Proposal for new implementations in ISO 9972

Benedikt Kölsch*[1,2], Valérie Leprince[1], and Adeline Mélois[2,3]

1 Cerema,
Direction Territoire et Ville
2 rue Antoine Charial
69426 Lyon, France
**Corresponding author: benedikt.koelsch@cerema.fr*

2 Cerema,
BPE Research Team
46 rue Saint Théobald
38081 L'Isle d'Abeau, France

3 LOCIE
Université Savoie Mont Blanc
CNRS UMR 5271
73376 Le Bourget-du-Lac, France

ABSTRACT

This article provides a summary of a comprehensive examination of the current ISO 9972 standard, focusing on the enhancements needed to improve its reliability and validity for airtightness tests in buildings. A working group composed of international experts has identified a list of issues warranting a potential revision of the standard. New recommendations are proposed based on research and consultation, including detailed considerations of previous guidelines and existing scientific literature. Key areas addressed include 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. The article also sheds light on the significance of the zero-flow pressure difference and the requirements of measurement equipment.

These improvements aim to ensure that the ISO 9972 standard is adequately adapted to the evolving demands of building airtightness testing, in line with the increasing legal and financial implications of this field.

KEYWORDS

Building airtightness, ISO 9972, Fan pressurization method, Measurement uncertainty

1 INTRODUCTION

The global concern for the conservation of finite energy resources has significantly increased over the past few decades, and notably more so in recent months. Prominently, the building sector is tasked with confronting significant challenges, given that it accounts for a large fraction of the world's energy consumption and carbon dioxide emissions. Beyond thermal transmission, unintended airflows through the building envelope contribute to about 20 – 40% of a building's heating and cooling energy (Leprince et al., 2011), potentially increasing mold formation, decreasing thermal comfort due to drafts and cold surfaces, and possibly interfering with the operational efficiency of existing ventilation systems.

Consequently, the demand for airtightness tests has risen in various European countries, becoming an indispensable element of energy performance regulations, particularly in new buildings. This applies to several countries, including Denmark, France, Germany, Ireland, and the UK (Leprince et al., 2017; Poza-Casado et al., 2020). These tests serve critical purposes such as measuring air leakage in buildings to comply with energy performance regulations, comparing the relative airtightness of various buildings, and quantifying the reduction in building air permeability following the execution of improvements.

The fan pressurization method, known as the Blower-Door test, is the most commonly employed technique for assessing the airtightness of buildings. The procedure for this measurement and the calculation methods for determining the air permeability of buildings using the fan pressurization method are defined in the ISO 9972 standard (*ISO 9972:2015*, 2015).

For outcomes to be comparable and trustworthy, the methods of measurement and calculation described in the standard must exhibit reliability, reproducibility, and consistency. The approach should ideally apply to all building types, and the results must retain their validity even under changing environmental conditions such as strong winds or solar radiation. In scenarios with unstable external conditions, a reliable estimate of the result's uncertainty becomes important. Recent developments and the growing number of tested buildings have underscored the need to improve the reliability of the method used for measuring a building's air leakage rate, as described in this standard (Hurel & Leprince, 2021).

This article aims to introduce a project and its methodology that intends to collect data and expertise from professionals in the field of airtightness to submit a proposed revision for ISO 9972 and proposals for potential new inclusions in the standard. It is important to clarify that the objective is not to officially revise the standard but to provide the best applicable knowledge for the official revision process in the ISO/TC 163/SC 1 technical committee (ISO committee for test and measurement methods). The project aims to propose a revised version of ISO 9972 while maintaining the existing process for testers. The ultimate goal of this project is to revise ISO 9972 so that it:

- allows the execution of the test under challenging conditions, including windy environments, extreme indoor-outdoor temperature differences, or high-rise buildings,
- enhances the reliability of the calculation process and provides a more accurate estimation of the uncertainty of measured and derived quantities,
- improves overall reliability and aligns more cohesively with other standards.

