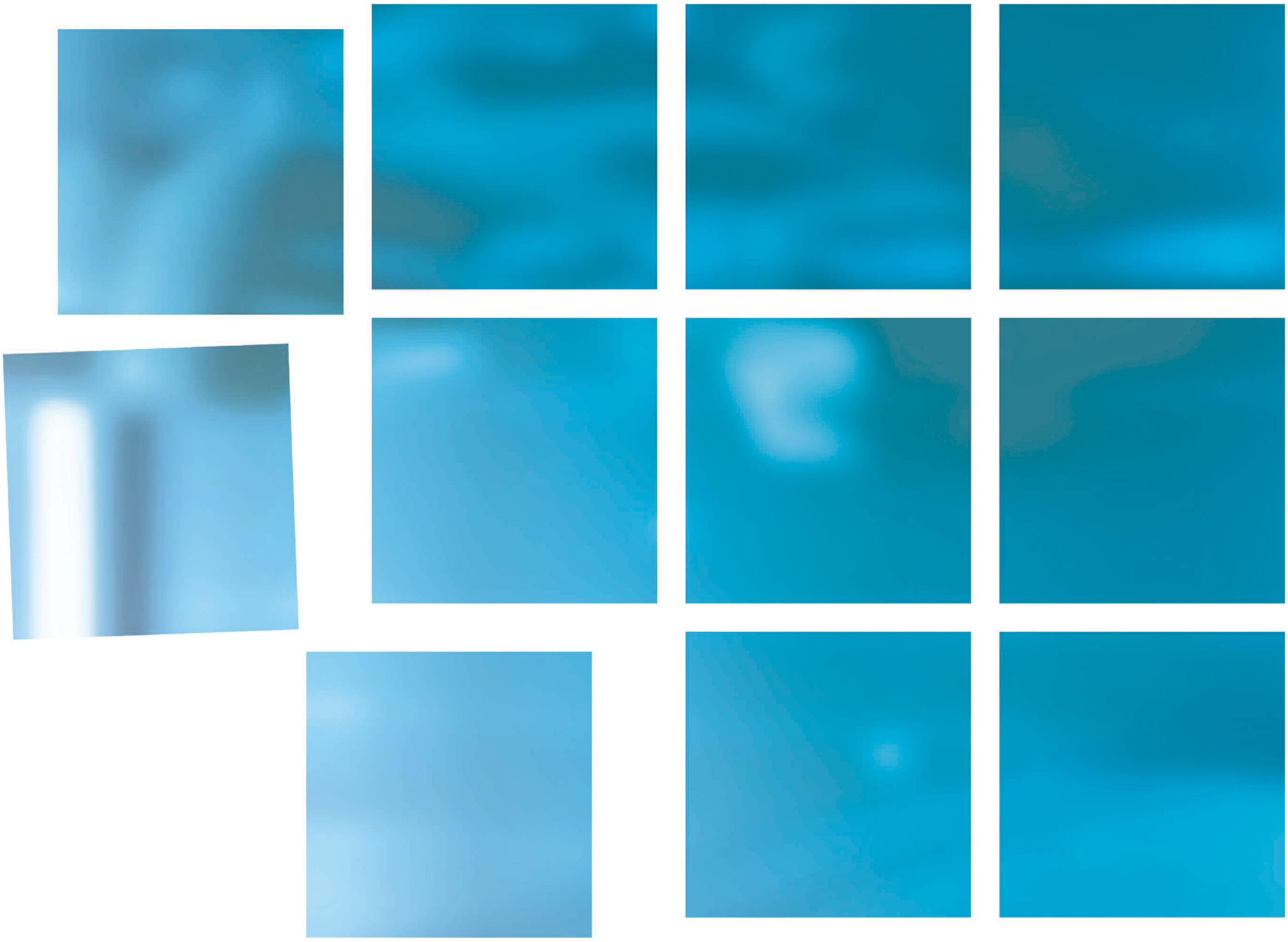

BUILDING AND DUCTWORK AIRTIGHTNESS

SELECTED PAPERS FROM THE REHVA SPECIAL JOURNAL ISSUE ON 'AIRTIGHTNESS'

This report has been produced by TightVent Europe

TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

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SELECTED PAPERS FROM THE REHVA SPECIAL JOURNAL ISSUE ON 'AIRTIGHTNESS'

This ebook has been produced by TightVent Europe, www.tightvent.eu

It includes a number of selected papers from the REHVA special journal issue on airtightness

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FOREWORD

The 2002 Energy Performance of Buildings Directive (EPBD) already indicated the potential importance of airtightness. With the 2010 EPBD recast and its ambitious 2020 targets, there is even more pressure on these aspects since for most European climates and countries, good envelope and ductwork airtightness levels are necessary to achieve nearly zero-energy buildings.

Several studies report an energy impact of leaky buildings on the order of 10 kWh per m^2 of floor area per year for the heating needs in a moderately cold region (2500 degree-days) and 0 to 5 kWh/m^2/year for the ducts plus the additional fan energy use. There is a growing number of studies showing the significant impact of building and ductwork leakage in hot and mild climates as well. The general consensus from these studies is that attention must be paid to building and ductwork airtightness in nearly all climate regions of the European Union to meet nearly zero-energy targets.

How do we achieve this in practice? First of all, building and ductwork airtightness has to be seen as a part of the building system. Legitimate concerns for energy efficient ventilation, comfort, skills development and market uptake must be considered in a holistic approach, addressing both new and existing buildings. There are promising signals with regard to the measures taken in several Member States to encourage better building and ductwork airtightness. For example, there are over 10 countries, covering all climate regions of Europe, with active (and usually very active) networks of professionals specialized in airtightness issues. Also, the steps taken by some Member States to improve building and ductwork airtightness, including actions on regulation, financial incentives, training, control and awareness raising, look promising.

In 2011, the TightVent Europe platform (www.tightvent.eu) was launched with a strong focus on market change in airtightness. The large number of attendees at the two last AIVC-TightVent conferences, as well as the large range of countries and issues addressed during these conferences, linking airtightness, comfort, indoor air quality and market transformation, show the growing interest in this topic.

This publication is a collection of the airtightness related papers in the special issue of the REHVA journal January 2013. REHVA and INIVE agreed to have a special issue focusing on the topic of airtightness, whereby INIVE was acting as guest editor and whereby it was agreed to have the right to publish these contributions as a separate publication.

On behalf of the TightVent partners, we wish you a pleasant and informative reading.

Rémi Carrié, Senior Consultant INIVE EEIG

Peter Wouters, Manager INIVE EEIG

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- BlowerDoor GmbH - Measuring Systems for air tightness (www.blowerdoor.de)
- BPIE - Buildings Performance Institute Europe (www.bpie.eu)
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33rd AIVC AND 2nd TIGHTVENT CONFERENCE
SUMMING UP OF AIRTIGHTNESS TRACK

The airtightness track at the AIVC conference consisted of 29 presentations organized in 7 sessions. In 3 sessions research work was presented dealing with various airtightness related aspects as requested in the call for papers. In 4 sessions invited presentations and structured discussions were offered to give an overview of some specific conference topics:

- Ductwork airtightness
- Quality and building airtightness
- Quality of domestic ventilation systems
- Philosophy and approaches for building airtightness requirements

In the following paragraphs a bird's eye view is given of trends and conclusions that appeared in the presentations and discussions in the airtightness track.

Arnold Janssens, Professor of Building Physics, Ghent University, Belgium

From airtightness requirements to quality assurance

A number of presentations showed experimental evidence of the fact that new buildings become increasingly more airtight, compared to buildings built in previous decades. This evolution is attributed to the strengthening of energy performance requirements, typically in European countries, and to innovations in construction practice. According to the European Energy Performance of Buildings Directive (EPBD) the influence of air infiltration on the energy use of a building is taken into account when assessing the energy performance. As a result, building designers pay more attention to airtightness in order to meet more severe energy performance requirements for new buildings. However, in some countries also explicit airtightness requirements are set in order to prepare the market for a change towards 'nearly zero energy buildings'. An example of this approach is the French RT2012 legislation, which requires the airtightness of all new residential buildings to be tested in order to show compliance to legal limits.

Several presentations showed that the specification of airtightness requirements alone is not enough to achieve good building airtightness in reality. When no quality framework is adopted, design intents for airtightness are not systematically met because of flaws and variations in workmanship. This was shown in a project in Greenland where a large number of identical flats in a building was tested and a standard deviation of 47% was reported. Creating airtight building envelopes entails profound changes in design and construction practice and requires careful planning of the overall building process. Therefore a number of quality management and training schemes were presented in order to master this process.

Sweden has a long experience with the implementation of quality ductwork systems and has included quality requirements in the AMA specification guidelines, based on subsequent partial testing. In France regulatory quality management processes are operational for building airtightness compliance by constructors, based on self-declared testing of a sample of the housing production. Control tests have shown that these schemes are very effective in achieving good airtightness in practice (Figure 1). Good examples of certification schemes for craftsmen were given by FLiB in Germany (Fachverband Luftdichtheit im Bauwesen), with guidelines for selection and installation of air barrier systems.

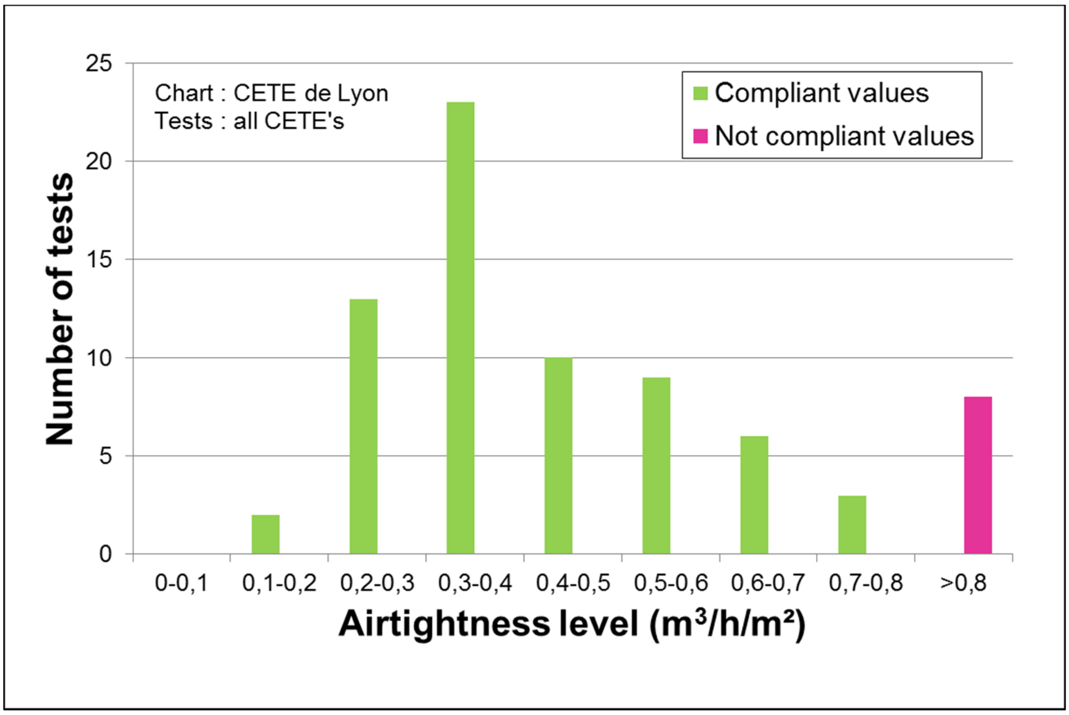

Figure 1: Results of control tests showing effectiveness of French quality framework for building airtightness compliance (85% compliance demanded, 89% compliance achieved), (Juricic et al.)

Air leakage testing and infiltration modelling

When airtightness requirements become more severe, also fan pressurization equipment and testing procedures to show compliance should allow to obtain reliable and repeatable test results. Several presentations were dealing with these issues. For testing single apartments in multifamily buildings different experimental procedures exist, and it is not always clear what one is measuring. A number of test results were presented quantifying the leakage distribution in apartments for different purposes: eg to assess the transfer of pollution between individual flats, or to assess the air leakage distribution ratio between internal and external partitions of apartments. A large-scale measuring campaign in high rise residential buildings in South Korea revealed that internal walls between flats often show the highest leakage (30-60% of total leakage).

