# Literature Review on Windows Airtightness Performances: Insights and Gaps

Martin Prignon[1]

[1] *Buildwise*
*Kleine Kloosterstraat, 23*
*1932 Zaventem, Belgium*
**Corresponding author: martin.prignon@buildwise.be*

**ABSTRACT**

Old windows make a major contribution to the authentic look of a façade, and maintaining those elements whenever possible is essential for the conservation of our architectural heritage. However, those are often leaky and are consequently responsible for high energy losses, acoustical and thermal discomfort, and incorrect sizing of the ventilation systems. Having a better knowledge of windows airtightness performance is crucial in assessing need for an intervention based on the balance between costs and impact. In this paper, we review 43 studies published between 1930 and today reporting on window airtightness measurements. The results show that the lack of standardized way of expressing the results and the small number of reported results and the bad repartition among studies make it difficult to draw solid conclusions, especially for in-situ measurements. Despite those limitations, certain trends can be observed based on the reviewed studies: (1) in-situ testing provides worse results than laboratory tests, which is explained by the window-wall interface, the deterioration over time and the deterioration during installation; (2) since the arrival of weatherstripped windows, there is no clear improvement of the windows airtightness over time, for both laboratory and in-situ testing; (3) among the different opening mechanisms, sliding windows are found performing worse than others; (4) among different materials for window frames, steel and aluminium are found performing the worse and wood the best. However, those conclusions were strongly hindered by the identified limitations; (5) existing windows are notably leakier than newly installed windows and the performance seems to decrease over the years, but this was based on a very few numbers of windows tested. Further work should focus on acquiring data from in-situ measurements on existing windows. Those study should report the results in terms of leakage characteristics and minimum information should be the opening mechanism, window frame materials, the period of construction of windows and the year of testing. Additionally, those trends were observed by analysing considerable number of studies with different objectives. Each of the trends observed here should be confirmed and confronted through dedicated studies.

**KEYWORDS**

Windows airtightness; Literature review; air infiltration; windows testing

## 1 INTRODUCTION

Windows play a crucial and significant role in our architecture thank to their capacity to admit natural light into interior spaces. Windows make a major contribution to the authentic look of a façade, and maintaining those elements whenever possible is essential for the conservation of our architectural heritage. However, old windows are often leaky, causing high energy and financial costs, as well as thermal and acoustic discomfort for the occupant. The level of leakiness is an important parameter for a building owner helping him to prioritise an intervention based on a balance between impact (e.g., energetic or comfort) and costs (e.g., financial or heritage value).

The first tests to assess the performance of windows regarding air infiltration were reported almost 100 years ago by (Larson et al., 1931). Over the years, multiple authors conducted studies on the quantification of window airtightness. Although each study draws its own conclusions, analyse the full range of studies conducted allows to answer some specific questions related to the evolution over time, the discrepancies between studies or the relevancy of testing more windows.

In this paper, we reviewed the scientific literature on windows airtightness, with a specific focus on the quantification of this component's performance. A total of 43 documents between 1930 and today were reviewed and analysed. Figure 1 shows the repartition of those references over time. Since 1930 the number of studies is constant over the year, except in the period 1940-1950 where no studies were reported and post-2010 where the subject provides a regain of interest. Note that the substantial increase post-2010 can be biased by the higher accessibility of the literature, and the impact of publication period in the research algorithms.

