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Impact of Energy Policies on Building and Ductwork Airtightness

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1 Introduction

Because energy use in the building sector represents a very large part of the total energy use and greenhouse gas emissions worldwide, many countries have developed or are developing ambitious policies to improve energy efficiency and conservation in that sector. This has resulted in regulations or wide-scale programmes urging the whole building sector and scientists to re-consider building design, quality of the works and commissioning, as well as priorities for research and development to achieve low energy buildings. This has brought to light issues neglected in the past, building airtightness being one of the most striking example. As demonstrated in the pioneering CEPHEUS project [1], because transmission losses through walls become very low in low energy buildings, building leakage, if not properly addressed, accounts for a very large fraction of the total energy losses. As a result, a number of initiatives started to raise awareness about building airtightness to study its positive impacts and possibly negative side-effects, and to help practitioners achieve good airtightness.

Ductwork airtightness impacts are another striking example of an issue overlooked in most countries, except in Scandinavian countries which have fostered airtight ductwork since the 1950s. Several studies show that in the context of Nearly Zero-Energy Buildings, benefits of airtight ductworks should definitely be considered, given the energy efficiency and IAQ impacts of duct leakage.

This paper investigates energy policies that have influenced building and ductwork airtightness based on a review of about 60 publications from the AIVC-TightVent conferences and workshops from 2011 to 2015. A few additional papers have been included to further support some of our statements.

2 Motivations for improving building airtightness

2.1 Energy use impacts

Energy savings have been a major driver for improving building airtightness in the past few years. This motivation was based on previous knowledge [2][3], but has been reinforced with recent studies demonstrating the huge savings potential of envelope tightening on a large-scale and the increasing share of energy losses due to building leaks with increasing building energy performance.

Whatever the method is to estimate infiltrations, all theoretical studies conclude on the importance of airtightness to reduce energy use of residential [4][5][6] and non-residential buildings [7].

We also found one recent experimental study on this topic. Coxon reports energy use measurements on two identical houses first with the same low airtightness values and secondly with one of them made airtight. He showed that improvement in air permeability from about 16 down to about 5 $m^3/(m^2.h)$ at 50 Pa, reduces heat losses between 31 and 35% [8].

2.2 IAQ impacts and building durability

Even if energy remains the main driver, there are increasing concerns for effective implementation of adequate ventilation provisions and for the impact of airtightness on IAQ and on building durability.

High or low building airtightness can positively or negatively influence building durability, depending on other critical factors including ventilation provisions, climate, construction type and usage. While a high degree of airtightness will likely enhance IAQ problems and structural damage (due to high moisture levels) in under-ventilated buildings, airflows through the building shell can enhance moisture built-up in the structure and insulating material. Moreover, inadequate ventilation patterns in leaky buildings may lead to similar problems as for under-ventilated buildings.

Richieri et al [9] have given numerical evidence of disturbed airflow patterns affecting IAQ due to poor airtightness. Several authors stress the need for appropriate ventilation provisions with improved airtightness in new and existing buildings [10] [11].

Booth also showed that limiting not only external infiltration but also interzonal infiltration is relevant, for comfort or health reasons, at least for some applications, e.g., healthcare buildings [12].

Also, we have heard anecdotal evidence of mould problems arising, prior to handing over the building, in very airtight buildings poorly ventilated during the construction phase for safety (theft) or practical reasons (no stable electricity supply). This problem deserves careful attention since mould growing inside walls may require physical access and removal of the mould, which is nearly impossible without physical damage to the structure.

Modelling air transfer through envelope leaks has been studied by many authors [13][14]. These models confirm the sensitivity of building structures to air exfiltration. Roels [15] and Steskens [16] give practical recommendations to limit the risk of condensation and degraded thermal performance in insulated pitched roofs. They conclude on the benefits of using a vapour-open or capillary-active underlay on the external side of the insulation layer.