2 METHODOLOGY

The overall objective of this project is to offer a revised version of ISO 9972 to enhance the reliability of airtightness measurements in the building industry. To this end, Cerema has initiated and now leads a working group of about 30 international specialists from 13 countries, all experts in building airtightness testing. This diverse assembly of experts, with substantial research contributions and experience as testers, manufacturers, and distributors of measurement systems, is spread across the globe. Figure 1 visually represents the institutions and geographical locations associated with these working group members.

This project is structured into three principal stages:

1. Identification of the areas requiring revision in the current standard and formulation of research questions essential for addressing the existing problems.
2. Production of collaborative research with the working group members for issues to be clarified or added to the existing literature.
3. Integration of the research findings into the standard and proposition of a revised standard at the ISO level.

The initial stage of the project involved the construction of a comprehensive list of issues associated with the current version of ISO 9972, which:

- are inaccurate or irrelevant,
- induce challenges in the execution of the test,
- manifest inconsistencies with other standards,
- represent gaps in the standard (elements that need to be added for enhanced clarity or to encompass new aspects).

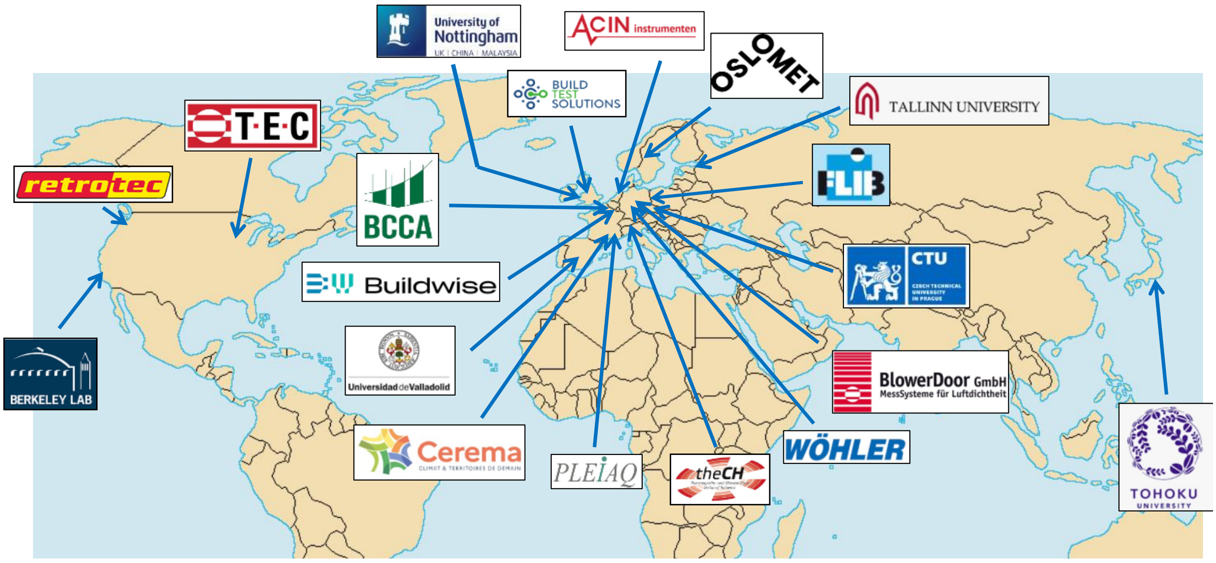

Figure 1: Affiliations of working group members, including universities, research institutions, and relevant companies

To create a comprehensive list of all relevant issues, an exhaustive survey was conducted among all working group members. Subsequently, the working group was divided into smaller sub-groups based on the members' areas of expertise and interests.

3 PROPOSED MODIFICATIONS TO ISO 9972

The working group has identified a comprehensive list of issues for a potential revision of the standard to enhance the method’s reliability and validity. A more detailed description of these issues and the reasons behind a necessary revision is provided in Kölsch et al. (Kölsch et al., 2023). This section introduces the initial considerations for proposed modifications.