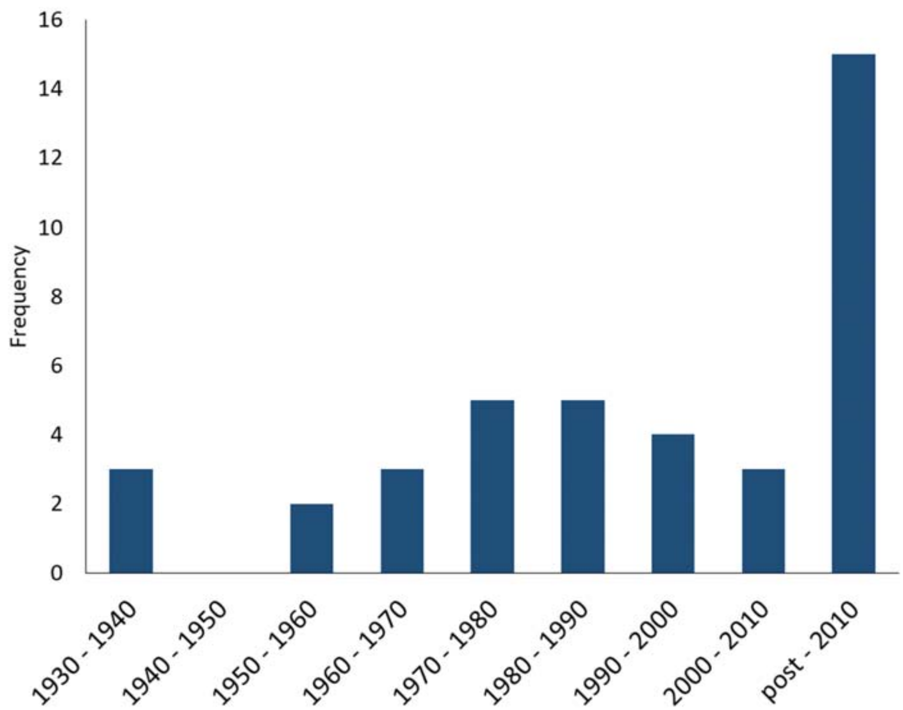


Figure 1: frequency of reported studies by period of publication.

This paper is structured as follows. Section 2 provides an overview of the studies integrated in the analysis as well as some key aspects of this analysis. Section 3 reports all the data coming from the studies and investigate some trends. Section 4 discusses the results with a specific focus on the limitations inherent to the available data. Lastly, section 5 concludes by summarizing the outcomes of this paper, the limitations, and the needed further research.

## 2 OVERVIEW OF THE STUDIES INCLUDED IN THE LITERATURE REVIEW

### 2.1 Methods for airtightness performance assessment

Among the 43 documents, eight were removed from the extended analysis for different reasons: one paper assesses the airtightness performance of windows through parametric approach and not measurements (Cheng and Li, 2018) ; one paper provides no information about the methodology for data acquisition (Jiu and Yu, 1983) ; six papers investigated the impact of an intervention on the airtightness performance by measuring the difference between pre- and post-intervention measurements, but the data provided could not be used to deduce the performance of the component itself (Catalina et al., 2020; Cuce, 2017; d'Ambrosio Alfano et al., 2016; Davies et al., 2005; Fernández-Agüera et al., 2012; Tombarević et al., 2023). In addition, two documents do not reported results of an experiment, but are databases: AIVC (Orme and Leksmono, 2002) and ASHRAE (ASHRAE, 2001). Note that the ASHRAE database is not provided anymore in the recent edition of the handbook of fundamentals. The 33 remaining studies can be divided in three groups based on the methods for performance assessment: laboratory measurements, in-situ measurements using the direct method, and in-situ measurements using the indirect method.

Laboratory measurements consist in placing the tested window in an equipment that allows to pressurize and depressurize the window alone, then the air flow needed to maintain a pressure difference between both sides of the window is recorded. The test method is defined in different standards as such as (ISO 1026, 2016) or (ASTM E283, 2019). In-situ measurements can be divided into two types: the direct measurements where the tested window is isolated from the rest of the building and is directly pressurized and/or depressurized; and the indirect component where a whole zone is tested using traditional methods (e.g., the fan pressurization testing) two times consecutive, with the tested window sealed between both tests. The component performance is then given as the difference between both tests. It has been shown in (Prignon, 2020) that the indirect method provides higher uncertainties than the direct method. However, in some cases the ease of installation makes it a relevant alternative to the direct method. Table 1 shows the repartition of the methods of assessment used among different reported studies.