2.3 Safety of occupants

Because good envelope airtightness helps prevent outdoor pollutants' entry into a building or a zone, shelter-in-place strategies have been studied and developed in several countries to protect people against toxic releases near industrial plants [17] [18] [19]. In France, the objective was to make sure that every building around such industrial plants provides a shelter—i.e., an indoor room sufficiently airtight—to protect occupants in the event of an outdoor chemical release. Guyot et al. gave an overview and first analysis of collected airtightness measurements for indoor rooms with information on the building use, the required airtightness level, the volume, the floor area and the year of construction [18]. The database gave a picture of the vulnerability of the housing stock around industrial plants and the overall cost consequences of this public policy. These field data can be used as input to multi-zone airflow and pollutant transfer model to study inter-zonal airflows. The same author developed the French software CONFINE [17] giving the required airtightness level to maintain toxic concentration under a given limit and duration in a shelter.

2.4 Perspectives

Studies have confirmed the impact of airtightness on building energy use; however, most studies have been assessed in climates where the heating demand prevails. Although we found some studies dealing specifically with energy savings and showing benefits of improved airtightness in hot and mild climates [6], these are generally too limited to draw conclusions that can be generalised to a building stock or type.

Regarding IAQ, overall, the studies confirm the motto "Build Tight, Ventilate Right" by showing how poor building airtightness affects the performance of ventilation systems; and inversely, the need for well-implemented ventilation systems in airtight buildings, whether new or existing. They also draw perspectives for future research, in particular, regarding inter-zonal infiltrations which may affect IAQ.

Regarding building durability, further research would be useful to agree on common bases for assessment methods of moisture-related problems, which could go as far as a standardised method. In turn, this would allow designers or guidelines to rate construction methods depending on their sensitivity to moisture damage. Also, practical ways to overcome moisture build up during the construction phase should be developed taking into account field constraints.

Finally, regarding occupants’ safety, further work on this topic would benefit from better knowledge of multi-zone infiltration including air transfer between rooms in and between dwellings.

3 Energy policies and building airtightness

3.1 Regulatory and programme requirements

Airtightness testing of new buildings is becoming common practice in more and more countries. Energy regulations and energy performance programmes are progressively becoming more stringent, pushing airtightness testing to show compliance.

In the UK, every new building must comply with air permeability requirements. The compliance must be justified with on-site measurements performed by certified testers [20].

In France, since January 2013, the energy performance (EP) regulation (RT, 2012) requires the building airtightness level to be justified (either through systematic measurement or application of a certified airtightness quality management (QM) approach). As a result, the number of airtightness measurements performed on residential buildings has been growing fast since 2007 (before 2007 a few dozens of buildings were tested each year; this number reached 20,600 in 2013 and around 100,000 in 2015) and buildings are gradually becoming more and more airtight [21].

Similarly, airtightness testing is mandatory in Ireland, since 2011 [22]. In Denmark, every new building must comply with a level of airtightness, tests are performed only on some of them selected by a third part (the mayor's office of the city).

In Belgium, testing is not mandatory. However, the EP regulation default value (v_{50} =12 m3/h/m²) favours the use of a value from a pressurisation test to achieve a substantial improvement in energy performance. Therefore, almost 30-50 % of new residential buildings are now tested.

In Germany testing is not mandatory, but a recent survey shows that in measured buildings n_{50}-values are much better than the benchmarks given in the German EP regulation (EnEV) [23]. The major driving force is EnEV combined with funding programmes of the KfW (Kreditanstalt für Wiederaufbau) with subsidies or credits with low interest rates only if an airtightness test is performed and the n_{50}-value complies with the benchmarks. Furthermore, when a test is performed, EnEV 2014 requires that airtightness is not higher than n_{50}=3 1/h for buildings without mechanical ventilation and n_{50}=1.5 1/h for buildings with mechanical ventilation.

In the US, various state building codes require the inclusion of an air barrier or whole building tightness limits (some of them include mandatory testing) [24].