A better knowledge of the air leakage distribution over the building envelope is also important to come to a more reliable extrapolation of fan pressurization test results at 50 Pa to air infiltration rates under natural driving forces (and related heat losses). While this extrapolation is typically based on rules of thumbs (the ‘rule-of-20’) or simplified steady-state models (Normalized Leakage), advanced simulation studies were presented to analyse the influence of uneven leakage distribution and unsteady wind conditions on air infiltration rates. Ultimately these studies should allow to develop more refined and accurate leakage models for infiltration heat loss assessment in high performance buildings.

IAQ and ventilation in airtight buildings

The fact that new buildings become more airtight is good news for the energy performance of buildings, but is also a reason for concern when indoor air quality and health issues are considered. In countries where residential ventilation traditionally relied on air leakage and on occasional opening of windows, such as in New Zealand, it is now found necessary to introduce reliable ventilation solutions to achieve acceptable IAQ and moisture control in new airtight houses. Even in countries where the installation of residential ventilation systems is part of the building code requirements, such as in most European countries, acceptable indoor air quality is not necessarily achieved. A number of multizone simulation studies were presented addressing IAQ performance in airtight houses. Although simulations showed that IAQ may improve with enhanced building air tightness, specifically for exhaust ventilation systems where designed air transfer is reinforced, the IAQ and indoor humidity achieved in airtight houses is sensitive to ventilation system design, sizing and installation errors.

However, some presentations discussed results of large-scale field studies showing striking evidence that installation quality of residential ventilation systems is typically insufficient. This was the case for studies performed in the Netherlands, Belgium and Estonia. Common shortcomings were insufficient supply ventilation capacity compared to design standards (in more than half of the investigated houses, Figure 2), increased noise levels in case of mechanical ventilation systems, and poor operation and maintenance. An overall conclusion was that together with increased building airtightness, more attention should be paid to ventilation system performance and installation quality, in order to guarantee healthy indoor environments. This requires a change of mind set, not only with building practitioners, but also with builders who should be more willing to pay the price for good quality ventilation systems.

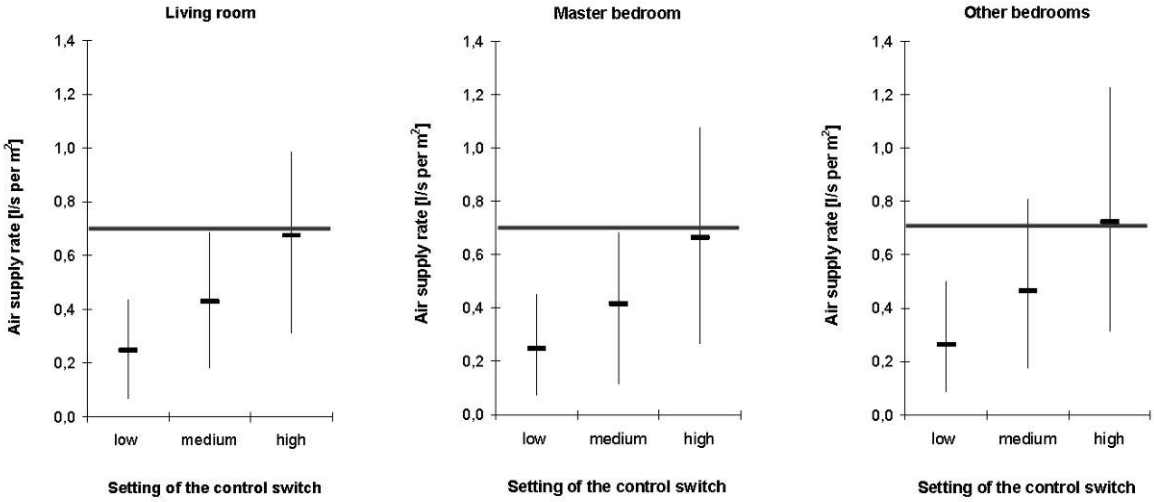

Figure 2: Air supply rates (average, P10 and P90) in the living room, master bedroom and other bedrooms in dwellings with balanced mechanical ventilation, at different control settings. The horizontal line gives the reference (minimum) level according to the Dutch Building Code (0,7 $l/s/m^2$), (Boerstra et al.).

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[2] Boerstra A., J. Balvers, R. Bogers, R. Jongeneel, F. van Dijken. 2012. Residential ventilation system performance: outcomes of a field study in the Netherlands. Proceedings of the 33rd AIVC Conference and 2nd TightVent Conference, Copenhagen, INIVE, 170-175.

PROPER BUILDING PREPARATION FOR ENVELOPE AIRTIGHTNESS TESTING

Proper building preparation is required before initiating an airtightness test. While this may seem surprising, HVAC systems often account for the most difficult part of the work. Taking this into consideration at the design stage of HVAC systems, however, can make the preparation easier.

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Introduction

When measuring the airtightness (or air permeability) of a building, there is a crucial question that needs to be addressed before starting work: **What is the objective of the measurement?**

This question, however, might be obscure for most people and may need refinement.

There are various reasons why one could measure the airtightness of a building:

- To check compliance with a building code or contract (e.g. $n_{50} \leq 2\ h^{-1}$);
- To check the effectiveness of new construction details (compared with other details in other buildings);
- To calculate the building's energy performance;
- To find and seal leaks;
- …

There are also different parts of a building that can be tested:

- The entire building;
- The thermally insulated part of the building;
- A new part of the building;
- One apartment in the building;
- All the apartments on a given floor;
- A block of offices in a factory;
- …

Hence, defining the objective of the test is essential for the operator who needs answers to practical questions:

- What part of the building is to be tested?
- What are the rules governing the test?
- What are the intentional openings in the envelope of this part of the building?
- What HVAC systems and other equipment are present in this part of the building?

All of this leads to the final question: What preparation does the building require?

Preparation in standards

Preparation of the part of the building subject to the test (hereafter called "the building") is specifically addressed in ISO 9972:2006 [2] and EN 13829:2000 [1], where different methods are described depending on the purpose:

- Method A (test of a building in use);
- Method B (test of the building envelope);
- Method C (test of the building in use) (not available in EN 13829).

In the current revision of ISO 9972 [3], the third method is replaced by a "free" method intended for specific purposes

such as checking compliance with energy performance regulations. It thus opens up the possibility of preparing the building in accordance with a national regulation while still complying with the standard.

A point in common with all three existing methods is that all doors and windows in the building envelope must be closed. Another common point is the opening of all interconnecting doors within the building (note that the present exception for cupboards and closets will probably be deleted in the revision of ISO 9972).

Preparation of HVAC systems

In addition to these easily accessible openings and a number of secondary ones like post boxes or cat flaps, the main preparation work relates to HVAC systems.

First, all devices taking air from or removing air to the outside must be turned off: heating systems with indoor air intake, mechanical ventilation and air conditioning systems, kitchen hoods, etc. Since test operators generally are not HVAC engineers, instructions for operation should be available if needed.

It is important to understand that measuring a building's airtightness involves pressurising or depressurising the envelope typically at 50 to 100 Pa. Therefore measures must be taken to avoid diverting combustion gases or polluted air from their intended routes and venting them instead into occupied spaces.

In some cases, e.g. when open gas boilers in apartments are connected to the same chimney, it might be necessary to turn off the boilers of all apartments in the building, even if only one of them is being tested.

Second, all intentional openings in the building envelope dedicated to HVAC systems must be treated according to the measurement method. The three possible treatments are closed, sealed or open (Table 1).

When openings must be closed for the test, leaks in the closing system are taken into account in the global air leakage rate of the building. This means that the choice of HVAC components such as closable externally-mounted air transfer devices can be of great importance, not only with regard to ventilation but also with regard to the building's airtightness.

The same consideration could apply to smoke dampers or shut-off dampers for ventilation systems, cooker hoods and open fires.

Table 1: Treatment of the intentional openings in function of the test method (ISO/CD 9972:2012 [3])

Classification of openings	**Method 1 Test of the building in use**	**Method 2 Test of the building envelope**	**Method 3 Test of the building for a specific purpose**
Ventilation openings for natural ventilation	Closed	Sealed	Closed, sealed or open as specified
Openings for whole building mechanical ventilation or air conditioning	Sealed	Sealed	Closed, sealed or open as specified
Openings for local mechanical ventilation or air conditioning (intermittent use)	Closed	Sealed	Closed, sealed or open as specified
Windows, doors and trapdoors	Closed	Closed	Closed, sealed or open as specified
Openings not intended for ventilation	Closed	Sealed	Closed, sealed or open as specified

When openings must be sealed for the test, their tightness depends on various factors:

- The skill and caution of the operator;
- The accessibility of the opening;
- Technique and material.

Remember that the highest pressure exerted on the building envelope during an airtightness test is approximately 100 Pa, which represents 10 kg/m². Thus, sealing works must be able to withstand this pressure. However, this is not always easy with large louvres for example (Figure 1).

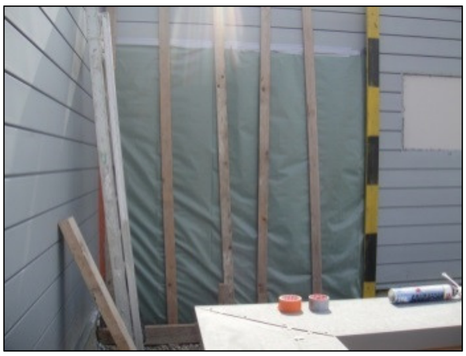

Figure 1: Sealing a large louvre can prove to be a difficult task

Sealing the mechanical ventilation systems is often necessary. There are three options:

- Sealing the air terminal devices;
- Sealing the air intake and exhaust;
- Sealing the main ducts.

Sealing the air terminal devices (ATDs) is often an easy job in single dwellings but can be very tedious in multi-family buildings or in office buildings for example. The most often used technique consists of removing the ATDs from the ducts and replacing them with rubber bladders (Figure 2). Alternatively ATDs can be sealed with adhesive tape.

Figure 2: Rubber bladders can be useful for sealing ventilation ducts

Another option is sealing the air intake and exhaust vents, but this often requires access to the roof or the top of a wall, which might entail specific security measures.

The third option consists of sealing the main ducts just before or after the air handling unit (AHU). This, however, requires access to the inside of the ducts through the AHU or a partial dismantling of the ducts, work that cannot be done by the test operator (Figure 3). Proper inspection panels in these ducts might be very useful here.

To eliminate the need to seal the ventilation systems, shut-off dampers could be installed in the air intake and exhaust ducts. These of course should be sufficiently airtight when closed, in order not to degrade the results of the airtightness test. These dampers would also be useful when taking shelter in buildings is necessary, e.g. in the case of a large-scale outdoor pollution release.

It is also important to note that the airtightness of the ventilation ducts can influence the results of a building's airtightness test. During the test, air indeed could leak out of or into the ducts within the building envelope, and again leak into or out of the ducts outside the building envelope. Sealing the ducts precisely where they go through the building envelope could avoid this problem, but it is generally not feasible in practice. Making the ducts airtight is therefore recommended not only for ventilation purposes.

Chimney flues for boilers, air heaters or stoves are often open (or even closed in the case of stoves) during the airtightness test of the building. They, however, could be sealed if required for the test. In this case, access hatches primarily intended for soot removal can be very useful (Figure 4).

Figure 3: Sealing the main ducts just before or after the air handling unit is an option, but it generally requires dismantling the ducts.

Figure 4: Access hatches in chimney flues can be very useful if the flues need to be sealed for the airtightness test.

References

[1] EN 13829:2000 Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:1996, modified)

[2] ISO 9972:2006 Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method

[3] ISO/CD 9972:2012 Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method

PERFORMING INTERMEDIATE CHECKS AND EARLY-STAGE TESTING OF AIRTIGHTNESS

Good building airtightness is now commonly regarded as an important prerequisite for both good energy performances, user comfort and service life of most modern buildings. Builders want to avoid the surprise of a poor air-tightness measurement result in the finished phase of a new building. Repairing documented air leaks can then be a very costly experience and a complicated process.

This paper gives effective methods to overcome this problem, by sharing some good experiences from the process of avoiding pitfalls and achieving good airtightness of buildings.

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Early-stage testing

Performing intermediate checks and early-stage testing of air tightness of the building envelope is becoming part of common practice in Norway. Locating and repairing leaks is at this stage is usually a very cost-effective task.

There are several approaches to early-stage testing:

Testing representative small parts of the envelope: In large building projects one may test representative parts of the envelope details that have been completed early compared to the rest of the project. The purpose of this is to gather experience that can be used further on other the parts of the project. This test is also useful as an extra quality assurance of as-built design, details and description of workmanship issues. This is especially helpful when the builder is confronted with building products or details that are new to the firm or to the industry.