Table 1: repartition of 33 analysed references by assessment methods

| Method used in the papers | N | References |
|---|---|---|
| Laboratory measurements | 16 | (Carruthers and Newman, 1977; Coleman and Heald, 1940; Fleury and Thomas, 1972; Konstantinov and Verkhovsky, 2020; Larson et al., 1931; Lund and Peterson, 1952; Mantle, 1958; Miškinis et al., 2019; Provan and Younger, 1986; Rousseau, 1991; Rusk et al., 1933; Sasaki and Wilson, 1965; Shoda et al., 1970; Van Den Bossche and Janssens, 2016; Villiere, 1962) |
| In-situ: direct measurement | 11 | (Daoud et al., 1991; Feng et al., 2020; Fournier et al., 2007; McGrath, 1982; Park and Kim, 2019; Persily and Grot, 1984; Prignon, 2020; Shapiro and James, 1997; Shaw, 1980; Ward and Sharples, 1982; Weidt, 1979) |
| In-situ: indirect measurement | 6 | (Almeida et al., 2017; Hall and Hauser, 2003; Kovanen and Sateri, 1997; Pereira et al., 2014; Pinto et al., 2011; Tamura, 1975) |

## 2.2 Metrics for airtightness performance of windows and standardization

The performance of the window is defined by the air leakage rate of the window at different pressure differences. The relation between both is usually provided using following equation:

$$q = C_w(\Delta p)^{n_w} \quad (1)$$

Where $q$ is the air leakage rate across the window for a pressure difference $\Delta p$, $C_w$ and $n_w$ are the leakage characteristics of the characterised window. In the analysis of the 35 studies (33 quantification studies and two databases), four important aspects should be considered for a relevant comparison of the reported results:

- There are three different ways information are provided: 7 studies provide the full test result (table or graphic), 7 studies provide the leakage characteristics (leakage coefficient and exponent), and 21 studies provide the airflow at a reference value. Note that the leakage characteristics can be deduced from the full test results and the reference value can be deduced from the leakage characteristics.
- Units used for airflows are [m³/h] in 18 studies, [cfm] in 5 studies, [cfh] in 4 studies, ELA (effective leakage area) in 2 studies, [L/s] in 3 studies, [dm³/s] in 2 studies and [m³/s], in one study. For the pressure difference (only relevant when the reference value is used), units are [Pa] for 15 studies, [in] of water for 4 studies and [mph] for 2 studies. Although translating results from one unit system to another is not difficult, having them presented in different ways can be an obstacle when comparing results with existing literature.

- When a reference value is used, a reference pressure must be defined. Using Pascals as a common unit, the reference pressure is 4 Pa for 2 studies, 10 Pa for one study, 50 Pa for 8 studies, 75 Pa for 5 studies, 100 Pa for 4 studies, and 600 Pa for one study. If a reference value is used, one can assume a value for the flow exponent and use equation (1) to express the results at a different reference value. A typical value for the flow exponent for buildings is $n = 0.65$ (ASHRAE, 2001), but a value of 0.6 is observed in this review, when looking at the 14 studies (Total sample size of 720) that provided enough information to deduce the flow exponent.
- The normalization of the results is usually done either considering $L$, the length of opening joint (18 studies); or $A$, the area of the window (7 studies). One study provides some results in terms of length of opening joint and others in terms of windows area, and 5 studies provide results normalized using both approaches. Three studies provide not-normalized results. When looking at the ratio $L/A$ based on the 5 studies using both approaches, an average value of 2.5 m/m² is found. This is an interesting observation since in the classification of EN 12207, a ratio of 4 m/m² is assumed in the definition of class boundaries.

In this paper, the results are presented using a reference value of airflow in m³/h at 50 Pa of reference pressure and normalized per meter of opening joint. When needed for conversion, an airflow exponent of 0.6 and a ratio $L/A$ of 2.5 m/m² were assumed. For 3 studies, the information was not sufficient to express the results in that way, and where consequently excluded in the following analysis.

### 2.3 Windows materials and typology

Different typologies and materials are analysed in the literature. However, the nomenclature used is different from one study to another. Here, we divide the results in four types of windows, based on opening mode:

- Horizontal sliding window,
- Pivot window, which includes vertical pivot, horizontal pivot, and awning,
- Single and double hung windows,
- Side-hung windows, which includes single side-hung, double side-hung, and tilt-and-turn.