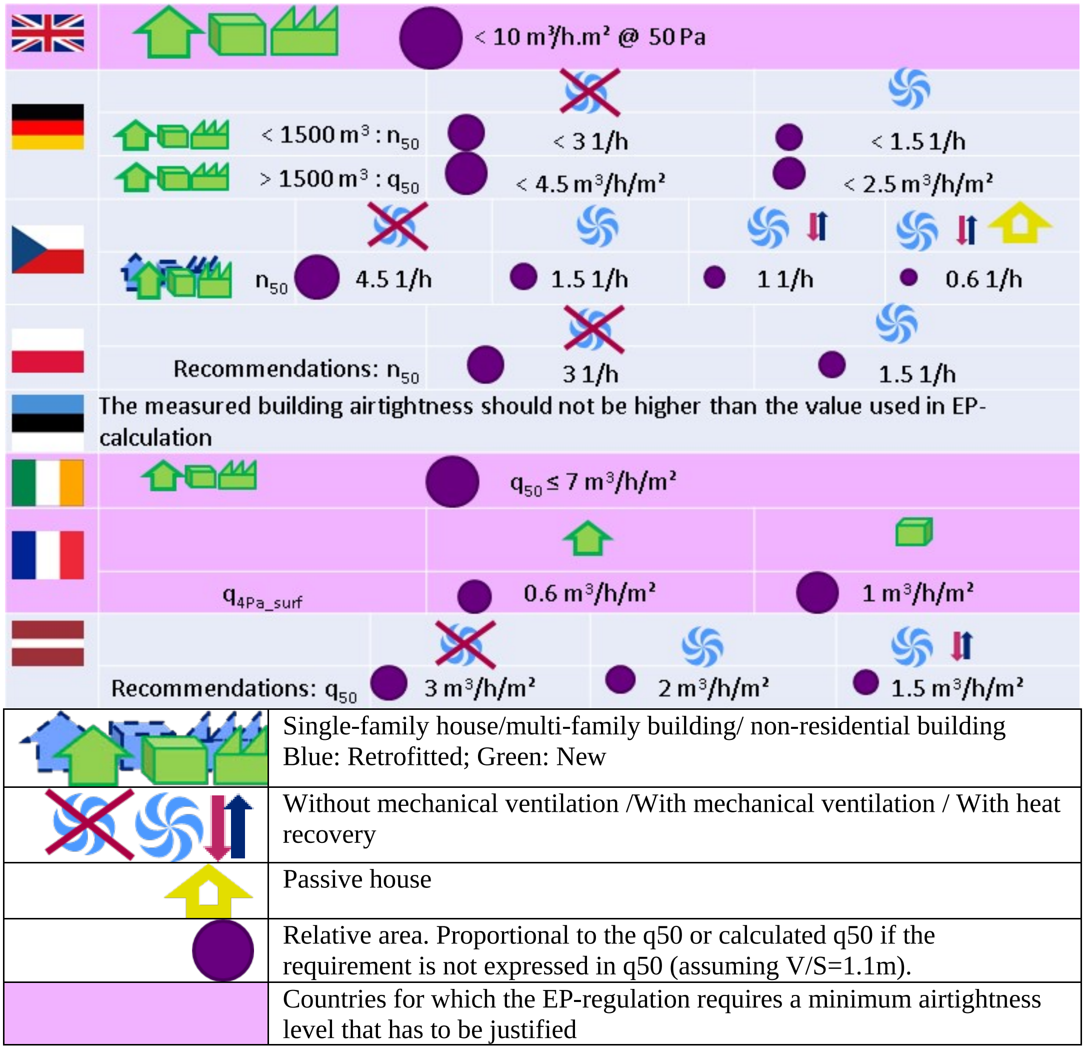


Figure 1 : Summary of airtightness requirements and recommendations in some European Countries (information gathered within Tightvent Airtightness Associations Committee)