3.1 Terms, definitions, and symbols

The current version of ISO 9972's terms and definitions are globally considered unsatisfactory in their formulation. We have revised this section to ensure consistency and alignment with established definitions present in ISO 80000-1 (*ISO 80000-1:2022*, 2022) and ISO 704 (*ISO 704:2009*, 2009). Moreover, we have incorporated definitions for the following missing key terms: air leakage, flow rate, zero-flow pressure difference, and induced pressure difference. These revised definitions can be found in Appendix 7.1.

3.2 Apparatus – maximum permissible measurement error

Chapter 4 of ISO 9972 outlines the necessary measurement devices. However, these are frequently presented as definitions, which is not correct. Consequently, we have proposed more precise and improved formulations and have recommended a consistent maximum permissible measurement error (MPME) for each instrument. The MPME is defined as the maximum difference between the reading of an instrument and the quantity being measured (*ISO/IEC Guide 98-4:2012*, 2012). This MPME can serve as an input parameter in the uncertainty calculation. These MPMEs can be found in Appendix 7.2. Additionally, we have decided to delete the paragraph concerning the periodic calibration of the measurement system, because general requirements regarding equipment maintenance and calibration of the equipment are already specified in ISO/IEC 17025 (*ISO/IEC 17025:2017*, 2017). Hence, there is no necessity to reiterate this in ISO 9972. We are considering providing an informative annex about the verification of measurement systems.

3.3 Temperature and wind speed measurements

The current version of ISO 9972 lacks explicit guidance on the need and the appropriate locations for measuring ambient temperature and wind speed during the testing. We have incorporated recommendations based on the Czech national guideline (Novák, 2019).

Measurement of the air temperature, both internally and externally, and in the environment from which the air flows enter the air flow rate measuring system (if it differs from inside or outside air temperature), is critical for correcting the air flow measurements for air density. In chapter 5.3.2 of the standard, the existing language merely requires that the temperature inside and outside the building be recorded before, during, or after the test. We have added instructions in this section, specifying that thermometers should be preconditioned for a sufficient time in the environment where the temperature will be recorded. Additionally, it is important to conduct measurements at multiple locations within the building to ascertain an average temperature that represents the internal air temperature. An informative annex is also planned to provide further recommendations on considerations during the measurement process.

Currently, wind speed and direction measurements are not required as input in any calculations within the standard, serving only as supplementary information. Nonetheless, higher wind speeds may indicate discrepancies in the results of repeated tests of the same building. The existing standard allows for the estimation of wind speed and force through visual assessment of tree movement in terms of the Beaufort scale. We have extended this to include the option of recording wind speed with an anemometer at ground level and obtaining data from a nearby meteorological weather station.

3.4 Zero-flow pressure difference

The zero-flow pressure difference is the pressure difference between the interior and exterior of a building when it is not artificially pressurized. The measurement is taken at the start and end of each test and provides an estimation of the actual wind and stack effects present in the building.

ISO 9972 enforces a strict condition for a test to be valid, insisting that the absolute value of the zero-flow pressure difference must be lower than 5 Pa. This stringent constraint on the zero-flow pressure difference is intended to limit the test uncertainty due to wind speed and stack effect. To mitigate the influence of high-frequency wind gusts that may act on the external pressure sampling, we have extended the recording period from 30 seconds to 60 seconds, capturing 1 data point per second, ensuring that each point is the average of at least 10 measurements as recommended by Hurel et al. (Hurel & Leprince, 2021) and Prignon et al.

(Prignon et al., 2021). Furthermore, the restriction to be lower than 5 Pa excludes high-rise buildings from being tested according to ISO 9972 as there is a high likelihood that such buildings exhibit a zero-flow pressure difference exceeding 5 Pa. As such, we recommend specifying in the standard that the absolute value of zero-flow pressure difference should ideally be lower than 5 Pa and also propose including the zero-flow pressure difference (and potentially its variability) in the uncertainty calculation of the derived quantities. The method to include the impact of the zero-flow pressure in the uncertainty is currently under investigation.