Additionally, the window can be weather-stripped or not. Regarding the materials, four different frame materials are considered: wood, PVC, aluminium, and steel.

## 3 VALUES FOR WINDOWS AIRTIGHTNESS

### 3.1 Laboratory measurements

Among 16 studies reporting laboratory measurements, three of them were removed: (Rousseau, 1991) conducted test on whole assemblies and do not focus on the window itself, and both (Coleman and Heald, 1940) and (Villiere, 1962) provided results that could not be normalized. Table 2 provides the list of references that were analysed, including the number of windows tested, if information is provided about windows type and windows materials, and if non-weatherstripped windows are tested or not.

Table 2: List of reference analysed for the laboratory measurements conducted on windows

| ID | Reference | N | Windows type | Windows materials | Non-WS |
|---|---|---|---|---|---|
| 1 | (Park et al., 2017) | 2 | Yes | Yes | No |
| 2 | (Larson et al., 1931) | 18 | No | Yes | Yes |
| 3 | (Rusk et al., 1933) | 17 | Yes | Yes | Yes |
| 4 | (Lund and Peterson, 1952) | ?* | No | Yes | Yes |
| 5 | (Mantle, 1958) | 1 | No | Yes | No |
| 6 | (Sasaki and Wilson, 1965) | 39 | Yes | Yes | Yes |
| 7 | (Shoda et al., 1970) | 8 | Yes | Yes | Yes |
| 8 | (Fleury and Thomas, 1972) | 3 | Yes | Yes | No |
| 9 | (Carruthers and Newman, 1977) | 131 | Yes | Yes | Yes |
| 10 | (Provan and Younger, 1986) | 772 | Yes | Yes | Yes |
| 11 | (Van Den Bossche and Janssens, 2016) | 305 | Yes | Yes | No |
| 12 | (Miškinis et al., 2019) | 33 | No | Yes | No |
| 13 | (Konstantinov and Verkhovsky, 2020) | 3 | Yes | Yes | No |

* No information provided about the number of elements tested, a value of 1 is considered in the weighted averages

A first analysis of the results (Figure 2) shows for each study the average airflow at 50 Pa, in m³/h per meter of opening joint. The error bars are given by the standard deviation of the reported results when it could be deduced. For weatherstripped windows the studies report values between 0.04 and 7.83 m³/(h.m), with a weighted average of 1.37 m³/(h.m) (each study is weighted with the number of windows tested). For non-weatherstripped windows, the studies report values between 1.66 and 8.71 m³/(h.m), except (Shoda et al., 1970) who reports one case at 25.94 m³/(h.m), which seems an outlier compared to other results. The weighted average for non-weatherstripped windows is 3.79 m³/(h.m). Note that (Provan and Younger, 1986) is the last study to report non-weatherstripped results. When looking at weatherstripped windows, no correlation is found between the year of testing (which is considered as the year of publication when no other information is provided) and the airtightness performance.

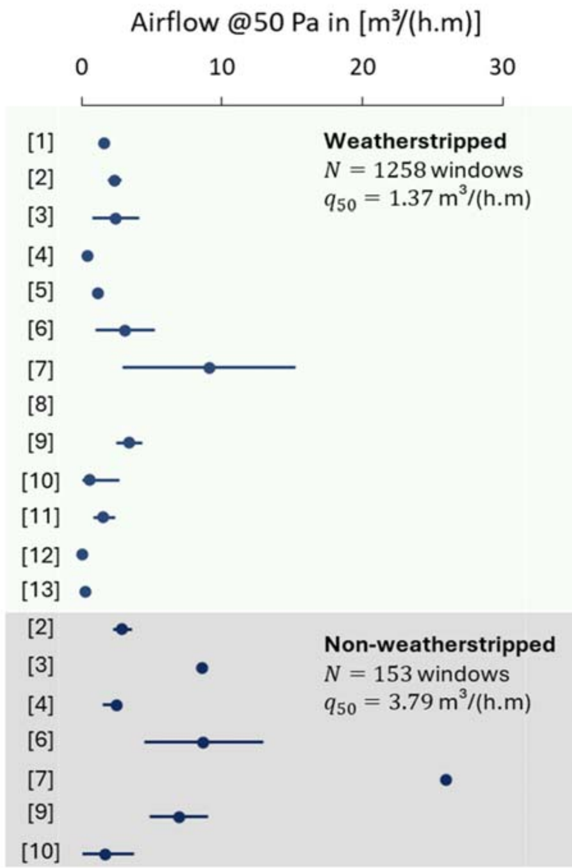


Figure 2. Average value for the airflow rate of each study, when windows are weatherstripped or not, for laboratory measurements.