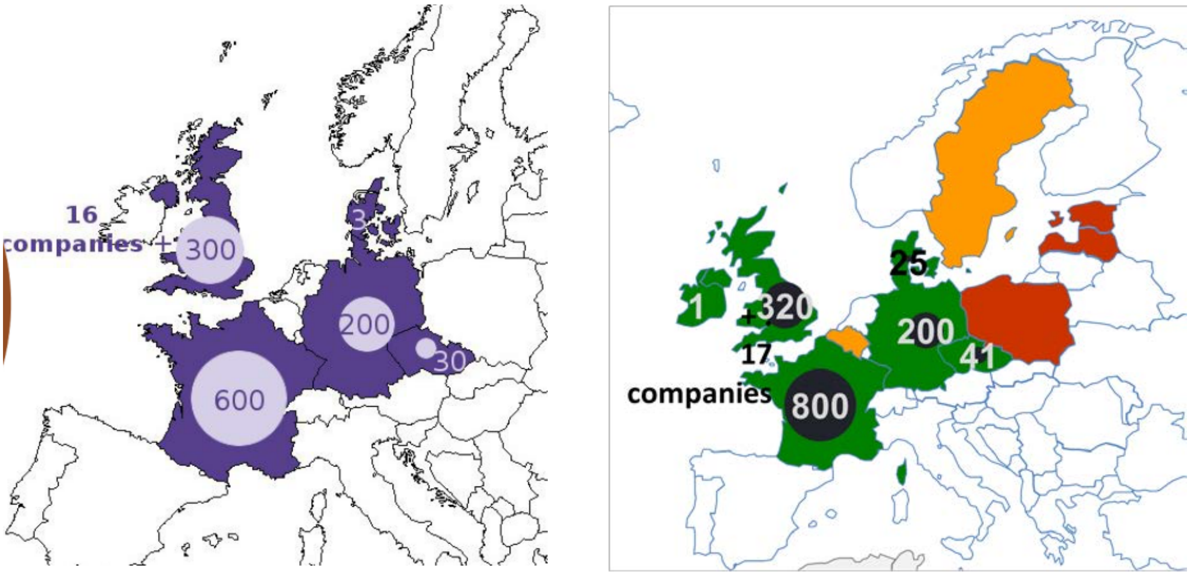
3.2 Qualification of testers and compliance frameworks

Qualification schemes for testers have been implemented in 7 European countries (Belgium, Denmark, France, Germany, Ireland, Sweden and UK); in the Czech Republic, there is no qualification but an association of testers with an ethical code. Those qualification schemes have been described and compared in a study by Leprince & Carrié [25]. Figure 2 gives an overview of the increase of qualified testers since 2013 in Europe, including the birth of a new scheme in Belgium and Sweden.

In the UK, the qualification has evolved in 2015, the government now accredits qualification bodies. Therefore there are now two qualification schemes for testers: ATTMA (Air Tightness Testing & Measurement Association) and iATS (The Independent Airtightness Testing Scheme).

In Belgium, a qualification process for testers was launched in 2014 [26]. Loncour et al. describe the Belgian framework for reliable fan pressurisation tests for buildings. It includes requirements for:

- the qualification of the testers (accreditation or qualification examination);
- the testing of material (calibration aspects);
- the technical criteria (e.g. pressure differences at zero-flow); as well as
- third party on site control (e.g. by repeating the measurement with the testers).



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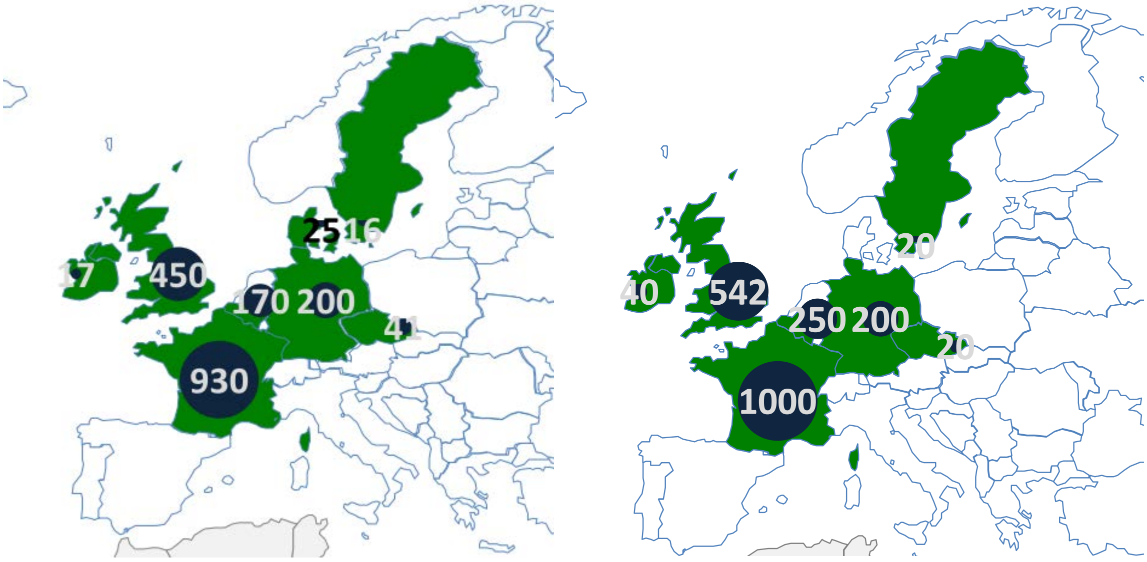

