Envelope Air Leakage in Denmark – A status report

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Abstract
Implementing the EU-directive 2002/91/EF in Danish legislation led to regulations in the Danish Building Regulations on air tightness in buildings set out by the Danish Enterprise and Construction Authority, a department of the Danish Ministry of Economics and Business Affairs.

From 2006 air leakage through the building envelope exceeding 1.5 l/s pr. m² heated floor area at 50 Pa was not permitted in new buildings. In addition Local Authorities have obtained legal rights to withdraw the Planning Permission if the building exceeds the limited value.

The legislation on air tightness in buildings conceived a series of national activities including:

- National initiative to establish a platform and society for measurement of envelope leakage
- Danish Building Research Institute released a new Technical Guidance 214 which deals specifically with envelope air tightness in new buildings
- Danish Standard launched Certification of measurement with Blower doors and infrared cameras
- In connection with the Certification of measurement educational and informational activities were launched

Legislation and initiatives forced architects, engineers, planners as well as builders and building authorities to focus on better practices for air tightness in buildings, but there is still a lot to learn!

This paper provides an overall status on how air tightness is dealt with in new Danish buildings and which problems occur and how we have dealt with them.

Introduction
Denmark represents 43.098 km² of land (excl. Greenland, Faroe Islands) and is part of Scandinavia. 20 % of the area is built-up area, while 80 % consists of agricultural area, woods, dunes, beaches, lakes and moors. Since the total coastline (incl. 407 islands) of
Denmark is 7300 km, especially wind and weathertightness (that is watertightness and airtightness) have been a main issue in our buildings throughout ages.

Weathertightness of buildings has been dealt with through legislation, regulation, building norms and a technical joint property based on building tradition and best practice in design and building.

Until 2006 no quantified specification of air permeability through the envelope existed. In the Building Regulations the envelope was simply described and therefore specified as airtight. Air tightness was not defined.

In 2006 legislation and regulations regarding construction and housing matters were adjusted and regulation on air tightness in buildings was set out by the Danish Enterprise and Construction Authority (formerly the The National Agency for Enterprise and Housing), a department of the Danish Ministry of Economics and Business Affairs.

Together with other regulations regarding the reduction of energy consumption in buildings the implementation of the EU-directive 2002/91/EF in the Danish Building Regulations conceived major demands for the air tightness in buildings. In short the regulation incorporates the following regarding airtightness; effective since 2006 and recently adjusted:

- From 2006 air leakage through the building envelope (w50 specific leakage rate) exceeding 1.5 l/s pr. m² heated floor area at 50 Pa is not permitted in most new buildings; from 2008 all new buildings
- From 2008 the result of a air leakage test of a building is to be presented as an average of the specific leakage rate for both the pressurization and depressurization test; 2 tests are now necessary
- In addition to the above it is stated in the regulation, that for buildings with large rooms, where the envelope surface area divided by the floor area is larger than 3, air leakage must not exceed 0.5 l/s pr. m² envelope area (at 50 Pa); effective from august 2008
- Test for air leakage of the finished building envelope in buildings must be performed in accordance with DS/EN13829 method B
- In the Planning Permission the Local Authority can state that the building owner is obliged to attain a test certificate stating whether the building as a whole is able to meet the above stated demand or not
- The Local Authorities are legislated by the Danish Enterprise and Construction Authority to check a minimum of 5 % of all new buildings

The regulation entitles the Local Authorities to check the air leakage in the finished building and/or check whether a measured leakage in the finished building is correct or not. In fact, Local Authorities can withdraw the Planning Permission if the building exceeds the limited value. They can then demand that the building owner brings the envelope air leakage down below the stipulated standard requirement.

It should be noted that regulations as to airtightness have been under way for some years and the level chosen was based upon a public hearing and several discussions held between the Danish Enterprise and Construction Authority and the Danish Construction Association. Based on a round robin airtightness survey involving blower door tests of 200 new family houses the Danish Construction Association suggested that the level of envelope airtightness
for a period of 5 years should be 1.5 l/s pr. m² heated floor area at 50 Pa, as this was the level, with the knowledge on airtightness, leakage in buildings and materials for prevention of airtightness at the time, builders were expected to be able to obtain. This level was accepted by the Danish Enterprise and Construction Authority and incorporated in the Danish Building Regulations.

The Danish Construction Association however expect that the Danish Enterprise and Construction Authority will change the air leakage through the building envelope (w50 specific leakage rate) in 2010 from 1.5 l/s pr. m² heated floor area at 50 Pa to 1.0 l/s pr. m² heated floor area at 50 Pa. For passive houses a level of air leakage through the building envelope (w50 specific leakage rate) of 0.4 l/s pr. m² floor area at 50 Pa is also expected.