Table 3 shows the weighted average performance of windows, depending on the opening mechanism. Sliding windows are found performing notably worse than other type of windows. Pivot windows seems to perform better, however only two studies reported those results: (Provan and Younger, 1986) and (Sasaki and Wilson, 1965) reporting respectively 392 and 4 tests on pivot windows.

Table 3: Airflow rate per windows type, for laboratory measurements

| **Windows type** | **N** | $q_{50}$ **[m/(h.m)]** | **References** |
|---|---|---|---|
| Hung | 233 | 0.93 | [2; 3; 6; 7; 9; 10] |
| Pivot | 396 | 0.40 | [6; 10] |
| Side hung | 343 | 1.00 | [1; 3; 6; 8; 10; 11; 13] |
| Sliding | 242 | 3.90 | [6; 7; 9; 10; 11] |
| Unspecified | 44 | 1.27 | [4; 5; 7; 10; 12] |
| All | 1258 | 1.37 | - |

Table 4 shows similar averages, but as a function of windows materials. Drawing conclusion about such a correlation is complicated because of the considerable number of studies labelled as “unspecified”. Indeed, both (Van Den Bossche and Janssens, 2016) and (Provan and Younger, 1986), combining together 85% of the tests, do not report results per materials. However, they suggest, in their work that no correlation was observed between the airtightness performance and the frame material. Note that steel windows represent less than 3% of the tested windows for the combined 1062 tests of (Van Den Bossche and Janssens, 2016) and (Provan and Younger, 1986). When looking at the 196 remaining cases, steel seems to perform the least and wood the most.

Table 4: Airflow rate per windows materials, for laboratory measurements

| Windows type | N | $q_{50}$ [m/(h.m)] | References |
|---|---|---|---|
| Wood | 72 | 1.32 | [2; 3; 4; 6; 12] |
| Aluminium | 99 | 3.36 | [6; 9] |
| Steel | 17 | 5.50 | [3; 5; 6; 7] |
| PVC | 8 | 3.37 | [1; 8; 13] |
| Unspecified | 1062 | 1.10 | [10; 11] |
| All | 1258 | 1.37 | - |

## 3.2 In-situ measurements

Among 17 studies reporting in-situ measurements four of them where removed from the analysis because the provided results could not be normalized: (Shapiro and James, 1997), (Pereira et al., 2014), (McGrath, 1982) and (Kovanen and Sateri, 1997). Table 5 provides the list of references that were analysed, including the number of windows tested, if information is provided about windows type and windows materials, and if the tested windows were newly installed or existing.

Table 5: List of reference analysed for the in-situ measurements conducted on windows

| ID | Reference | N | Test method | Windows type | Windows materials | New |
|---|---|---|---|---|---|---|
| 1 | (Weidt, 1979) | 192 | Direct | Yes | Yes | Yes |
| 2 | (Shaw, 1980) | 17 | Direct | Yes | No | Yes & No |
| 3 | (Ward and Sharples, 1982) | 10 | Direct | Yes | No | No |
| 4 | (Persily and Grot, 1984) | 18 | Direct | Yes | No | No |
| 5 | (Daoud et al., 1991) | 154 | Direct | Yes | Yes | Yes & No |
| 6 | (Fournier et al., 2007) | 10 | Direct | No | No | Yes |
| 7 | (Park and Kim, 2019) | 3 | Direct | Yes | No | * |
| 8 | (Feng et al., 2020) | 1 | Direct | Yes | Yes | * |
| 9 | (Prignon, 2020) | 13 | Direct | Yes | Yes | Yes |
| 10 | (Pinto et al., 2011) | 2 | Indirect | Yes | No | Yes |
| 11 | (Tamura, 1975) | 17 | Indirect | Yes | Yes | No |
| 12 | (Hall and Hauser, 2003) | 10 | Indirect | Yes | No | Yes & No |
| 13 | (Almeida et al., 2017) | 23 | Indirect | Yes | Yes | Yes |