3.5 Regression analysis

The ISO standard prescribes the use of a least squares technique to deduce the airflow coefficient (C) and pressure exponent (n) from the collected experimental data. In most cases, an ordinary least square method (OLS) is used to calculate these coefficients, accomplished by minimizing the sum of the squared differences between the measured values and the predicted values from the model only in the y-direction ($\mathrm{y_i} = \ln(Q_i)$)).
However, Delmotte (Delmotte, 2013) observed that the application of OLS is only valid if all measured values in the y-direction are equally uncertain and the uncertainty in the x-direction ($\mathrm{x_i} = \ln(\Delta P_i)$ is negligible, a condition rarely met during an actual measurement.
This limitation has been addressed by the German national annex DIN EN ISO 9972 (*DIN EN ISO 9972:2018-12*, 2018) and the Canadian standard CAN/CGSB-149.10-2019 (*CAN/CGSB-149.10-2019*, 2019), which introduce a weighted least squares (WLS) method. This WLS method acknowledges that measurements taken at low pressures have higher uncertainty and show a more significant influence on the regression, attributed to the nonlinearity of the pressure-flow relationship. Thus, the measured data are weighted using the square of the volume flow in the regression. Delmotte (Delmotte, 2013) advises using WLS only when uncertainty in the x-direction is insignificant. Despite this, Delmotte (Delmotte, 2017) asserts that this condition is rarely satisfied in practice, and introduces an alternative: the weighted line of organic correlation (WLOC). The WLOC uses the standard uncertainty at each pressure-flow data point as a weight and optimizes the distances in both x and y-directions. Studies (Delmotte, 2017; Kölsch & Walker, 2020; Prignon et al., 2019, 2018) have demonstrated that this method significantly enhances airflow predictability and reduces the variability of flow coefficient and pressure exponent. A comparison of the regression results of the OLS and WLOC methods is shown in Figure 2. It reveals that data points with greater measurement uncertainty have less impact on the regression. Consequently, we propose integrating the WLOC into the revised version of the standard. Integrating this method will also have an impact on the uncertainty calculation.

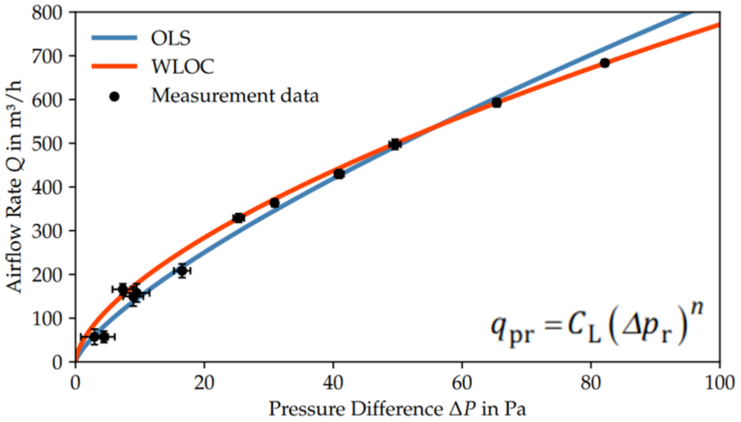

Figure 2: Comparison of OLS and WLOC - linear display (Kölsch & Walker, 2020)

3.6 Airflow corrections

For the resulting airflows to be both valid and comparable, it is important to correct them to standard temperatures and pressure conditions. This ensures the comparability of tests even when they are conducted under varying conditions. Unlike ASTM E772-19 (*ASTM E779-19*, 2019) and CAN/CGSB-149.10-2019, ISO 9972 currently requires only simplified corrections. These simplifications are suitable when the barometric pressure is negligible, the blower door calibration is near the reference conditions, and the pressure exponent is close to 0.5 (Walker et al., 1998). However, the airflow rates through system components and leaks are influenced by factors such as air viscosity, air density, and pressure exponent. Given modern computational equipment, the necessity and appropriateness of simplifying these corrections have been questioned (Carrié, 2014). Therefore, we propose the implementation of the following corrections for airflow and flow coefficient (here as an example for pressurization), as stipulated in the ASTM standard (with airflow rate q, airflow coefficient C, pressure exponent n, air density ρ, and dynamic viscosity of air μ):

$$q_{env} = q_m \left(\frac{\rho_e}{\rho_{int}}\right) \tag{1}$$

$$C_L = C_{env} \left(\frac{\mu_e}{\mu_0}\right)^{2n-1} \left(\frac{\rho_e}{\rho_0}\right)^{1-n} \tag{2}$$