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Figure 2: Evolution of the number of qualified testers in Europe [58]

3.3 Database developments

The development of databases confirms the growth in the number of tests performed in Europe. It gives valuable statistical data to better understand the impact of building characteristics on airtightness [27], [21], [28]. It is also an important tool to estimate the impact of regulations, EP programmes (new and retrofitting) on building airtightness [21], [29].

The French database managed by Cerema gathers over 65,000 data points [21]. In US, the Lawrence Berkeley National Laboratory (LBNL) Residential Diagnostics Database contains more than 130,000 data points [30].

In the U.K., qualification schemes ATTMA and iATS introduced in 2015 and 2016 mandatory lodgement for all members representing over 540 test engineers across the U.K. ATTMA has worked with the main fan manufacturers used in the U.K. to support the development of their test software to be able to lodge tests from within the software [31]. For ATTMA, in average, this system lodges around 550 tests per working day.

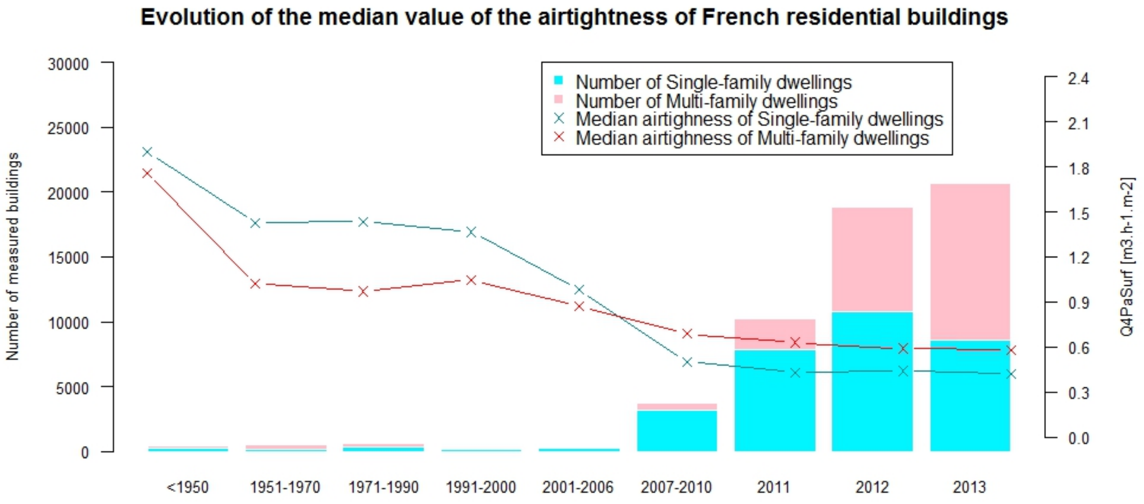

Figure 3 : Evolution of the airtightness envelope measurement and their results for residential buildings [21]

3.4 Improvement of test methods

3.4.1 Calibration of pressurisation test equipment

In compliance frameworks, implying potential legal issues with large financial consequences, the reliability of testing devices is of great concern. This is why calibration requirements have been discussed extensively in several countries. As a result, several rules have been introduced or revised, for instance:

- In the UK, annual calibration of manometers, flowmeters and thermometers by a laboratory accredited by the UKAS (United Kingdom Accreditation Service) has been mandatory for years.
- In France, after 3 years of discussion, annual calibration of the manometer by a COFRAC (French Accreditation Committee) accredited laboratory is now required; the flowmeter has to be calibrated every 2 years [32]. Along these lines, some manufacturers recommend calibration by an accredited laboratory to improve their reliability [33].
- In Belgium, measurement devices have to be calibrated every 2 years, either by a BELAC (Belgian Accreditation Structure) accredited laboratory, an ISO9001 laboratory or by the manufacturer. Moreover, in Belgium since 2015 the qualification includes onsite control where the controller may check the good condition of the devices [34].
- In the Czech Republic, round-robin tests are organised to check reliability of both measuring devices and testers [35].
- The revised international standard ISO 9972:2015 has strengthened requirements regarding measurement devices. A pressure-measuring device is an instrument capable of measuring pressure differences with an accuracy of ± 1 Pa in the range of 0 Pa to 100 Pa (instead of ± 2 Pa in the range of 0 to 60 Pa in 13829:2000) and a temperature measuring device shall have an accuracy of 0,5 K (instead of 1 K) [36].

3.4.2 Building preparation

Building preparation errors are probably the dominant source of uncertainty in an airtightness test [37]; for instance, omitting to seal an intentional ventilation opening will increase the measured leakage area by about the size of that opening, which will likely be a major problem for most low-energy buildings. This has led several countries to lay down rules to explain in which circumstances openings should be closed, sealed, or left as is.

Leprince et al. compared building preparation rules for airtightness testing in 11 European countries [38]. The authors pointed out that even though the reference testing protocol in Europe is described in EN 13829 (now EN ISO 9972:2015), many countries have developed specific guidelines to detail or adapt to the standard’s requirements. Time of measurement and building preparation differs significantly from one country to another (Figure 4), even when the same method is used and without clear and technically-sound motivations behind the choices. The two methods described in the standard are either too detailed or insufficiently described to fit with the specificities of each country regarding building preparation. The study concluded that the revision of the standard should:

- on one hand describe more precisely the basic principles of the preparation to avoid ambiguities and,
- on the other hand, allow some flexibility to the countries to specify rules consistent with their energy performance calculation method.

This supports “method 3” in ISO 9972:2015, which is one of the major changes compared to EN 13829:2000. "Method 3" is to be defined at national level which allows adapting the measured extent and the building preparation to the purpose and context of the test.

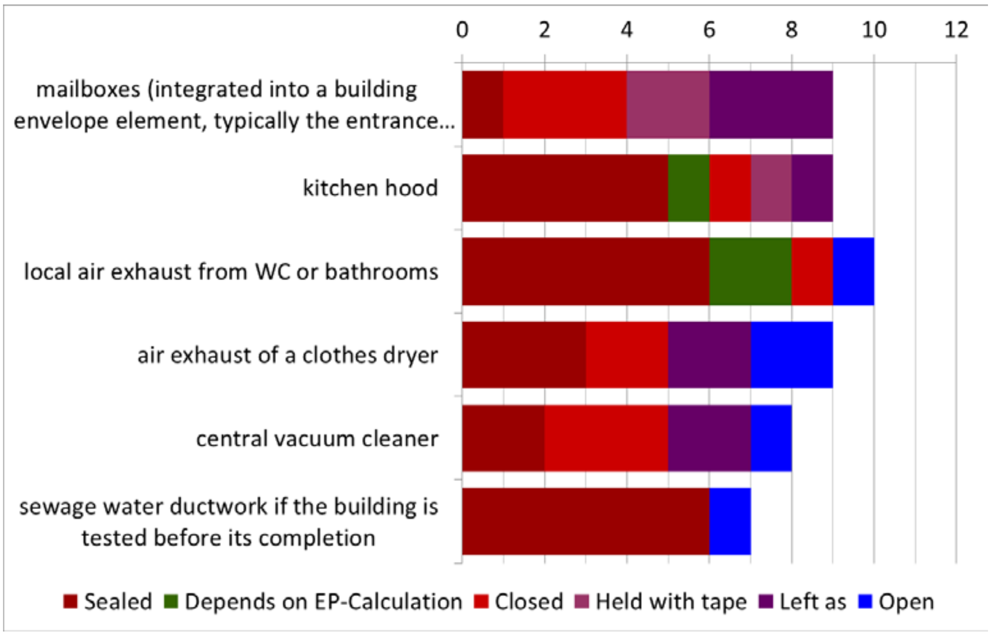

Figure 4: Various types of preparation for "other openings" among respondents (European countries) [57]

3.5 Information on airtightness performance and tools for practitioners

3.5.1 Characterisation of airtightness products and systems performance

Building airtightness policies have had a pivotal influence on the development of information related to the characterisation of products. For instance, Mees gives an overview of products used for airtightness with information on their durability [39]. Van Mieghem gave an overview of sealing products and standards that can be used to characterise their performance in terms of air permeability, VOC emissions, movement capacity, etc. [40].