* Not enough information about year of testing and/or year of installation

Figure 3 (left) shows for each study the average airflow at 50 Pa, in $m^3/h$ per meter of opening joint. The error bars are given by the standard deviation of the reported results when it could be deduced. The results reported by (Fournier et al., 2007) of 57.56 $m^3/(h.m)$ seems an outlier compared to the other studies where the average lies between 1.66 $m^3/(h.m)$ and 12.47 $m^3/(h.m)$. Figure 3 (right) provides the results after removing the 10 cases from (Fournier et al., 2007). The weighted average is 7.43 $m^3/(h.m)$ considering all studies and 6.32 $m^3/(h.m)$ when the results reported by (Fournier et al., 2007) are removed. Note that the results from (Fournier et al., 2007) were removed from the rest of the analysis in order to avoid the large impact of this outlier in the global analysis.

The results are relatively similar when using direct and indirect methods (6.02 $m^3/(h.m)$ and 8.55 $m^3/(h.m)$ respectively), which is in line with what (Prignon, 2020) found: a difference in the random error is observed when comparing both methods, but no systematic difference. Those results are notably worse than the laboratory results. This was expected because of two major differences in the tested components: (1) laboratory measurements usually measure the window frame alone, while in-situ measurements are used to quantify the total performance, including the window-wall interface, (2) laboratory measurements are conducted on new windows while in-situ measurements reports results from newly installed and existing windows. This means that a difference is also observed because of the deterioration during installation and the deterioration over time for the windows.

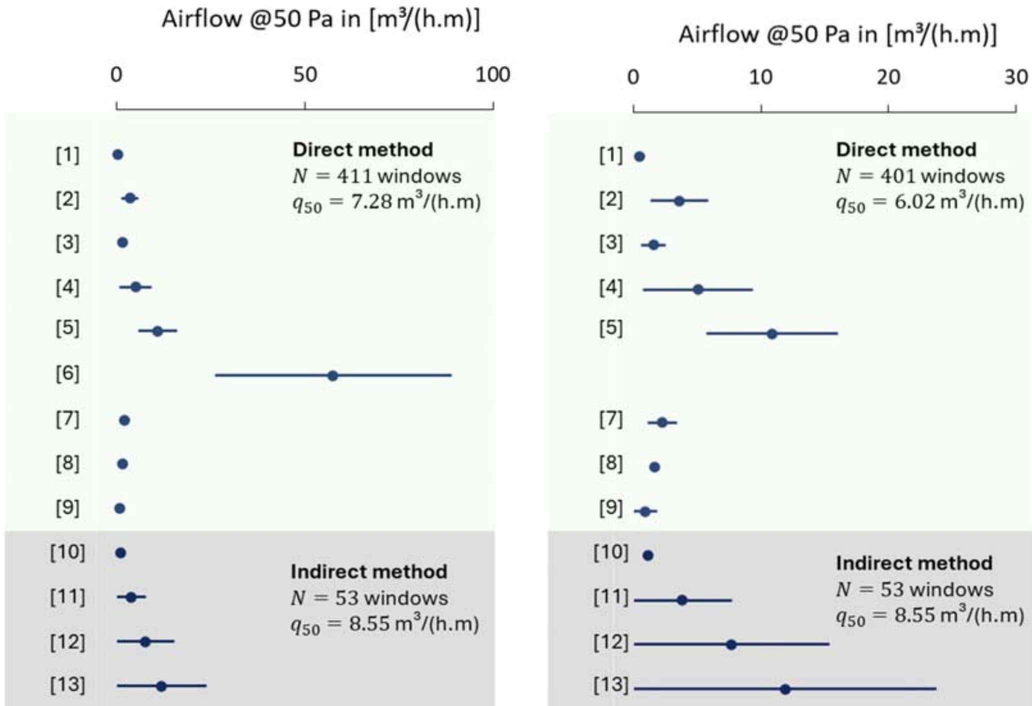


Figure 3. Average value for the airflow rate of each study, for indirect and direct in-situ measurements