One method of doing this testing is by defining and pressurizing a temporarily isolated representative zone, as shown in Figure 1.

Figure 1: Temporary “tent” made from plastic foil, with a (red) blower door mounted. The amount of air that is sucked out of the tent by the fan in the blower door equals the leaking air that passes through the details of the façade being tested. A person inside the tent may easily detect air-leakages in the facade by just feeling with his hand along joints and details in question, if the air pressure inside the tent is kept at a lower level than the outside (around 50 Pa). This picture is from a new large building with passive-house ambition ($n50 < 0,6\ h^{-1}$). (Photo: Tormod Aurlien)

In this case, one measures the leakages from the test zone, including leakages from the temporary “tent”. Designers and contractors may draw conclusions of good detailing, if one reaches good levels of airtightness. In the opposite case, one may not draw too strict quantitative conclusions, as some of the leaking airflow may come from the tent.

Testing zones: Another approach is to pressurize a zone. These zones are often volumes of the building that are supposed to be airtight from other zones for other reasons too, like fire zones of a large building. In early stages of this kind of a building project, extra preparations are often required to insure air-tightness from the other zones. Just achieving a pressure difference by use of a fan (not needing to read the measured leakages), and using a thermography camera, the technician may detect problems that need to be fixed for the rest of the project. Figure 2 shows one example of a practical issue that had not been thought about in the design phase of the project: temporary anchoring of the outside scaffolding. In this case, the design was immediately changed for the rest of the building project, and the already built part has been repaired.

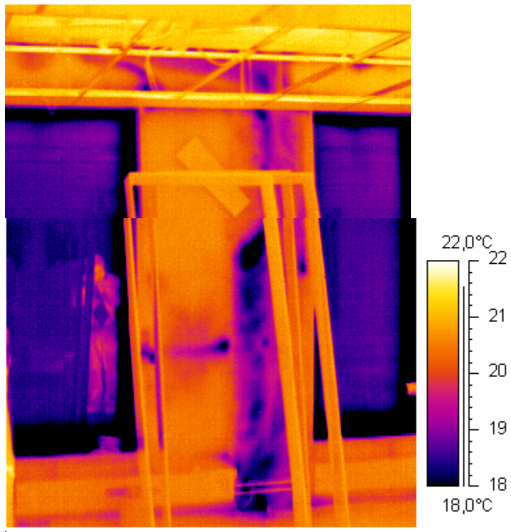

Figure 2a: Thermography from inside of construction shown in next photo

Figure 2b: Leaky wind barrier detail, from anchoring of the outside scaffolding (Photos: Tormod Aurlien).

Wind-tight-layer testing: What seems like a Norwegian speciality is our relatively new emphasis on testing detached and semi-detached houses in early wind-tight-stage, often by using low-cost simplified equipment. A very large part of our population lives in these houses, and small firms usually build them.

Common experience from numerous airtightness measurements that have ended up with high air permeability levels, shows that trying to repair leaks on the inside often is nearly fruitless. A report often has thermograms pinpointing the leaks, but the technician only detects where the leakage airflow enters the inside of the building, not its source. The source may be somewhere in the outer wind-tight layer. Once the air has leaked in from the outside, it is easily distributed through cavity constructions that are filled with highly permeable insulation. As constructions have become thicker, often with the vapour-barrier being placed at a defined distance from the surface materials, it has become increasingly more challenging to detect the flow paths using infra-red cameras or other detection techniques.

A natural response to this has been to perform airtight-measurements in the stage where the outer layer is complete, doors and windows are in place etc., but *before* insulation is placed from the inside and covered. Leakages are readily detected in this stage, by just feeling with the hand, having an inside under-pressure through use of the measuring fan. Furthermore the repair of these leakages is very cheap and easy.

We know of three measurements in this early wind-tight-stage being performed in the 80's in Norway. A later similar measurement that took place in 1998 caught great interest.

An initiative from The Norwegian Homebuilder Association soon led to simplified equipment being designed and spread to the market of their members in the building industry (Figure 3).

www.Flexit.no
300 – 1 500 m^3/h @ 50 Pa

www.villavent.no
(Systemair)
Small < 500 m^3/h
Medium 500 – 1 500 m^3/h
Large 1 500 – 3 000 m^3/h
@ 50 Pa

Figure 3: Simplified Norwegian equipment for air-tightness measurement of smaller buildings.

The initial philosophy was to just create a pressure difference between the building and the outside (exceeding around 30 Pa and possible to feel by hand on foils etc. being tight). If the craftsman using the fan failed to achieve any pressure difference across the wall, then his job was to find the leaks and repair them, until a pressure could be detected. This simple approach was very good! The project caught on, and it soon evolved into having some quantified results coming out of the process too.

Response from craftsmen

Doing airtightness testing on a more regular basis has been met with a bit of scepticism by some building firms. On the other hand, a very common reaction by skilled craftsmen, is that they very much appreciate being valued for the effort that they put into good craftsmanship and reaching technical goals, like air-tightness; not only being valued for their effort towards the aesthetic finish. It is nice being told in forehand in the project that measurements are planned, though. Being given the tools to perform these checks by oneself is even nicer. This last point has been an important reason for development of the simplified-method testing: the possibility for the builders to perform testing themselves.

An important additional argument for performing these simplified-method tests is that airtightness testing requires being on site on exactly the right time in the building process, when the level of completeness is just appropriate. Craftsmen dislike being stopped in progression, having to wait for someone with the right equipment to come when they have the capacity to do it themselves. As an illustration, one might note that the early-stage measurement on the building shown in Figure 4 was performed a little bit too early; one balcony door was not mounted yet, the result of challenges in timing.

Figure 4: Norwegian wooden building being in early-wind-tight-stage. Windbreak layers are of nonwoven HDPE fabric. Some parts of the wall have gypsum boards in addition, to reach fire resistance goals.

The importance of final-state measurement

Quite recently the air tightness of the whole building from which Fig. 1 is shown was measured. In this case governmental funding for passive house activity, requiring airtightness measuring, was released based on the preliminary measurements from the tents. It could have been awkward, though, if the required airtightness goals were not met in the final measurement of the whole building. Fortunately, the final-state measurements met the ambitious goals. Both builder and customer were happy.

Experience from several measurements in both early stage and in finished stage on the same building shows that one might end up with a poorer airtightness at the final stage compared with the early-stage-measurements. In fact, many things happening during the late part of the building process may cause extra air-leakages to the buildings. Examples include ventilation ducts being installed in a late phase, with little attention to making penetrations airtight, or balconies being mounted delayed in the building process, the improvised anchoring causing leaks.

The conclusion is that early wind-tight-stage measuring should be followed up by a finished-state measurement. The early wind-tight-stage measurement should be recognized as a good insurance for the builder against blunders or incidents causing trouble with the customer in a later stage. It also serves as a powerful tool in the process of gathering experience to achieve the intended level of airtightness, especially with unfamiliar processes, details and materials, and thereby becoming everyday practice in a rapidly changing industry.

The level of measurement accuracy for the fans and other equipment used is not extremely important, when used in early stage measurements. The purpose of these initial depressurisations is not data with high accuracy. We must assume that the following final measurements are carried out with sufficiently precise equipment. It is equally important that competent users of the equipment, who understand and perform this according to international standards, do these measurements.

Change of Norwegian regulations: 3rd party independent inspection of design and workmanship for airtightness level is becoming mandatory at the start of 2013 for most of the Norwegian new buildings. It is going to be exiting to follow how this turns out and develops.

Measuring is being recognised as being needed to prove this important quality: *Detailed design is necessary, but not sufficient to reach targeted level of airtightness needed for low-energy buildings.*

RESEARCH INTO THE EFFECT OF IMPROVING AIR TIGHTNESS IN A TYPICAL UK DWELLING

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The UK's Air Tightness testing & Measurement Association (ATTMA) is a trade body that represents the UK's leading air-tightness testing and consultancy firms. Most of the work undertaken by these firms is for the builders of new housing and buildings, who are required to prove that they have achieved the required level of air-tightness in their buildings in order to satisfy Building Regulations.

In England and Wales, it has been a requirement that all types of new buildings and dwellings have to be tested since 2006. Prior to this, most buildings were neither designed nor built with air-tightness in mind; primarily because there was no requirement for testing. Consequently it is generally accepted that older UK houses and buildings are on average quite 'leaky'. Indeed, research conducted by the Building Research Establishment (BRE) over 10 years ago determined that a typical UK dwelling leaked at a rate of 11.48 m^3, per m^2 of their external envelope, per hour at an air pressure differential (between inside and outside of the envelope) of 50 Pa (see below). The minimum standard permissible under current UK Building Regulations is $10m^3/(m^2.hr)@50$ Pa, although usually in order to attain overall compliance with calculated CO_2 limits, a far lower (better) figure has to be both specified and achieved.

Effect of envelope air tightness on energy use?

A frequent point of discussion among ATTMA members is the fact that, set against this background of generally 'leaky' existing building and housing stock in the UK, there is an opportunity to significantly improve the energy and carbon performance of our existing building and housing stock by means of simple, low-tech but effecting air-sealing measures. The barrier to this seems to be in lack of awareness as to the extent of the benefits that can be realised by this approach. This is reflected in the range of attitudes that air-tightness specialists come up against amongst builders, building inspectors and even building managers/owners; ranging from some who regard air-tightness as being as fundamental and vital as weather-tightness to those who regard it with apathy, scepticism or even hostility.

Experiment needed for reliable data

What is needed is more reliable *evidence* as to the positive impact that improved air-tightness can deliver in a typical UK building or dwelling, alongside an appropriately designed and controlled ventilation system. Aside of those whose at the extremely sceptical end of the aforementioned spectrum, most building professionals, and indeed the general public would acknowledge the general principle that a less air-leaky building is likely to be more energy and carbon efficient, and more comfortable for the occupants (providing the ventilation is appropriate). However, the problem is the lack of a sense of scale or quantity.

With this in mind, in 2010 the ATTMA decided to attempt to provide some evidence by means of commissioning a research project by the BRE, who are themselves members of ATTMA and acknowledged experts in air-tightness, but who are also unrivalled in their ability to undertake building performance research projects of this type.

The brief given to BRE was to undertake research to demonstrate the impact on the space heating load in a typical UK dwelling that arises when the air-permeability of its external envelope is improved. For this purpose, the BRE provided two of its purpose-built 'test houses', located on the BRE's, Watford site. The two dwellings are largely identical mid-terrace houses situated side-by-side, with construction details that are typical of millions of existing UK dwellings.

The two dwellings in the test are largely identical mid-terrace houses situated side-by-side, with construction details that are typical of millions of existing UK dwellings.

The test methodology was that of whole-house co-heating testing, the principle of which is described below. In short, it is a method of accurately determining the aggregated thermal losses of an unoccupied building. The testing was undertaken by Mr Arron Perry and Mr Nigel Waldron from BRE's Building Technology Group overseen by Mr David Butler, between November 2010 and March 2011. Air-permeability testing was provided by Jamie Best of Melin Consultants.

Test buildings and testing procedure

The two similar houses were used in order to provide a 'control'. For each, the co-heating testing and analysis was conducted in two phases: firstly with them both having an equally high average air-permeability, then secondly with one having its air-permeability left high, while the other had its air-permeability made much lower by means of sealing up its fabric. Each "phase" of testing lasted several weeks in order to gather sufficient data for analysis.

Air permeability testing was used to determine the air-permeability of each house at the beginning and end of each testing phase.

	Phase 1 Air Permeability ($m^3/(m^2.hr)$@50Pa)	**Phase 2** Air Permeability ($m^3/(m^2.hr)$@50Pa)
House 1	15.60	15.60
House 2	15.78	4.88

Measured air permeability of test houses in the test phases 1 and 2

The air-permeability levels for both houses were deliberately increased for the first phase of the testing in order to create a larger margin of measured improvement. This was done by the air-tightness tester deliberately introducing holes into the external walls and ceilings of the houses until repeated air-permeability testing showed that both houses were exhibiting an air-permeability of between 15 and 16 ($m^3/(m^2.hr)$@50Pa). They then both subjected to co-heating testing to demonstrate establish the baselines for each. A few weeks later, House 2 was sealed and tested down to just under 5 ($m^3/(m^2.hr)$@50Pa), while House 1 was left unchanged. The measurement of heat loss then resumed, with House 1 effectively acting as the 'control'.