There is a revived interest for the long term performance of airtightness products. Although it was a key subject of research in the second part of the 80's (mostly in the USA and Canada), very few studies were published during the 90's and 2000. The long term performance is studied by artificial aging of products and constructions and by measuring buildings again after a few years of use.

Although there are a number of studies addressing this issue [41], [42], [43], [44], [45, there is no consensus yet on the protocol(s) to test the longevity of sealing systems and materials, which leads to significant discrepancies in the results. Nevertheless, the following general conclusions can be drawn:

- the quality of the implementation of the airtightness barrier has a great impact on the durability;
- products do not have the same behaviour under extreme conditions (extreme temperature, humidity or pressure);
- aging strategy has to be consistent with loads applied on products, the strategy may differ between exterior, indoor or embedded air barrier;
- a standardised procedure for artificial aging of airtightness products is missing to characterise products and constructions.

As regards on-site longevity assessments with measurements after a few years of completion of the building, it seems that the building airtightness decreases in the 3 first years after completion and then stabilises [46], [20], [47], [48]. Nevertheless, there is a lack of understanding of the influencing factors explaining those results.

3.5.2 Guidelines

In Europe, various documents intended for craftsmen and designers have been published in the last years. In 2010, the Mininfil project in France produced a collection of almost 200 technical drawings describing how to deal with the airtightness of junctions [49]. In 2015, the CSTC (Centre Scientifique et Technique de la Construction) has published a technical note on building airtightness gathering both technical information, schemes and information on products and durability proposed solutions [39]. In Germany, FLIB together with KfW issued a "guidelines airtightness concept" with a databank of construction details online [50].

Guidelines are also summarised in publications such as “The 10 steps to conceive and build airtight buildings” [51] or "How to construct a domestic pitched roof with high thermal quality?" [15]. The continuous air barrier requirement is now included in ASHRAE 90.1-2010 "Energy standard for buildings except low-rise residential buildings" [24]

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Figure 5: *Example of guidelines for craftsmen and designer in Europe, Left: Carnets Mininfil, Center: Note d'information technique du CSTC, Right: German "guideline airtightness concept" [49]*

3.5.3 Quality management approach

Implementing an airtight building requires planning and coordination. Implementing a quality management approach has proven to be an efficient way to reach airtightness targets. In France, having an "approved quality approach" is one of the two ways to justify airtightness levels (systematic testing is the other way). More than six years of experience are reported in various publications [52] [53] [54] [55] [56] and prove the effectiveness of the approach as long as it is well-defined and well-controlled. In France, this approach has been a success among single-family house builders. The scheme to obtain an "approved quality approach" has evolved to fulfil requirements. Certification bodies (in agreement with the French ministry for construction) are now in charge of the certification of quality approach and perform on site controls to check its implementation [57].

Kotol et al [58] and Bracke et al [47] studied the reproducibility of the leakage level achieved by the same construction method and workmanship. Kotol et al stressed the need to adopt a quality framework for homogenous workmanship, and concluded that the specification of an airtightness requirement is not enough [58]. Bracke concludes that the standard deviation is only 12% in 8 identical houses achieved by the same workers, which supports that systematic testing may not be necessary when a quality approach is implemented.

3.6 Perspectives

In the past 5 years, we have observed significant policy changes with regulations or programmes requiring building airtightness testing or strongly pushing better building airtightness, and consequently, development of qualification schemes, data collection, improvement of test methods, information on airtightness performance and tools for practitioners.

We expect that the development of databases will significantly help the analysis of the impact of some of these measures in the next years, including the market impact of the regulatory measures in terms of building airtightness improvements and innovation; the relevance or update of default values based on field data; the analysis of frequent defects and ways to overcome them.