Table 6 shows the impact of windows type on the airflow rate at 50 Pa for the in-situ measurements. Unfortunately, the small number of measurements and the large discrepancy between studies make difficult to draw solid conclusions from those results. This is especially true for the pivot windows, where 78% of the windows tested come from (Daoud et al., 1991). This means that the observed difference may also be related to the experimental designs of the study itself rather than the windows type. For the rest, the trends seem similar but less pronounced than the laboratory measurements: sliding windows perform worse than hung and side hung windows.

Table 6: Airflow rate per windows type, for laboratory measurements

| Windows type | N | $q_{50}$ [m/(h.m)] | References |
|---|---|---|---|
| Hung | 49 | 3.39 | [1] |
| Pivot | 32 | 17.01 | [1; 2; 5; 12] |
| Side hung | 172 | 5.17 | [1; 5; 8; 9; 11; 12; 13] |
| Sliding | 182 | 6.36 | [1; 2; 3; 5; 7; 10; 11; 13] |
| Unspecified | 19 | 5.85 | [4; 13] |
| All | 454 | 6.32 | - |

When investigating the correlation with windows materials, although the results are in line with the observations made for laboratory measurements (i.e., aluminium windows perform worse than wood windows), the same observation is made than for the windows type: the repartition of tested windows among studies hinders the drawing of strong conclusions. Indeed, 67% of the results for aluminium windows come from (Daoud et al., 1991) and 87% of the results for wood windows come from (Weidt, 1979).

Table 7: Airflow rate per windows materials, for in-situ measurements

| Windows materials | N | $q_{50}$ [m/(h.m)] | References |
|---|---|---|---|
| Wood | 175 | 2.70 | [1; 9; 11; 13] |
| Aluminium | 219 | 9.26 | [1; 5; 8; 9; 13] |
| Unspecified | 70 | 6.17 | [2; 3; 4; 7; 10; 12] |
| All | 454 | 6.32 | - |

In-situ measurements are usually preferred over laboratory measurements in two cases: when there is a demand for measuring the difference between the manufacturer's datasheet and the real in-situ performance (including the impact of the window-wall interface and the damages during on site installation) or to assess the performances of existing windows and the potential impact of renovation. Table 8 provides the results obtained for newly installed windows compared to existing windows. Note that the studies of (Daoud et al., 1991) and (Hall and Hauser, 2003) were characterized as unspecified because they do not provide enough information to differentiate existing windows from newly installed windows. Nevertheless, (Daoud et al., 1991) state that when window age is $< 10$ years, age has no impact and that older windows had improved performances. Additionally, the standard deviation of newly installed windows was found larger than for older windows, suggesting that quality control has declined over time. Contrary to the observations made in (Daoud et al., 1991), here the newly installed windows are found performing better than existing windows (2.35 $m^3/(h.m)$ and 6.85 $m^3/(h.m)$ respectively). However, as for the opening mechanism and the materials, the repartition of number of windows tested was also a problem in this analysis since 87% of the newly installed windows were tested by (Weidt, 1979).

Table 8: Airflow rate for newly installed windows and existing windows, for in-situ measurements

| Windows type | N | $q_{50}$ [m/(h.m)] | References |
|---|---|---|---|
| Newly installed | 220 | 2.35 | [1; 2; 9; 10] |
| Existing | 73 | 6.85 | [2; 3; 4; 11; 13] |
| Unspecified | 161 | 11.51 | [5; 7; 8; 12] |
| All | 454 | 6.32 | - |

When looking at existing windows, an interesting information is the age of the window when the test is conducted. Since the data from (Ward and Sharples, 1982) were not enough detailed to include those windows to the analysis, 63 windows were divided in three categories: 0 – 10 years, 10 – 25 years and above 25 years. Results in Table 9 show that there seems to be degradation over time. However, the number of results reported in each category is low, as such as the number of different studies reporting it.