The Co-heating Test Methodology

The co-heating test is a practical method of determining the combined fabric and infiltration heat loss of an unoccupied house. It involves electrically heating the houses to a constant indoor temperature. Correlation of the measured electrical heat input and solar heat gains with indoor and outdoor air temperature difference allows an estimation of the whole house heat loss coefficient.

Since the tests were undertaken during winter, the room air temperature in each house was controlled to a constant temperature between 18 and 23°C using electric heaters so that an average temperature difference of between 10 and 20°C was maintained between room and outside air temperature.

Electric convector heaters were installed in the main rooms and were controlled on a zone basis by accurate proportional temperature controllers with remote temperature sensors located centrally in the zone at approximately 1.5 m above the floor. The electricity consumed by the fans was accounted for by including them in the metered heater supplies. One pulse output kWh electricity meter (1000 pulses per kWh) was provided in each zone. To maintain an even temperature distribution throughout the houses, all internal doors were fully open and air circulation fans were used to mix the internal air. The fans were installed on poles above each heater to prevent stratification and encourage air circulation without excessively high air speeds.

External air temperature was measured by a shielded sensor near the north elevation of the terrace. Solar irradiance was measured by a Kipp and Zonen pyranometer mounted on a weather mast on the north field area of the BRE site.

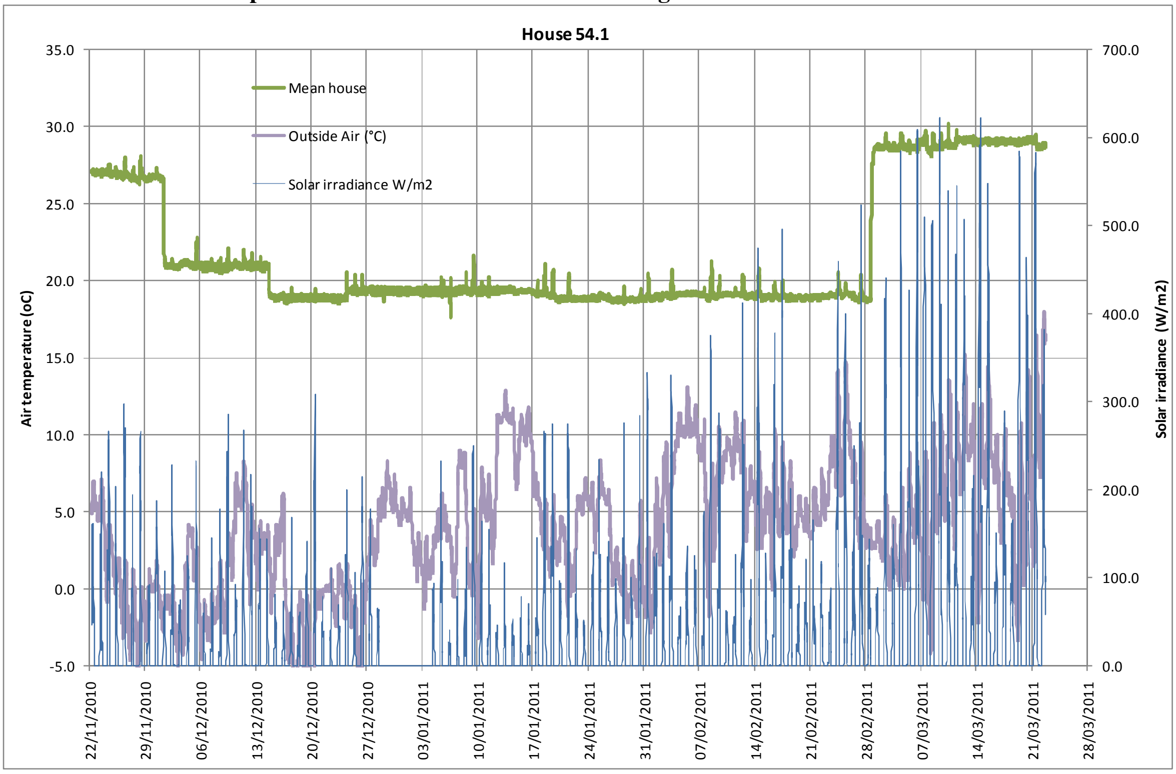
In order to minimise unaccounted for heat gains and losses all external windows and doors and other openings were closed and all electricity consuming appliances and lighting was switched off. Access to the houses was also restricted to an absolute minimum during the duration of the co-heating tests.

Electricity consumption, room air temperatures, external air temperature and solar irradiance were continuously measured and recorded using battery powered data loggers (Eltek SQ1000) with a recording interval of 15 minutes.

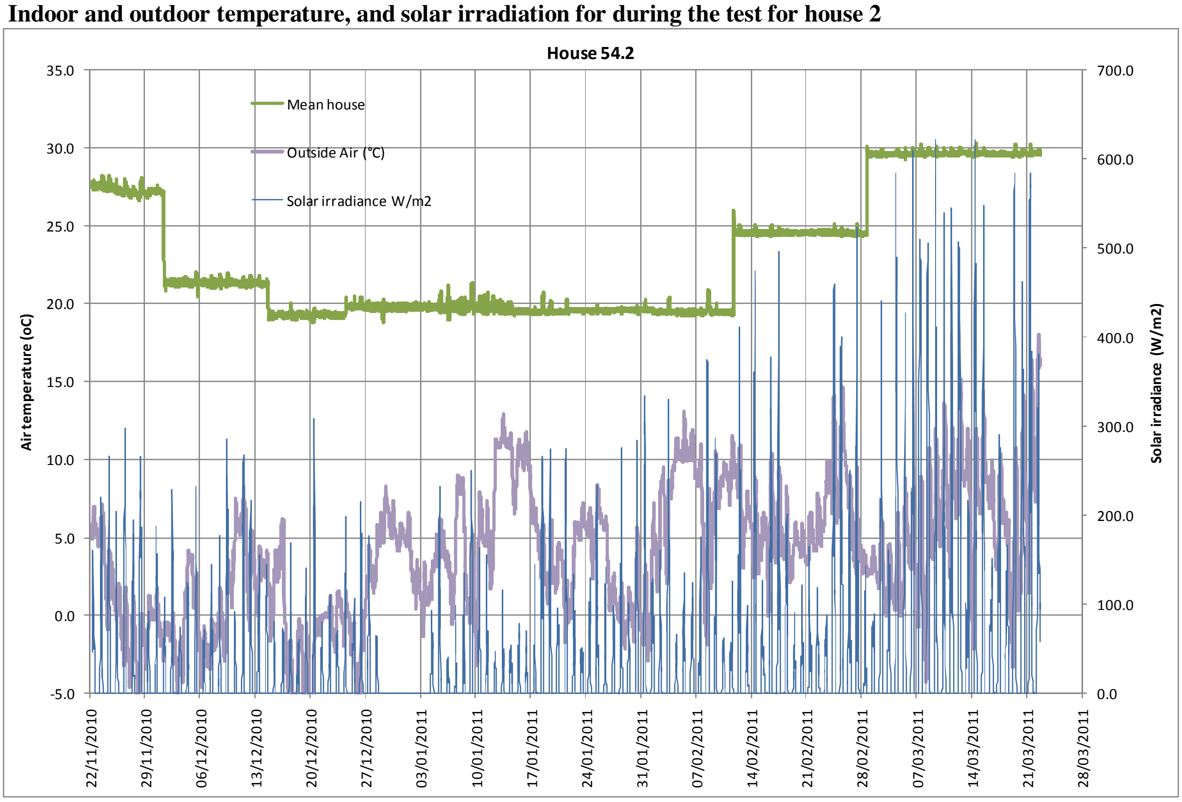
Solar heat gains were determined by analysing the measured solar irradiance data using a simple window solar heat gain model. The window model took account of the window glass area, orientation and glazing type. Raw solar irradiance measured at each house on a horizontal plane was apportioned to each vertical orientation using the fraction of hourly CIBSE cooling load data on each orientation (CIBSE Guide A, Table 5.19 Solar cooling loads).

The calculated solar gains were added to the measured electrical heating energy to determine the total heat input necessary to maintain the specified mean internal air temperature. The houses were assumed to have low / medium thermal mass and therefore it was assumed that the majority of solar heat gains received during a day and absorbed into the house fabric would be released to the house interior in the same 24 hours period. Therefore the correlation of heat input with mean internal and external air temperature difference was assessed on a 24 hours or daily basis.

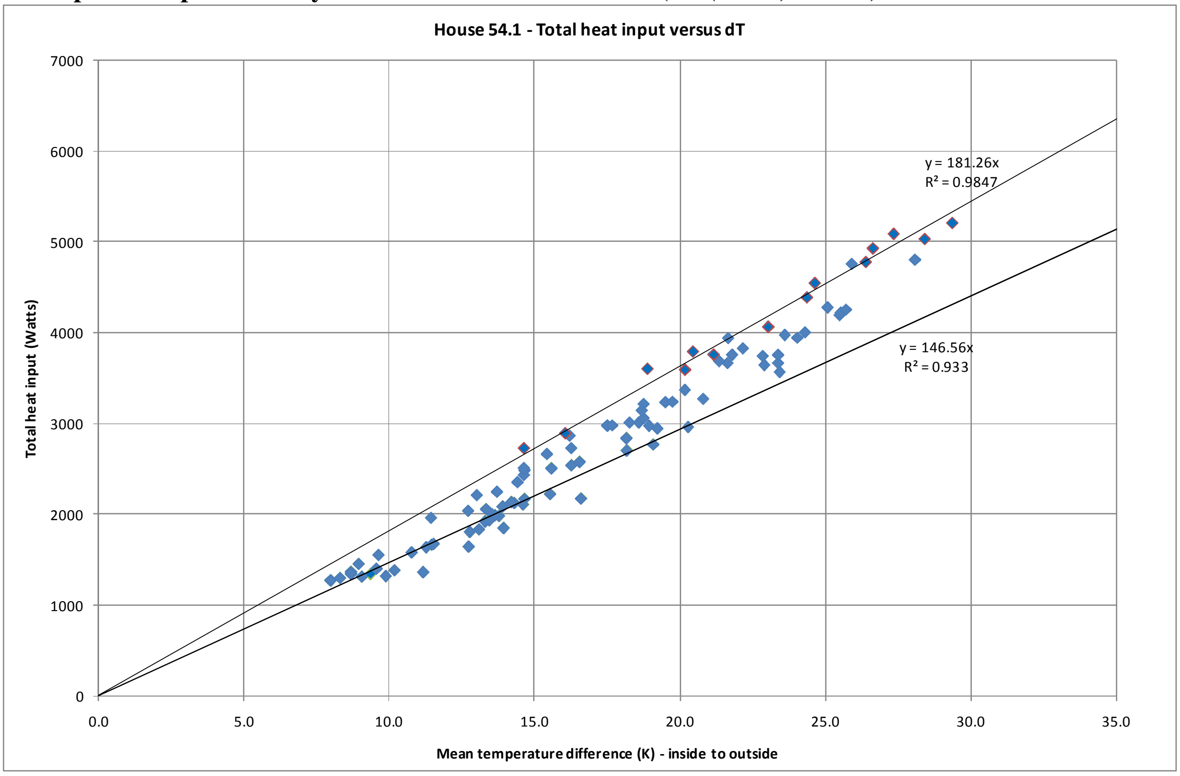
Indoor and outdoor temperature and solar irradiation for during the test for house 1