4 CONCLUSION AND OUTLOOK

Due to rising awareness regarding building airtightness and an increasing number of performed airtightness tests, the experiences and knowledge regarding test reliability and validity are increasing. Because of related legal and financial issues, reliable and valid tests have become more critical. Therefore, Cerema started a project and set up a working group of international experts to improve and revise the ISO 9972 standard. This article presents a selection of the suggested improvements to the standard.

In addition to the aspects elaborated in this article, the project aims to address several other vital factors, including:

- Building preparation: It might be beneficial to describe the basic principles of building preparation in the current version of the standard more precisely and avoid ambiguities.
- Placement of external pressure taps: The location of the external pressure taps is important, as it serves as a reference for every pressure difference measurement, including zero-flow pressure measurements. It is crucial that ISO 9972 provides clear guidance on whether the pressure difference across the building envelope or the equilibrium internal pressure should be measured, as it directly impacts the location of external measurement probes.
- Comprehensive calculation of measurement uncertainty: The standard should offer a unified and comprehensive approach to calculating measurement uncertainty, considering all potential error sources. This includes instrumentation inaccuracies, environmental influences, and methodological factors.

5 ACKNOWLEDGMENTS

The authors thank the working group members for participating in this project and for their valuable contribution to this work.

6 REFERENCES

ASTM E779-19—Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. (2019).

CAN/CGSB-149.10-2019—Determination of the airtightness of building envelopes by the fan depressurization method. (2019).

Carrié, F. R. (2014). Temperature and pressure corrections for power-law coefficients of airflow through ventilation system components and leaks. Proceedings of the 35th AIVC Conference.

Carrié, F. R., & Leprince, V. (2016). Uncertainties in building pressurisation tests due to steady wind. Energy and Buildings, 116, 656–665. https://doi.org/10.1016/j.enbuild.2016.01.029

Carrié, F. R., Olson, C., & Nelson, G. (2021). Building airtightness measurement uncertainty due to steady stack effect. Energy and Buildings, 237, 110807. https://doi.org/10.1016/j.enbuild.2021.110807

Delmotte, C. (2021). Airtightness of buildings – Assessment of leakage-infiltration ratio and systematic measurement error due to steady wind and stack effect. Energy and Buildings, 241, 110969. https://doi.org/10.1016/j.enbuild.2021.110969

Delmotte, C. (2013). Airtightness of buildings—Calculation of combined standard uncertainty. Proceedings of the 34th AIVC Conference.

Delmotte, C. (2017). Airtightness of Buildings – Considerations regarding the Zero-Flow Pressure and the Weighted Line of Organic Correlation. Proceedings of the 38th AIVC Conference.

DIN EN ISO 9972:2018-12—Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (9972:2018-12). (2018). Beuth Verlag.

Hurel, N., & Leprince, V. (2021). Impact of wind on the airtightness test results. AIVC Ventilation Information Paper No 41.

ISO 704:2009—Terminology work - Principles and methods. (2009).

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

ISO 80000-1:2022—Quantities and units - Part 1: General. (2022).

ISO/IEC 17025:2017—General requirements for the competence of testing and calibration laboratories. (2017).

ISO/IEC Guide 98-4:2012—Uncertainty of measurement — Part 4: Role of measurement uncertainty in conformity assessment. (2012).

Kölsch, B., Mélois, A., & Leprince, V. (2023). Improvement of the ISO 9972: Proposal for a more reliable standard to measure air leakage rate using the fan pressurisation method. Proceedings of the 13th International BuildAir-Symposium.

Kölsch, B., & Walker, I. S. (2020). Improving air leakage prediction of buildings using the fan pressurization method with the Weighted Line of Organic Correlation. Building and Environment, 181, 107157. https://doi.org/10.1016/j.buildenv.2020.107157

Leprince, V., Bailly, A., Carrié, F. R., & Olivier, M. (2011). State of the Art of Non-Residential Buildings Air-tightness and Impact on the Energy Consumption. Proceedings of the 32nd AIVC Conference.