Table 9: Airflow rate as a function of windows age at the time of testing for existing windows, for in-situ measurements

| **Windows age** | **N** | $q_{50}$ **[m/(h.m)]** | **References** |
|---|---|---|---|
| 0 – 10 years | 23 | 4.53 | [2; 4; 13] |
| 10 – 25 years | 35 | 6.73 | [2; 11; 13] |
| Above 25 years | 5 | 17.02 | [13] |
| All | 63 | | - |

## 4 DISCUSSION

When a study reports testing results of windows airtightness, it usually provides enough information to meet its own objective. However, it misses sometimes basic information that could be relevant in the context of correlation assessment as it was done in this paper. Based on this literature review, we suggest for any study in that context to include at least:

- The method used for testing, which are laboratory measurement, in-situ direct measurement or in-situ indirect measurement.
- The number of windows tested, the type of opening mechanism, the materials of windows frame. In case of in-situ measurements, the age of the window and the installation period should also be provided.
- The airflow rate at 50 Pa per meter of opening joint should be the reference value. Ideally the windows characteristics (i.e., $C$ and $n$) should be given so the airflow rate at any pressure difference could be deduced without any assumption on the leakage exponent. When possible, the area of the window should also be given.

Since standardized laboratory testing are now widespread practice for windows manufacturers, the number of test available is large (more than 1.400 vs. less than 500 for in-situ measurements). In addition, the number of variables in laboratory testing is lower, leading to a lower standard deviation of the results and, consequently, a lower number of measurements needed to draw relevant and significant conclusions. In this study, conclusions on in-situ measurements were complicated to draw because of the considerable number of variables and of the small number of data available. This is especially true when measuring the performance of existing windows with a specific focus on the performance deterioration over time. This question is of foremost importance given the ambitions of putting in place optimal renovation strategies. Indeed, that information is relevant in (1) choosing the more durable solution and (2) identifying the real potential of improvement when an intervention is done on a window.

## 5 CONCLUSION

In this paper, we reviewed around 40 papers reporting measurements related to windows airtightness between 1930 and today. Among those, 33 could be used to directly deduce airtightness performance of windows, divided as follows: 16 laboratory measurements, 11 in-situ direct measurements and 6 in-situ indirect measurement. A series of interesting insights were deduced from the literature review:

- When needed for normalization of the results, following information could be used for windows: an airflow exponent of $n = 0.6$ (average based on 720 cases from 14 studies) and an opening joint length to window area ratio of $L/A = 2.5$ m/m² (based on 429 cases from 5 studies).
- Based on laboratory measurements, (1) weatherstripped windows perform better than non-weatherstripped windows. However, those are not used anymore; (2) among weatherstripped windows, the year of test does not seem to impact window airtightness; (3) sliding windows are found performing the worse and pivot windows the best, but only two studies report results on pivot windows; (4) aluminium frames perform the worse and wood the best, but only 15% of the tested windows could be used to draw this conclusion because

of the lack of information. Those observations are not in line with the observations made by (Van Den Bossche and Janssens, 2016) and (Provan and Younger, 1986).

- Laboratory measurements provide better results than in-situ measurements, probably because the window-wall interface that is included in in-situ measurements, the deterioration during window installation and the deterioration over time.
- Based on in-situ measurements, almost no conclusion can be drawn because of the small number of reported studies and the bad repartition of them among different studies. Although trends are observed, those should not be considered as evidence because of those limitations.

In-situ measurements of windows airtightness provide high-quality information, especially on existing windows. Those could be helpful in defining durable choices based on the deterioration over time, and in predicting the real impact of a renovation on the global performance of the building. However, when looking at this review, testing on existing windows represents less than 5% of the total amount of windows tested. Further work should focus on acquiring high-quality data over airtightness performance of existing windows, depending on the year of installation. Additionally, those trends were observed by analysing considerable number of studies with different objectives. Those trends should now be confronted to dedicated studies, especially on the potential of improvement for leaky windows for different type of intervention (e.g., new joints or complete replacement).

## 6 ACKNOWLEDGEMENTS

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