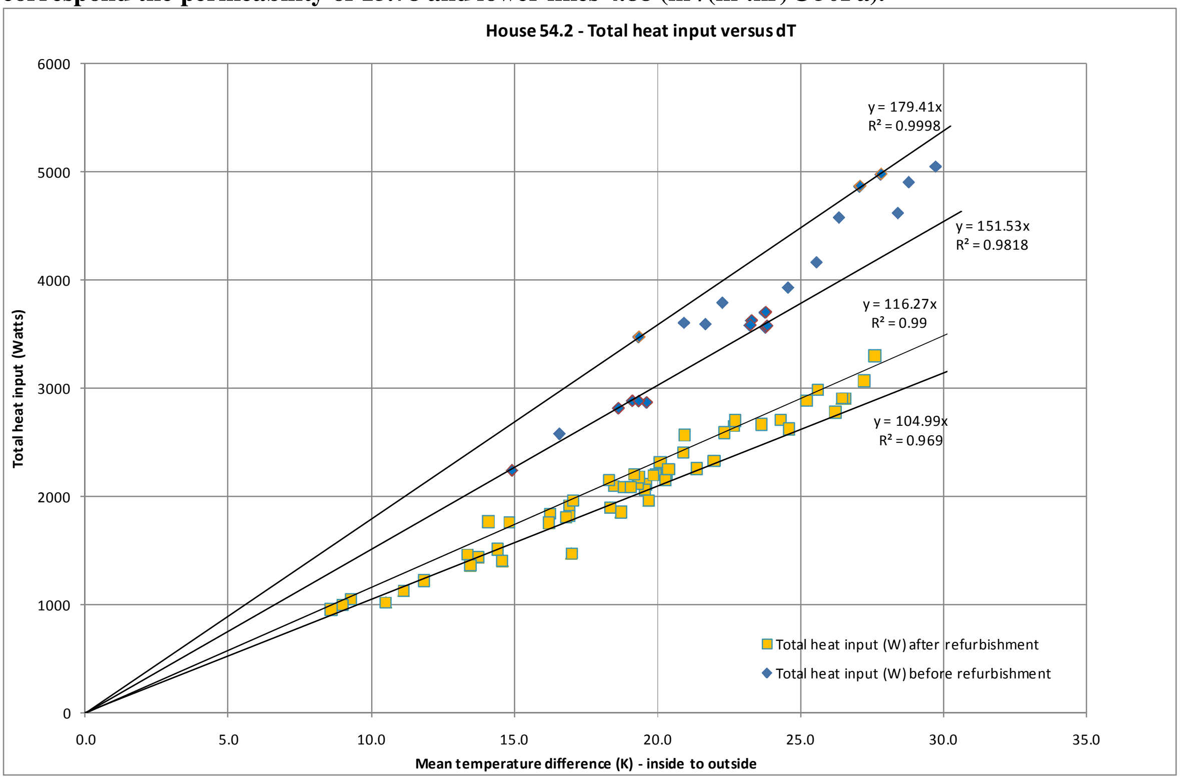
Indoor and outdoor temperature, and solar irradiation for during the test for house 2



Heat loss coefficients for house 1 with different air tightness of building envelope. Upper lines correspond the permeability of 15.78 and lower lines 4.88 ($m^3/(m^2.hr)$@50Pa).



Heat loss coefficients for house 2 with different air tightness of building envelope. Upper lines correspond the permeability of 15.78 and lower lines 4.88 ($m^3/(m^2.hr)$@50Pa).



Test results

The room air temperature in each unit was controlled to a range of fixed temperature values using electric heaters so that an average temperature difference of at least 10°C was maintained between room and outside air temperature. Solar heat gains were determined by analysing the measured solar irradiance data using a simple window solar heat gain model.

Linear regression analysis yielded the following heat loss coefficients (with forced y-axis intercept of y=0):

	Phase 1 Heat Loss Coefficient (W/K)	**Phase 2** Heat Loss Coefficient (W/K)
House 1	146.6 to 181.3	
House 2	151.5 to 179.4	105.0 to 116.3

Heat loss coefficients calculated from the measures heating energy use during the test phases 1 and 2

The difference between the lower and upper regression line coefficients for each data set is assumed to be the effect of wind speed.

Their relative heat loss performances can be attributed to almost entirely the difference in fabric air-permeability as all other factors remained the same for both; in particular, the climatic conditions that they were exposed to during the testing phases.

The overall conclusion was this: the reduction in heat loss in House 2 resulting from the air leakage sealing measures, corresponding to an improvement in air permeability from 15.78 to 4.88 ($m^3/(m^2.hr)$@50Pa), was between 46.5 and 63.1 W/K, equivalent to between 31 and 35% reduction in heat loss.

ATTMA argue that it is reasonable to assert that there exists a linear relationship between air-tightness and heat loss (assuming all other factors remain constant). Therefore, it would for example be reasonable to assert that an improvement in air-tightness from, say 11.5 to 5 $m^3/(m^2.hr)$@50Pa would yield a reduction in heat loss in the order of 15%. Therefore, if typical UK houses were remedially air-sealed from their current state (i.e. an average leakage rate of 11.5 m3/(m2.hr)@50Pa to a not unreasonable level of 5 $m^3/(m^2.hr)$@50Pa, then one could expect to see an average saving in heating costs of up to 15% over the life of the property.

Obviously this saving is at risk of being eroded by occupant behaviour and in particular by losses from ventilation. Nonetheless, weighed against the relatively minimal one-off cost of locating and permanently sealing the air-leakage sites, the argument is compelling.

Acknowledgement

Much of the technical content of this article is taken from the BRE's Report number 271-943, "Co-heating Tests on BRE Test Houses Before and After Remedial Air Sealing" by David Butler and Arron Perry.

SWEDISH EXPERIENCE WITH AIRTIGHT DUCTWORK

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Why is it important to have a tight ductwork?

Many studies have identified defective ventilation systems and insufficient airflows as a main reason for occurrence of sick buildings - the supply air needed to assure a good air quality should thus reach the areas where it is needed and not disappear along its transport through the building.

Duct systems account for a large fraction of the energy use in a building. This is further increased with a leaky duct system. The supply air flow has to cover the sum of total nominal air flow and the leaking flow. With leaky ductwork this will lead to a considerable and costly increase of the needed fan power.

There are several good reasons to reduce the air leaks from ductwork:

- Correct air flows to and from the rooms are dimensioned to ensure that emissions and heat loads are kept within set values and that air quality (AQ) and thermal quality (TQ) are acceptable.
- Duct leaks can result in disturbing noise.
- When leaky supply and extract air ducts are installed above a false ceiling part of the air will take the simplest way, from the supply duct direct to the extract duct without bothering to pass through the connected rooms.

In spite of these good reasons to use tight ductwork we found in two EU projects that designers, installers, building managers and owners in some countries often ignore the benefits of airtight duct systems. This has probably resulted in poor ductwork installations in a large fraction of the building stock. In these countries, installation is probably often undertaken using conventional in situ sealing techniques (e.g. tape or mastic), and therefore the ductwork airtightness is very much dependent upon the workers' skills.

AMA – an old and reliable Swedish system to ensure high quality ductwork

Starting already 1950 – i.e. for more than 60 years back in time – we have been using a quite unique quality assurance system in Sweden covering all aspects of building and installation technologies. Practically all buildings and their installations in Sweden are performed according to the quality requirements in the AMA specification guidelines (General Material and Workmanship Specifications). These requirements are made valid when they are referred to in the contract between the owner and the contractor.

The requirements for tight ventilation ductwork systems were included in AMA already in the early sixties. Sweden has thus a long and unbroken tradition of demanding and controlling tightness of ventilation ductwork. During this long period, since 1966, the AMA tightness requirements have been raised in tact with technology improvements and increased energy costs.

AMA is a tool for the employer (developer/future proprietor) to specify his demands on the new building and its installations. It is a work of reference – you use the parts that are relevant for your project by referring to these parts in your building specification. As an employer – you have to state what you want, check that you get it, and be prepared to pay the price for it!

The requirements are based on accepted demands – the requirements are regularly updated in accordance with technology development and (LCC-) costs. The technology development has probably to some extent been influenced by the regularly increased AMA demands.

Changes of the demands are prepared by a working group and discussed with – and accepted by – building owners, contractors and consultants. The demands are to be specified in measurable units and in such a way that the tenderers and contractors understand them and are able to calculate a price.

Ductwork airtightness demands in AMA 1966 – 1972

It started with the AMA version 1966 when two "tightness norms", A and B, were defined. It was also requested by the contractor to spot-check the tightness in a minimum of 10 m² duct perimeter area.

In AMA 1972 the requirements were transformed into two "tightness classes" A and B (same as the EUROVENT classes today). Class A was the basic requirement for the complete duct system in the air handling system (i.e. including dampers, filters, humidifiers and heat exchangers). It was advised to raise the requirement to meet Class B when the system operates for more than 8 hours/day and the air is treated (cooling, humidification, high class filters etc.).

A ductwork system is not specified to be tight – instead the permissible leakage rate at a specified test pressure is stated as a tightness class – that is possible to measure!

Tightness classes in Eurovent (AMA)

A: lowest class; B: 3 times tighter than A; C: 9 times tighter than A, and D: 27 times tighter than A. The tightness classes are defined by a leak factor in l/s, m². The AMA has 400 Pa as standard test pressure. See lines in Figure 1.

In the USA (ASHRAE) the classes are raised in steps of two times tighter: C_L48: lowest class, C_L24: 2 times tighter than C_L48 and so on till C_L3: 16 times tighter than C_L48 (Figure 1).

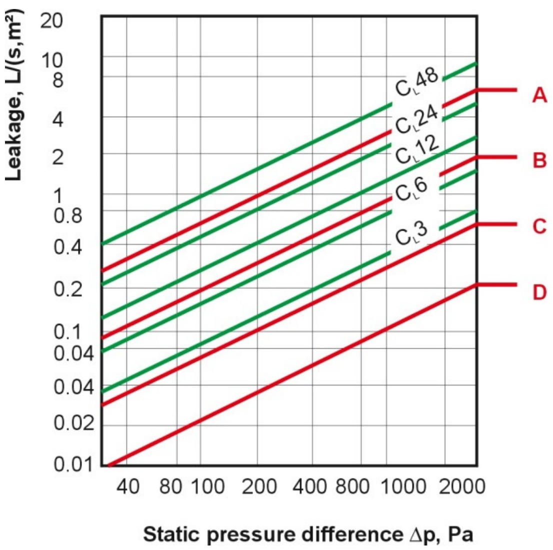

Figure 1: Comparison between European (Eurovent and AMA) Tightness Classes A – D and American (ASHRAE) Tightness classes C_L3, C_L6 etc.

With the Swedish AMA version 1983 Tightness Class C was added for round ductwork larger than 50 m² while Class B was required for round duct systems with a surface area smaller than 50 m² and also for rectangular ductwork. Class A, the lowest class, was only accepted for visible supply and exhaust ducts within the ventilated room. In AMA 1998 Tightness Class D was added (D is 3 times tighter than Class C). The use was not specified. It is an optional requirement for larger circular duct systems and where leakage can lead to hazards. AMA 2007 raised the requirements still another step – now also rectangular ductwork has to meet tightness class C.

How is the tightness tested – and by whom?

Requirements and demands can be worthless unless they are controlled. AMA thus also states the demands and the requirements for tightness testing of the ductwork. The leakage rate at a specified test pressure is stated – this is possible to measure! – and it is compared to the permissible value for the prescribed tightness class.

This control is normally done by the contractor as a spot check where the parts to be checked are chosen by the owner's consultant. This is specified in AMA and thus being a part of the contract (i.e. the cost for the test is normally included in the contract lump sum). AMA also states the first part of the ductwork to be tested to be 10 % of the total duct area for round duct systems and 20 % for rectangular ducts.

The control of whether the leak factor value is acceptable is measured by the contractor normally under the supervision of the owner’s consultant. The contractor is required to hand over a filled in and signed AMA protocol to the owner.

The tightness of the ductwork is controlled in the following manner: The consultant points out which part of the ductwork he wants controlled.

The test fan (“provfläkt”) is connected to the ductwork where all openings are sealed (“täcklock”) (Figure 2). The fan is started and the airflow (“läckflöde”) needed to keep test pressure (“provtryck”) at e.g. 400 Pa is measured. The actual leak factor is calculated by dividing the airflow (l/s) by the in situ measured (or taken from drawings) surrounding area of the tested duct system. The result is then compared with the leak factor for the prescribed tightness class as found in the AMA tables.

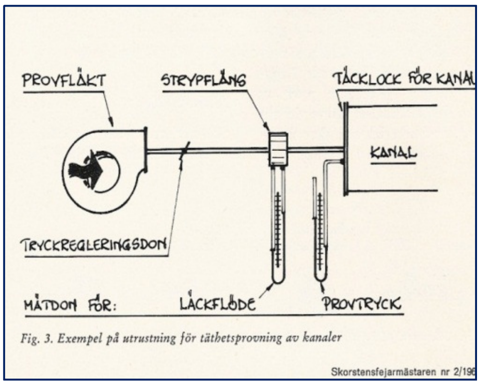

Figure 2: The test equipment for measuring the ductwork leakage from an article in 1966 by same author as this article – when AMA first required ductwork tightness. The principle is still the same!

If this result is equal or lower than required the system is accepted. If not the contractor has to tighten the leak points and measure this part anew. He is now also required to check a new system part of the same size. (This is specified in AMA to be a 10% part of the system for round duct systems and 20 % for rectangular systems). If also this second measurement shows an unsatisfactory result he has to check the whole system until everything is accepted.