Nevertheless, we have identified several areas with significant knowledge gaps, including:

- possible side effects of policy gaps and inconsistencies that may lead to degraded indoor air quality (for instance, means to secure ventilation provisions in new and existing buildings or to avoid the development of moisture during construction);
- the assessment of the durability of airtightness products and systems, both with laboratory characterisation with artificial aging and on-site assessments;
- the effectiveness of certification/qualification tester schemes to improve input data used in energy performance assessment methods;
- practical testing methods in large buildings. Whereas it is clear that sampling rules to achieve consistency between tests on sub-zones and the whole building are difficult to find—there is no useful correlation between building cracks in different parts of a building—such rules can be useful in a compliance framework to conventionally determine if the building airtightness is compliant based on tests on sub-zones. Nevertheless, it remains unclear which rules are appropriate to limit deviations to compliance;
- integrating the impact of wind in uncertainty analyses in order to allow testers to perform tests in windier conditions than those specified in ISO 9972, yet keeping confidence in that the building airtightness is compliant with requirements.
- integrating information technology (IT) in airtightness software to improve the reliability of tests by automatic fill-in fields (ex. localisation, meteorological data, etc.), to help central data collection, and to ease control of testers.

4 A worrying negligence of ductwork airtightness impacts

Duct leaks are known since many years to be detrimental to energy use and indoor air quality. However, there has been a relatively limited body of literature addressing this problem in the past 5 years. This is likely due to the fact that this problem is either resolved (in Scandinavian countries) or poorly addressed in standards and regulations which seem to be the main missing drivers in other countries.

Regulatory energy calculation very seldom account for duct leakage impacts. In Europe, only France and Belgium consider ductwork airtightness as an input in the energy calculation. In these two countries, there is no regulatory minimum requirement but better ductwork airtightness; if justified, reduces the calculated energy use.

It seems that only two recent French programmes (Effinergie+ and Effinergie BEPOS) require proving the achievement of minimum ductwork airtightness levels. The approach is quite similar to that developed for envelope airtightness: the required levels have to be justified by testing with a qualified tester or with the application of a quality management approach. Effinergie also requires a visual check of the completeness of the system and gives guidelines to perform and analyse airflow rate measurements. Note that, while the protocol requires a visual check of the ventilation system, as of today it does not require the measurement of the airflow rates. This is due to the lack of knowledge on the uncertainties obtained when measuring airflow rates at air terminal devices when the label was developed.

Overall, the intent is to foster the concern for proper functioning of ventilation systems, as several field studies have shown a non-compliance rate over 50% for ventilation provisions [59], or pointing out excessive ductwork leakage. Note that the recent schemes in UK and Flanders (Belgium) requiring commissioning of ventilation systems with airflow rate measurements [60] [61] should also positively influence ductwork airtightness, because required airflow rates are unlikely to be met with excessive duct leakage.

Unfortunately, as of today it is too early to evaluate the relevance of these schemes. The collection of qualified testers' data should allow scheme holders to analyse their market impact progressively, starting in the coming months for Effinergie.

One could regret that building airtightness and ventilation performance (including ductwork airtightness) are not addressed simultaneously in most regulation and programmes, given their close interaction. This loops back to IAQ and building durability issues mentioned above.

5 Conclusions

Dissimilar progress has been made in the past 5 years on the topic of building and ductwork airtightness. Although there is clear evidence of a market transformation on the subject of airtightness in several countries, there remains potential for substantial energy savings and improved indoor environmental quality by addressing simultaneously ventilation performance and building and ductwork airtightness. Measures taken to grasp this potential shall address issues such as energy efficient ventilation, comfort, skills development and market uptake in a holistic approach, addressing both new and existing buildings. Measures should build on the recent developments in several member states, in particular on building airtightness compliance and quality control. Appropriate legislation and standards appear essential to support this effort.

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This information paper is based on a review of about 60 publications from the AIVC-TightVent conferences and workshops from 2011 to 2015. A few additional papers have been included to further support some of our statements. Although we have not restricted our literature review to specific parts of the world, the majority of the publications we found come from Europe and the USA.

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