Leprince, V., Carrié, F. R., & Kapsalaki, M. (2017). Building and ductwork airtightness requirements in Europe – Comparison of 10 European countries. Proceedings of the 38th AIVC Conference.

Novák, J. (2019). Implementation of the EN ISO 9972 standard into the Czech Republic. Proceedings of the 11th International BuildAir-Symposium.

Poza-Casado, I., Cardoso, V. E. M., Almeida, R. M. S. F., Meiss, A., Ramos, N. M. M., & Padilla-Marcos, M. Á. (2020). Residential buildings airtightness frameworks: A review on the main databases and setups in Europe and North America. Building and Environment, 183, 107221. https://doi.org/10.1016/j.buildenv.2020.107221

Prignon, M., Dawans, A., Altomonte, S., & Van Moeseke, G. (2019). A method to quantify uncertainties in airtightness measurements: Zero-flow and envelope pressure. Energy and Buildings, 188–189, 12–24. https://doi.org/10.1016/j.enbuild.2019.02.006

Prignon, M., Dawans, A., & Van Moeseke, G. (2021). Quantification of uncertainty in zero-flow pressure approximation. International Journal of Ventilation, 20(3–4), 248–257. https://doi.org/10.1080/14733315.2020.1777020

Prignon, M., Dawans, A., & Van Moeseke, G. (2018). Uncertainties in airtightness measurements: Regression methods and pressure sequences. Proceedings of the 39th AIVC Conference.

Walker, I. S., Wilson, D. J., & Sherman, M. H. (1998). A comparison of the power law to quadratic formulations for air infiltration calculations. Energy and Buildings, 27(3), 293–299. https://doi.org/10.1016/S0378-7788(97)00047-9

7 APPENDIX

7.1 Revised terms and definitions

air leakage

passage of air through unintended path in the shell of an enclosure

Note 1 to entry: This passage includes flow through joints, cracks, and porous surfaces, or a combination thereof, induced by the fan used in the procedure described in this document (see Clause 4).

flow rate

quotient of the amount of fluid passing a given plane by the duration

air leakage rate

quotient of the amount of air leakage by the duration

building envelope

shell separating the inside from the outside environment or another building

volumic air leakage rate

deprecated term: air change rate

quotient of the air leakage rate by a reference volume

Note 1 to entry: In this document, the reference volume is the internal volume of the building.

areic air leakage rate

deprecated term 1: air permeability

deprecated term 2: specific air leakage rate

quotient of the air leakage rate by a reference area

Note 1 to entry: The reference area is commonly the area of the building envelope or the floor area of the building.

equivalent leak area

area of a single orifice which, for the same applied pressure difference, would pass the same air flow rate as the leaks of the building envelope under consideration

areic equivalent leak area

deprecated term: specific effective leakage area

quotient of the equivalent leak area by a reference area

Note 1 to entry: The reference area is commonly the area of the building envelope or the floor area of the building.

to close an opening

to make an opening hermetic by an appropriate means

Note 1 to entry: Examples of appropriate means are adhesives, inflatable balloons, or stoppers.

zero-flow pressure difference

admitted term: natural pressure difference

pressure difference prevailing between inside and outside a building when no air flow is generated by forces other than wind and stack effect

induced pressure difference

pressure difference generated between inside and outside a building by forces other than wind and stack effect

Note 1 to entry: In the present document, the other force is a fan (see clause 4.2.1).

7.2 Revised maximum permissible measurement errors (MPME)

Table 1: MPME of measurement instruments

Measurement instrument	**MPME**
Monometer	not larger than ±1 Pa or 1 % of the reading, whichever is greater for the measurement interval that includes the measured quantity
Air flow rate measuring system	not larger than ±5 m^3/h or 7 % of the reading, whichever is greater
Thermometer	not larger than ±1 °C in the range of -30 °C to 50 °C
Barometer	not larger than ±300 Pa
Hygrometer	not larger than ±5 % of relative humidity