Is the testing worth the money?

The costs for the tests – the first 10 %, then next 10 % if not accepted and then the whole system - is part of the contract, i.e. covered by the contractor.

The mechanical contractor can either make the tightness test with his own personnel, provided he has equipment and skilled personnel, or he can use a specialized contractor. In both cases he has to cover the costs which can be quite considerable if the tests have to be repeated due to bad test results.

This has certainly led to high quality ductwork standard in Sweden for the following reasons:

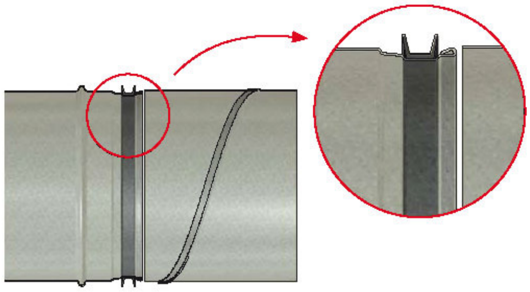

Figure 3: An example of a duct connection fulfilling class C requirements. The rubber seal is compressed and tightens the gap

The contractors do their best to avoid costly setbacks from inferior duct quality, the duct manufacturers are competing in inventing and marketing tight duct systems that are easy to install. Both circular and rectangular duct connections are provided with rubber gaskets that are very tight compared to older (and foreign) systems. New types of duct joints have reduced earlier laborious installation works.

Comparison of test results in three EU countries

The EU-project SAVE-DUCT found that duct systems in Belgium and in France were typically 3 times leakier than EUROVENT Class A, see Figure 4. Typical duct systems in Sweden fulfilled the requirements for EUROVENT Class B and C and were thus between 25 – 50 times tighter than those in Belgium and France.

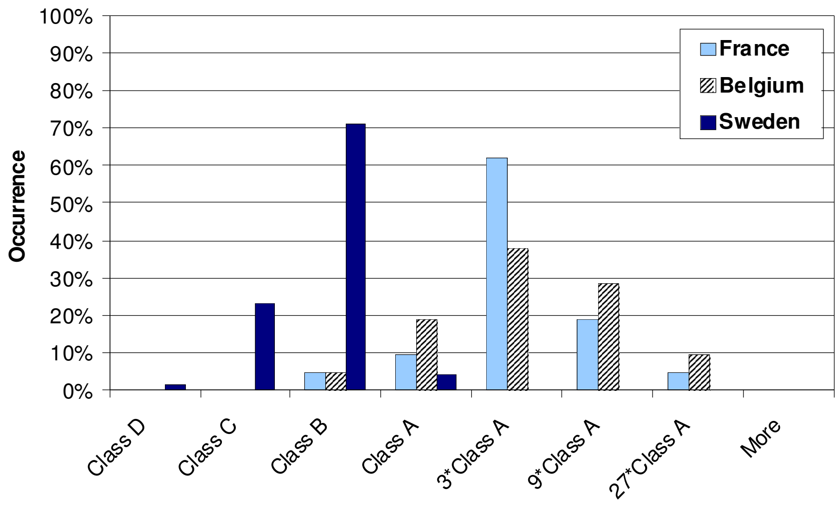

Figure 4: Results from the EU-project Airways. In the figure the bars show the percentage of tested ductworks in each tightness class. The tightness class 3 x Class A etc. had to be expanded to fit the results from leaky ductworks in the evaluation.

Why this large difference?

The most probable reason for this large difference is that Sweden has required tight ducts since the early sixties whereas in the two other countries tightness of ductwork is normally neither required nor tested.

Renovation of ventilation systems

During the period 1965 – 1975 it was decided by the Swedish Parliament that a large number of dwellings should be built to solve the acute crisis and reduce the housing queue and improve the dwelling standard. Statistics show that 1 006 000 dwellings (thus the name “The Million Program”) were built during this period mostly in multi-family buildings but also to some extent in row houses. These houses have now reached an age when most of them are in acute need of renovation, not least when it comes to their installations. A standard ventilation principle in those buildings was extract ventilation with air being supplied from the outside through grilles in the external walls.

A common renovation solution today to improve the ventilation is to install a supply air system, keep – but clean and tightness test – the extract ducts and connect both duct systems to a new air-handling unit installed in the attic space. This provides several important improvements: the air intake is thus placed high up toward the back side of the building instead of at low level toward the street, the supply air (even though it is much cleaner than in the previous case) passes through a high class filter (class F7 is a common standard), a heat exchanger reduces the energy use. The noise from the fans in the unit is attenuated to reduce the noise transmitted through the ducts to the flats.

To install a new supply air ductwork in an existing occupied building requires new installation methods. The inhabitants of the house should be disturbed as little as possible and for a very short time, preferably only during one day. This is of course a new and interesting market for the suppliers and several similar methods to solve this have been designed.

The illustrations show one of these systems where all the necessary components are prefabricated.

Figure 5: The supply air duct for the flat is fixed to a light framework at the ceiling. The duct is hidden behind a cladding fixed to the same framework – everything is done, quickly, by the duct fitter.

Another example when an old ventilation installation was replaced can be found in a high-rise office building in downtown area of Stockholm.

This building was the first of five rather identical high-rise office buildings in the City Centre of Stockholm (Figure 6). The architecture of the building was the result of an architectural competition (all five buildings, similar in height and dimensions, had its own architect). They were the result of a drastic reconstruction of a large part of the downtown area of the city when most of the old 18th and 19th century buildings were torn down and replaced with new office and commercial buildings.

The building was inaugurated in 1959, which was an extremely hot summer in Sweden. As typical for the time, the window/wall ratio was high, 76%. Following the normal design in Sweden at that period, the building was not equipped with any comfort cooling.

The supply and exhaust air was distributed through concrete shafts connected on each floor to branch duct systems. As there was no shadowing from other buildings the indoor temperature during the hot summer 1959 raised to above 35°C and the top floors of the building had to be abandoned for a few weeks.

After nearly thirty years of operation the building was thoroughly renovated in 1997. All installations were refurbished and the old ventilation system replaced with a modern air-conditioning system. New plant rooms were built on the roof of the building connecting to the old concrete shafts.

Instead of using the shafts as plenums for supply and exhaust air respectively, the shafts were literally filled with circular ducts as each floor plan was provided with its own separate supply and extract ducts. As each floor represents its own fire cell, the supply and exhaust ducts are provided with fire dampers (and regulating dampers) in the rooftop plant room as shown in Figure 6.

Figure 6: Ducts for the different floors pass down through common shafts, one for supply and one for extract air. The photo shows part of the supply ducts with their fire dampers.

This technical solution required that fifteen ducts were installed in each of the shafts. This was possible by using circular ducts. The ducts were also delivered in 6-m lengths thus reducing the number of vertical joints considerably. The very compact installation reduced the necessary space for the vertical shafts and increased thus the floor area that could be let.

The design of the duct systems had to be studied in detail on how the supply and extract ducts were entering to or emerging from the shafts to prevent unnecessary collisions and facilitate the installation work. The ducts were tightness tested in turn as they were installed to prove that they were fulfilling the tightness requirements of class C.

Conclusion

This Swedish way of working has been shown to be very effective in raising the quality of ductwork. Our long time focus on ductwork quality in Sweden has resulted in very low air leakage in normal Swedish duct installations which has promoted air quality, thermal comfort and sustainability.

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DUCTWORK AIR-TIGHTNESS REQUIREMENTS IN PORTUGAL

Portugal introduced, for the first time, in the 2006 Building Regulations, a requirement on the airtightness of the ductwork in new HVAC installations. A test is required during commissioning. Data on compliance is however still quite scarce to conclude how effective this requirement is in practice.

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EPBD context and CEN standards

The EU Directive 2002/91/EC and its recast published in 2010 (Directive 2010/31/EU) on the Energy performance of Buildings (EPBD) only include requirements for regular inspection of air-conditioning systems of an effective rated output of more than 12 kW (article 15), as well as heating systems including a boiler with nominal power above 20 kW (article 14). Inspections should identify opportunities for removing inefficiencies in the whole systems in a cost-effective way. There is no specific requirement for ductwork air-tightness, but this is certainly one issue that inspectors should analyse because leaking ducts have an important role in increasing energy consumption in air-based heating and cooling systems.

EN 15240 describes the methodology to perform inspections for air conditioning systems. However, given the large share of ventilation systems in the energy use in buildings, CEN also developed EN 15239 for the inspection of ventilation systems, even when they are not included in the strict scope of article 15 of the EPBD. Together with EN 15378, concerning the inspection of heating systems, these standards cover the inspection of HVAC installations.

Test procedures and measurement methods for air conditioning and ventilation installations are described in EN 12599. They include checks, for instance, of the accessibility and cleanliness of the system according to EN 12097 and EN 15780, as well as measurements, e.g., of airflow rates or ductwork leakage (with reference to EN 12237 and EN 1507).

Commissioning requirements in Portugal

As part of the transposition of the 2002 version of the EPBD, new regulations were adopted in Portugal and came into force in 2006. Requirements for new HVAC systems included for the first time a set of mandatory tests that must be carried out during commissioning, before the building receives its use permit.

Although there is no specific requirement on duct air-tightness for new HVAC systems in both versions of the EPBD, its relevance can be argued on the basis of the following arguments:

- The overall goal of the EPBD is to obtain energy-efficient buildings. When a new building is completed, all its components, both fabric and technical systems, should be energy-efficient. Although the Directive 2002/91/EC only required MS to put in place minimum requirements for the building envelope, the recast EPBD corrected that oversight and it now foresees minimum requirements for both envelope and technical systems components. It thus seemed logical, even back in 2006, under the umbrella of the first EPBD, to impose a minimum performance requirement on ductwork airtightness as part of the overall energy - efficiency requirements in the Portuguese building regulations.
- If a new ductwork system is not airtight from the start, it will be a lot more difficult and costly to make it airtight later, after an inspection report identifies this opportunity for improvement. Recommendations for improvements must be cost-effective and it is often too costly to replace or to improve the performance of an inefficient ductwork system. Therefore, it also seemed logical that, in new buildings, ductwork had to be airtight when it was first installed.

Therefore, the 2006 Portuguese building regulations focussed on ductwork airtightness for new systems being installed, rather than just considering improving ductwork performance in the context of the regular inspections required by the EPBD.

The aim of the tests is to demonstrate that the installation is functioning as designed, in operational terms, but also meeting the minimum energy efficiency and indoor air quality (IAQ) targets set in the legislation.

Proof of the results of these tests, consisting of a detailed report, must be handed to the Qualified Expert (QE) who will issue the Energy Performance Certificate (EPC) for the building, who may ask for further tests if he/she is not satisfied with the report or just for confirmation (random check). Often, the QE is present while the commissioning tests take place. The EPC is required by the local authorities before issuing the building’s use permit.

Tests on the ventilation system include:

- Airflow delivered to each room in accordance with design parameters;
- Overall cleanliness of the whole ductwork and other components, such as air handling units and fans;
- Airtightness of the ductwork.

The regulations do not require a specific testing methodology, but tests must follow recognised procedures, such as described in EN 12599.

Ductwork airtightness test

Ductwork air-tightness is often considered to be an issue in cold climates only. There has however been a significant amount of work in hot and mild climates, in particular in the US, that demonstrates the important energy savings potential that can be achieved by reducing duct leakage.

In Portugal, up until 2006, there was no check on the quality of the ductwork (most often, building owners did not require the check simply to avoid its cost), and its performance was in general quite poor (high leakage, cheap materials used), resulting in significant losses, with important negative consequences in terms of the energy efficiency of the whole installation (more air had to be circulated and treated to compensate for the leakage). Moreover, it was often impossible to meet the minimum fresh air rates in many spaces, resulting in degraded IAQ levels. The new regulation aims at ensuring minimum levels of IAQ and improved energy efficiency during operation of the building, by adopting a life-cycle perspective and moving away from the up-to-then prevailing strategy of lowest possible first cost.

To comply with the Portuguese regulation, ductwork leakage of air conditioning installations of buildings larger than 1000 m^2 may not exceed 1.5 $l/s.m^2$ under a static pressure of 400 Pa (Class A limit according to EN 12237 is 1.32 $l/s.m^2$ at 400 Pa). Air-tightness tests should be carried out using the following procedure (Figure 1):

- A 10% random sample of the ductwork is selected and tested by the inspector. If the measured leakage is below 1.5 $l/s.m^2$, no further testing is required;
- If the first test is not satisfactory, a second test is performed, after the contractor takes corrective measures, again on the initially tested ducts plus an additional randomly selected 20% of the ductwork. If these tests are satisfactory, no further testing is required.
- If the previous test is still unsuccessful, the contractor must take additional corrective measures and the final test(s) must cover the whole ductwork until the required airtightness is met.

