan test power law extrapolation, with poor agreement between the pressurisation and depressurisation curves (Zheng, Smith, & Wood, 2023)

Schiricke & Kölsch developed their study on another alternative for measuring air leakage detection; an acoustic beamforming method based on a microphone array technology assuming that sound primarily follows the same paths as air through the building envelope (Schiricke & Kölsch, 2023). They presented the results of large-scale testing and demonstration of acoustic air tightness measurements. More specifically, facades of 37 rooms of multi-storey buildings with unknown leakages were measured at three office buildings of different ages and heterogeneous building envelope structures. This field study provided valuable experience into the practicality, speed, and interpretability of acoustic signals, along with the method's large-scale applicability and potential for further developments. Their findings suggested, that a significant number of potential leakages can be detected, confirming the method's basic functionality for large buildings. Furthermore, a comparison of the distribution of the Acoustic Assessment Score (ASS) and the Multi Frequency Assessment Score (MFAS) within the different buildings suggested, that the applied acoustic method managed to discern the airtightness quality of the three buildings.

Colour Code	Acoustic Assessment Score	Evaluation of acoustic signals	Description of subjective criteria
	0	very unlikely leakage	Peak of signal is at implausible location (e.g. on a window pane or facade panel, or outside the area under consideration)
	1	unlikely leakage	Some indications that the signal is probably not caused by a leakage (e.g. wide spread shape of the sound source) or Peak of signal is at rather implausible location (e.g. close to a plausible location but just off the mark)
	2	likely leakage	Peak of signal is at plausible location (e.g. joints between different materials or roof and wall), or even at particular plausible location, but with a much weaker signal.
	3	very likely leakage	Peak of signal is at a particular plausible location (e.g. seals in door and window frames)

Figure 13: Description of the colour code for the evaluation of acoustic signals and their criteria (Schiricke & Kölsch, 2023)

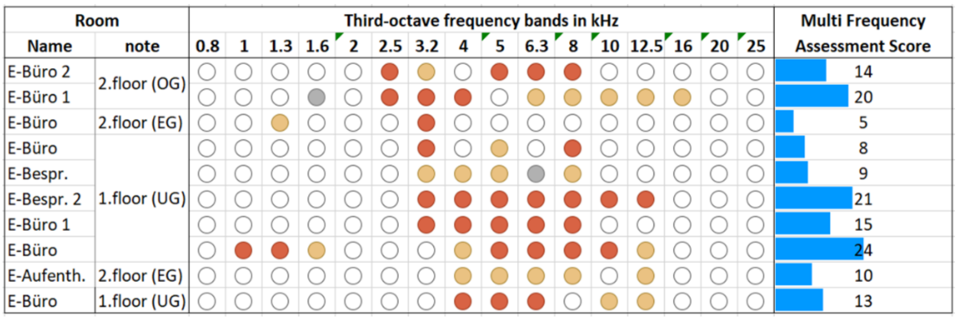

Figure 14: Evaluation of acoustic signals for each measured room in Building E (Schiricke & Kölsch, 2023)

Predictive methods

Is it really possible to predict airtightness?

Poza-Casado et al. introduced a predictive model for airtightness, offering an alternative procedure for airtightness estimation (Poza-Casado, Rodríguez-del-Tío, Fernández-Temprano, Padilla-Marcos, & Meiss, 2023). The model was developed from an airtightness database which included a representative sample of the residential building stock in Spain (400 dwellings). A General Linear Model (GLM) was considered to assess significant variables related to the climate zone, the age of the building, typology, building state, construction system, and dimensions. With an R^2 value of 0.429, the model can explain 42.9% of the variability of the response, containing 12 main effects and 2 interactions. Despite identified limitations, the model is robust, and it provides valuable knowledge regarding the airtightness of dwellings and the factors that impact its performance the most. Therefore, it is intended as a useful tool - for decision-making process before building construction or retrofitting actions - although it cannot be seen in any way as a substitute of on-site testing.

Parameter	Coefficient	Parameter	Coefficient
Intercept	0.273	Shutter position. P04	0a
Retrofitting state. Original	0.137**	False ceiling. FC0	-0.313***
Retrofitting state. Retrofitted	0a	False ceiling. FC1	-0.264***
Climate zone. A3	0.346**	False ceiling. FC2	0a
Climate zone. B4	0.545***	Typology. Multifamily	0.412**
Climate zone. C1	0.273	Typology. Single-family	0a
Climate zone. C2	0.630***	Heating system. No heating	0.074
Climate zone. C3	0.053	Heating system. Underfloor heating	-0.041
Climate zone. D2	0.575***	Heating system. Ducts	0.261***
Climate zone. α3	0a	Heating system. Other systems	0.173
Period of construction. Before 1980	-0.329***	Heating system. Heating units	0a
Period of construction. Since 1980	0a	Number of bathrooms. 0	0.610**
Window permeability. Class 0 or 1	0.596***	Number of bathrooms. 1	0.347***
Window permeability. Class 2	0.322***	Number of bathrooms. 2	0.183
Window permeability. Class 3	0.255***	Number of bathrooms. 3	0.090
Window permeability. Class 4	0a	Number of bathrooms. 4 or 5	0a
Window material. Steel	0.071	Share of windows	0.045***
Window material. Aluminium	0.074	Share of opaque envelope	0.003
Window material. Wood	0.298***	Period of construction. Before 1980 * Share of opaque envelope	0.010***
Window material. PVC	0a	Period of construction. After 1980 * Share of opaque envelope	0a
Shutter position. P01	0.195*	Typology. Multifamily * Share of opaque envelope	-0.009**
Shutter position. P02	0.144**	Typology. Single-family * Share of opaque envelope	0a
Shutter position. P03	-0.123		

a. This parameter is set to 0 as it corresponds to the reference class of the variable.
* stands for p-value ≤ 0.1, ** for p-value ≤ 0.05 and *** for p-value ≤ 0.01

Figure 15: Equation of the final GLM predictive model for airtightness (Poza-Casado, Rodríguez-del-Tío, Fernández-Temprano, Padilla-Marcos, & Meiss, 2023)

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