This procedure was inspired by the AMA requirements in Sweden.

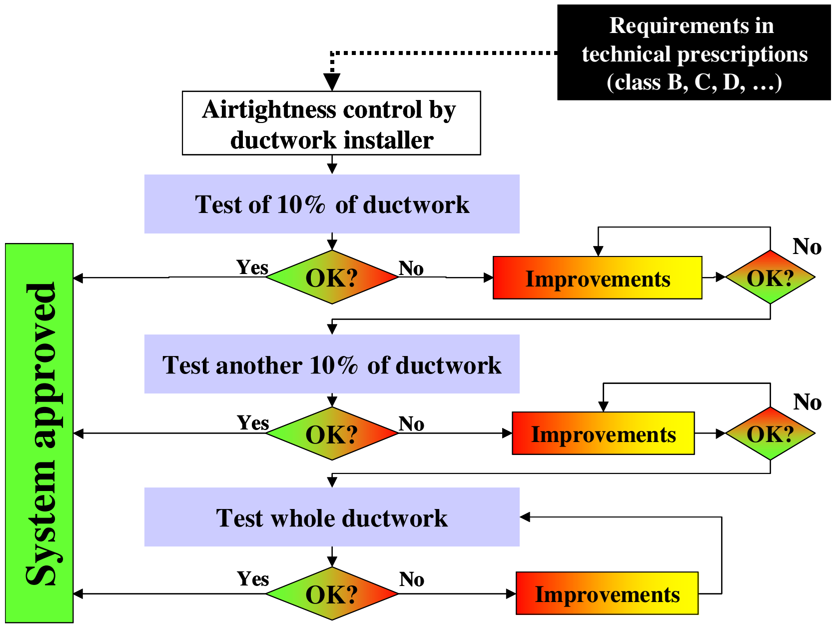

Figure 1: Swedish approach in framework of AMA procedures. The procedure now in use in Portugal is identical except for the initial requirement, which is defined in the regulation with a maximum leakage rate of 1.5 $l/s.m^2$ at 400 Pa (Class A limit according to EN 12237 is 1.32 $l/s.m^2$ at 400 Pa).

The new regulations in action

The new regulations apply to buildings larger than 1000 m^2 that begun their licensing procedure after 2006. Taking into account design and construction, this cycle usually takes, for large buildings, at least 3-4 years before completion. Therefore, there are not yet much data on the success of the new regulations. The first large buildings that had to comply with these new regulations only finished the construction phase late in 2009 and during 2010. New construction activity has also been quite low during the last few years due to the prevailing financial crisis and, therefore, the number of buildings affected by these new regulations is still rather small.

However, there is proof that the market adapted to the regulations. The share of pre-fabricated round ductwork with quality seals between ductwork components increased significantly (from <5% in 2006 to 30% in 2010). For rectangular ducts, the technology evolved to achieve better seals along duct sections and at unions between two consecutive sections, namely at the corners, representing now 20% of the market (extraction ducts carrying air that is not recirculated, e.g., from toilets and wet-zones, are still usually low-quality ducts). Welded and screwed joists disappeared since then. In parallel, a few specialized companies now offer duct leakage testing services in the market, while there were none in 2006.

Although only few EPCs have been issued for large new non-residential buildings so far, there is anecdotal evidence that the required commissioning tests (not just ductwork leakage) resulted, in most cases, in significant delays to the construction phase, with the corresponding negative backlash. Despite this, the new regulations that must be published to transpose the recast EPBD in Portugal, expected in 2013, are not expected to relax these air-tightness requirements for new ductwork to be installed.

Conclusion

It is too still early to say if the new regulations have been successful (the number of completed new HVAC installations falling under the new requirements is still rather small) and the data regarding the actual performance of few buildings constructed with the new requirements have not been fully analysed yet for lack of statistical significance. But ductwork technology evolved, and there is quantified proof that better quality components are now much more used, and ductwork leakage testing, as well as ductwork cleaning, are now new niche markets that appeared since the new regulations entered into force.

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EVALUATION OF AIR LEAKAGE AND ITS INFLUENCE ON THERMAL DEMANDS IN MADRID'S OFFICE BUILDINGS

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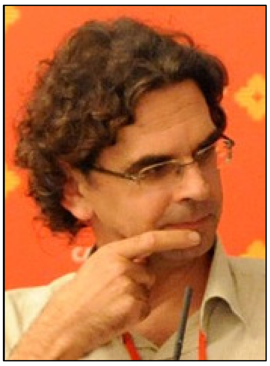

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Introduction

The major consequences of infiltration are the thermal losses derived from it, which account, in some instances, for high percentages of the total building's thermal demands [1] and therefore, in energy intensive buildings, cause important economic losses. However, air leakage careful analysis and management is usually the exception rather than the norm.

Four office buildings in Madrid have been analysed at two different levels: air leakage tests and mathematical modelling. In this way real ELA, and the instantaneous and mean infiltration values have been determined, as well as its effects on the heating and cooling demands. This process highlighted different recurring building pathologies, which, although only tested in this small simple, lead to belief this could be a clear picture of the current situation.

This analysis is a part of a bigger project on the multidisciplinary study of the energy behaviour of commercial buildings in Madrid, under the umbrella of the major commercial district development "Desarrollo Urbanístico de Chamartín (DUCH)".

Development

The methodology used is structured in two separate steps: firstly, the air leakage tests to determine the main parameters of the case study buildings. Secondly, modelling of infiltration allowing the characterisation of the transient model and the resulting data analysis.

Air leakage test

The different air leakage test standards consist in pressurizing and de-pressurizing the study zone using ventilators (usually placing a BlowerDoor [2]) and determining the necessary airflow to achieve a set pressure. In the present case the tests were carried out in the four buildings at store level.

This technique yields the Effective Leakage Area (ELA). Assuming the total building's air leakage through the different cracks can be represented as the infiltration through a mouthpiece of equivalent area, the cracks' dimensions can be represented as a single effective area [3], or ELA. Thus, the ELA is usually used, at a set reference pressure, to represent the leakage through the envelope.

However, as some previous studies have shown [4], and for a couple of the current analysed buildings, substantial infiltration occurs between the study zones and some adjacent ones, some of which are unconditioned, consequence of a deficient building process. Thus, it becomes necessary to differentiate between external and internal air leakage. To achieve this, the Zone Pressure Diagnostic (ZPD) was used, which indicates what the corresponding ELA is for the analysis zone with regards to the adjacent and non-external surfaces, and so the ELA for the external ones [5].

Infiltration modelling

Infiltration can be broken down into a climate independent component (ELA), and another dependent on climate conditions, in a non-lineal effect. The climate independent component can be partially quantified by the field tests, whilst the climate interaction requires of a model to calculate its effect. The ASHRAE's [6] recommended Lawrence Berkeley Laboratory (LBL) have been used for this purpose. This model establishes that air infiltrations are a function of permeability of the building and the pressure differences through its envelope. These pressure differences are induced by air temperature differences (Stack effect) and the wind's pressure.

The above-described methodology has been implemented in TRNSYS, considering weather and monitored data, with the aim of achieving transitory infiltration values, and the determination of the effect of air leakage in the buildings' thermal behaviour.

Results and discussion

The exposed methodology has only been implemented in three of the four buildings originally selected. In the remaining one, although the air leakage test was tried, the required pressure differential values (50Pa) were not achieved due to the construction pathologies. Both the influence of the pathologies in the building envelope and the ones in the internal partitions adjacent to unconditioned spaces posed too high an obstacle for the consecution of reliable results.

The characterisation of the three analysed buildings is determined through the parameters on Table 1. Out of the field test undertaken for the three buildings, Table 2 shows their characteristic values.

Table 1: Characterisation of the analysed buildings

Parameter	Units	Description	Building A	Building B	Building C
Year	year	Year of building	2010	2008	2009
N_plan	Storey	Number of storeys	6	10	4
Type	--	Type of construction	Heavy	Light	Light
Per_window	%	Percentage of window	> 90%	> 90%	> 90%
Surf_bui	m^2	Building's total envelope	5 398	10 632	7 448
Vol_bui	m^3	Building's total volume	25 147	93 600	36 689
Height_bui	m	Building height	23	42	15

Table 2: Summary results of the air leakage tests

	Building A	Building B	Building C
$ELA_{test}(cm^2)$	7,479	5,483	1,295
$ELA_{ZPD}(cm^2)$	3,739	0	0
$ELA\ (cm^2)$	3,739	5,483	1,295
$ELA\ (cm^2/m^2\ facade)$	6.36	17.69	4.56
Roof and slab infiltration ratio over the total (R)	0.23	0.02	0.04

It can be observed that the infiltration levels between floors are only relevant in Building A, and that the *ELA* of building B is greater than for the other two buildings. These parameters are the ones used in the equations of the LBL methodology implemented.

The shown results, although being one of the objectives of the analysis, are not very intuitive. In order to make them clearer, they are applied to the different conditions and TRNSYS [7] models for the buildings, so that the air renovations due to infiltration and their effect on the buildings' thermal demands can be obtained. As an example, the infiltration instantaneous values for the same week in April are shown for the three buildings (Figure 1).

The results were synthesized into a weighted average value for infiltration (average infiltration values for the considered time interval, based on wind speed ratios for each orientation), a variation in demands and power on the Spanish regulatory reference (variation of thermal demands with calculated instantaneous infiltration vs. infiltration derived from the interpretation of the

Spanish regulation [4-8]), and variation in demands and power supposing no infiltration (variation of thermal demands with calculated instantaneous infiltration vs. no infiltration). Table 3 shows values obtained using monitored climate data from February to September.

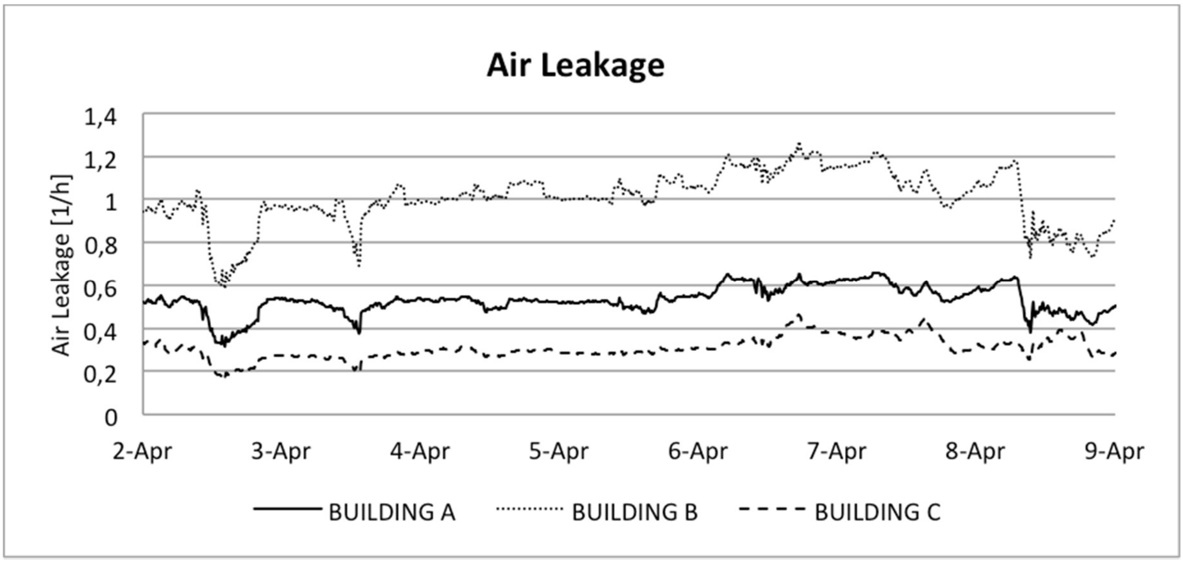

Figure 1: Infiltration in the three buildings as a function of the main façade orientations, for a week in April

Table 3: Summary of transitory results of the infiltration models

Parameter	Units	Description	Building A	Building B	Building C
$\dot{Q}_f\_ave$	1/h	Weighted average infiltration value	0,44	0,81	0,27
ΔQC_{SPAREG}	%	Cooling demand variation percentage on Spanish regulation reference	1	14	1
ΔQH_{SPAREG}	%	Heating demand variation percentage on Spanish regulation reference	-79	-100	-78
PC_{SPAREG}	%	Cooling power variation percentage on Spanish regulation reference	-4	-11	-4
PH_{SPAREG}	%	Heating power variation percentage on Spanish regulation reference	-72	-100	-83
$\Delta QC_{NOINFIL}$	%	Cooling demand variation percentage on no infiltration	3	17	3
$\Delta QH_{NOINFIL}$	%	Heating demand variation percentage on no infiltration	-94	-100	-91
$PC_{NOINFIL}$	%	Cooling power variation percentage on no infiltration	-6	-13	-6
$PH_{NOINFIL}$	%	Heating power variation percentage on no infiltration	-100	-100	-100

Where the variations on demands are obtained by comparing the excess (positive) or the default (negative) of the integrated temporal values of the reference case over the entire period, versus the integrated temporal values of the real case over the entire period. By following the same procedure, positive values for Power means that reference case have a bigger value, while negative one's means the opposite. The variables whose values are 100, indicate that in the reference case, the values of demand or power are zero.

In the data can be observed the proportion of the weighted infiltrations and, most importantly, the great variation in demands and powers between the models based on real data and those based on regulations. Also the weight of the infiltration on energy demands and powers can be noticed through the comparisons with no infiltration scenarios. The major influence on heating demands vs cooling ones could be due to a combination of the high internal loads of these buildings, and because of minor infiltrations in summer season when, at the same time, non-occupancy periods exists.

It is worth mentioning, based on the established values and the singularities observed during the field tests, that, mainly in the A and B buildings, the result is a reflection of a poor quality in the construction process, rather than not meeting the current regulatory standards. Equally, comparing the results obtained with other references for office buildings in the US [1] or Australia [9], the magnitude order is very similar.

However, it is very complicate to compare the results for the three different buildings, as those have very different characteristic parameters. That is why the results were normalised based on the buildings' height (parameter affecting the wind speed directly), the ELA (air tightness level for the façade), and the form factor for the building (ratio envelope surface/volume). Normalizing each of these parameters for Building A the following are obtained:

Figure 2 is a graphic representation, hourly based and for a week in April, for the values of Table 4.

Table 4: Infiltrations for the comparative analysis between buildings and on key parameters

Infiltrations		**Building A**	**Building B**	**Building C**
Base Results	1/h	0.44	0.81	0.27
Normalization by height	1/h	0.44	0.62	0.32
Normalization by form factor	1/h	0.44	1.18	0.34
Normalization by ELA	1/h	0.44	0.56	0.77

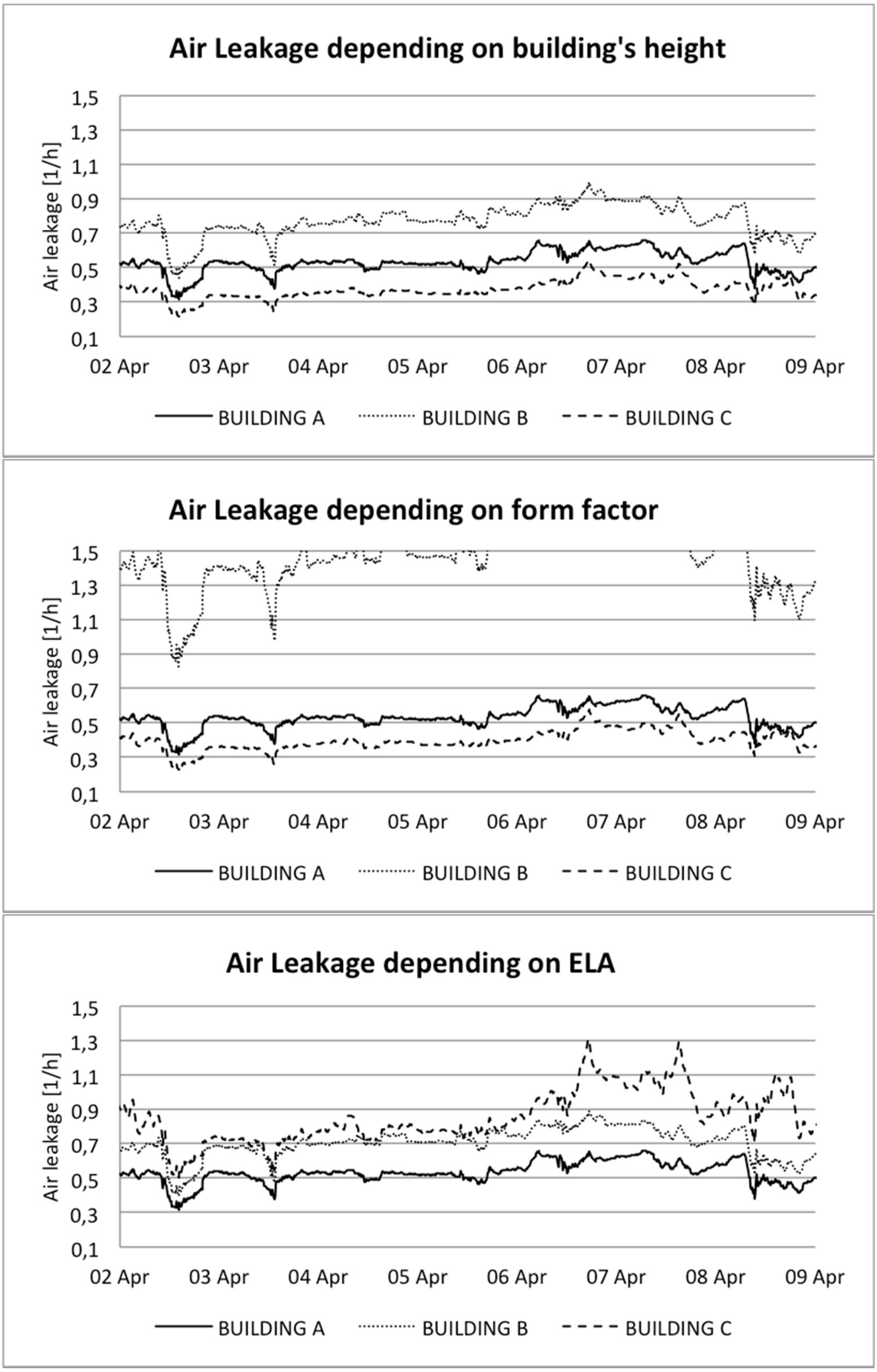

Figure 2: Infiltrations for a week in April of the three buildings considering B and C normalized to A-building's height (top), form factor (centre), and ELA (bottom).

It is seen that the ELA is the main factor in the models. The second one is the height which conditionsthe wind on the façades. The form factor appears as a second order derivative influenced for the other two parameters.

Conclusions

The main conclusions refer to the feasibility, necessity and interest in undertaking this type of test, both in new construction and in existing buildings. It is also necessary to integrate detailed models in the design tools, verification and buildings' intelligent energy management, as well as in certification tools. Implementing such analysis in the building process would detect building pathologies, enabling the improvement of the construction processes by establishing priorities depending on the constructive solutions adopted. It would also allow the design process to be informed under cost-efficiency parameters, closer to reality certifications, as well as a more accurate intelligent building management. Equally, and taking into account other similar projects undertaken in different latitudes

[10], a more deep analysis and from a stronger architectural point of view could relate constructive pathologies and architectural solutions, with different values for the present latitudes.

For the analysed buildings, their infiltration values are considerably high, with the consequent effect on the thermal demands and high-energy bills. This is mainly due to a poor construction process and practice, although having small form factors, or being low buildings, helps minimizing such effect.Equally, the order of magnitude in the variation of demands with respect to the normative case would justify, in terms of running costs, undertaking the necessary reforms to fix these problems. The strongest evidence lies in the building where the test could not be successfully completed due to the elevated air leakage both with the outside and the adjacent spaces. One should question if this is just an exception or the norm in old enough buildings (1992) in this geographical location

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Partners

Diamond Partners

Eurima is the European Insulation Manufacturers Association. Eurima members manufacture mineral wool insulation products. We actively support TightVent to develop knowledge and application of efficient airtightness solution for a successful implementation of the recast of the EPBD. This requires a good coordination between strong insulation and well-functioning ventilation in order to guarantee both energy efficiency and good indoor air quality.

Lindab is an international group that develops, manufactures, markets and distributes products and system solutions primarily in steel for buildings and indoor climate. With TightVent Europe, we learn more about the process of building airtight and energy efficient buildings; we fine-tune our product range by networking with suppliers confronted with the same issues. Our ambition is to transfer this knowledge all the way to building owners, architects/consultants, construction companies and workers.

Soudal NV is Europe's leading independent manufacturer of sealants, PU-Foams and adhesives. The company, established in 1966, proudly remains family owned. Soudal serves professionals in construction, retail channels and industrial assembly and has 45 years of experience with end-users in over 100 countries worldwide. Since sealing, bonding and insulating is our business, we actively support the Tightvent platform. And with 7 manufacturing sites on 4 continents and 35 subsidiaries worldwide, we hope to contribute to a wide-scale implementation of nearly-zero energy buildings

Tremco illbruck has a leadership position in the sealants and building protection market throughout Europe, Africa and the Middle East. Our efforts are focused on Window, Façade, Coatings, Fire Protection, Insulating Glass and non-construction industries. Through TightVent Europe, we share our experience and expertise in the airtight connection of building components to reach ambitious goals and to improve knowledge of building professionals by implementing training programs in the EU.

Wienerberger is the world's largest producer of bricks and No. 1 on the clay roof tiles market in Europe with 245 plants in 27 countries. TightVent Europe enables us to further develop and optimize the sustainable building solutions we offer to our customers. Moreover, we want to transfer knowledge to our customers (both builders, renovators and building professionals such as architects, engineering agencies, contractors, etc.) by means of theory- and practice-oriented training courses, seminars, workbooks etc

Platinum Partners

Since 1989, BlowerDoor GmbH has been a pioneer in the fields of airtightness, especially airtightness measurements, and BlowerDoor product design in Europe. Synergies in engineering, product development and training have made the Minneapolis BlowerDoor a high quality device for air tightness measurements all over the world. BlowerDoor GmbH actively supports TightVent to achieve a good and durable quality in building air tightness as one important criterion to reach the ambitious goals of the Energy Performance of Buildings Directive (EPBD) recast.

Since 1980, Retrotec has pioneered the manufacture of advanced air permeability measurement equipment and analysis software. Retrotec has for many years been actively involved in the development of new standards for ISO and NFPA fire suppressant containment standards and large building testing standards for the US Army Corps of Engineers. With its renown experience and high-quality systems used in over 60 countries around the world, Retrotec looks forward to contributing its expertise to help reach TightVent's ambitious goals.

Gold Partners

Aeroseal offers an effective solution for testing and sealing ductwork leakage from the inside using a water-based sealant. The Aeroseal application is capable of sealing new and existing ductwork in commercial and residential buildings. Aeroseal's aerosol ductwork sealing technology was invented and developed at Lawrence Berkeley National Laboratory in 1994. Aeroseal is looking forward to creating a long lasting relationship with TightVent Europe, and maintaining high efficiency within buildings

The Buildings Performance Institute Europe (BPIE) is an independent, non-profit organisation based in Brussels. BPIE supports the development of ambitious but pragmatic building-related policies and programs at both EU and Member State levels. We timely drive the implementation of these policies by teaming up with relevant stakeholders from the building industry, consumer bodies, policy and research communities. With the TightVent Europe Platform, our ambition is to play a key role in implementing policies on building and ductwork airtightness, bearing in mind ventilation needs.

CDPEA has been created in 2007 as a resource centre for building professionals in the field of sustainability, indoor air quality and energy performance in the Aquitaine region. CDPEA reaches directly a growing network of 5000 professionals with its tailored services in training, research and dissemination. CDPEA actively contributes to TightVent activities and thereby brings expertise and field feedback from professionals on airtightness. We look forward to strengthen our collaboration with TightVent to further increase the impact of both our organizations towards nearly zero-energy targets.

Platform facilitator

INIVE is a registered European Economic Interest Grouping (EEIG) that brings together the best available knowledge from its member organisations in the area of energy efficiency, indoor climate and ventilation. INIVE strongly supports and acts as facilitator of TightVent Europe because it clearly fits within the objectives of our grouping, namely, fostering and structuring RTD and field implementation of energy-efficient solutions and good indoor climate in new and existing buildings.