The demand for better air tightness conceived quite some uncertainty on how to fulfill Danish Building Regulations in all levels of the Danish Building Industry.

**National initiatives**

As a result of the legislation, air tightness tests and infrared scans boomed and with the tests a series of problems arose. Many questions came up e.g. how to trust a blowerdoor test, how to solve problems with detected leakage in the envelope and how to handle air tightness in the design. This lead to a national initiative taken by my colleague esteemed building engineer Mr. Lars Due and myself to establish a platform and society for measurement of envelope leakage; the foundation of the Danish organization KLIMASKAERM, which translates from Danish as The Building Envelope Society.

The society was established on 5th July 2006, with an inaugural of 50 members and is rapidly rising. The society consists of surveying companies who document air tightness, perform infra-red scans, diagnose leaks and give advice on how to solve problems with for example causes of leaks, insulation etc. Suppliers and manufacturers of insulation products, sealants, and suppliers of testing equipment are listed as associated members. KLIMASKAERM’s areas of interest are air tightness, thermal performance of buildings, leakage problems and protection of the envelope as a whole. Associated problems with mould and indoor climate are also incorporated.

The main idea is to communicate experience within these areas, to discuss problems in a relevant forum, to give and review ideas within the areas of interest, exchange views and ideas and to give third party advice in how to handle regulations and measurement. KLIMASKAERM have also established an office based at the Consulting Engineering Company BMT and have already held seminars and conferences on air tightness and indoor air problems throughout Denmark.

At the end of the summer period in 2007 the Danish Building Research Institute (SBi) released a Technical Guidance 214 which deals specifically with envelope air tightness in new buildings, commented by members of KLIMASKAERM. (For further information on the issues covered by the this publication please consult Danish Building Research Institute directly).

The Danish Standards Institute, in close association with KLIMASKAERM, launched a Certification of measurement with Blower doors and infra-red cameras end 2007. In connection with the Certification educational activities have also been launched spring 2008.
and series of informational activities e.g. a paradigm for a quality assurance guide on blower door tests and infrared scanning as well as new seminars and a homepage are being prepared by KLIMASKAERM.

**Typical procedures for dealing with air tightness**

At present the procedure on how to deal with air tightness in Denmark is as follows.

In the design of buildings only architects and engineers who focus on building detail tend to specify that the finished building is to undergo a test according to DS/EN13829 to fulfill the Danish Building Regulations. In some cases building detailing is part of the building contract, often subverted due to costs or contractual agreement with the contractor. Therefore the builder himself will perform the test or if he is unable to do so, take on a consultant or a specialist to undertake the responsibility of providing a test.

In the building process some builders tend to have preliminary tests done during the erection process in order to detect whether part or a unit of the building is air tight. The test is usually carried out before finishes to the building such as fixtures and fittings, wallpaper, flooring etc. are applied. All parties are well aware that a full test of the finished building is necessary to document air tightness before handover to the owner is initiated.

The not so common, but easiest, way to deal with air tightness demands is if the owner in the building contract specify that a test according to DS/EN13829 has to be provided as part of the contractors quality assurance.

As not all Local Authorities in the Planning Permission state that the building owner is obliged to attain a test certificate stating whether the building as a whole is air tight and in accordance with the Building Regulations, some buildings are not tested. In this case the specified air tightness in the Building Regulation is still effective as it the building owner is responsible that the demand is met.

Typically a test will be performed on request letting the claimant inform the consultant of the area and volume of the building in question providing all drawings necessary to perform a test and if requested a full technical survey of the envelope and its specific leakages will be arranged.

Before the test the building is thoroughly prepared and all preparation works are recorded. Open windows and doors are closed and internal doors left open etc.; all according to the specification in the standard DS/EN 13829 method B. As ventilation systems often are not regulated properly, the system is shut down and sealed under a test. As persons not involved in the test tend to disturb testing and/or damage preparation made, we normally ask them to either leave the building or to occupy themselves with activities not involving opening of the building envelope or the use of ventilation system.

As it is our experience that no building is fully airtight a test for air leakage through the envelope normally is followed up with an IR-scan involving depressurization up to 50 Pa after the test for air permeability. Even if a test meets the demands for air tightness stated in the Danish Building Regulation the IR-scan is used to detect major leakages and cold bridges; also after any corrections made by the builder. While the author acknowledges that there can be some cases where a thermographic survey is inadequate, we always make sure that the
 thermo images reflects an actual leakage by measuring the wind speed at the assumed leakage. Smoke tests are sometimes used to underline our registration on digital photos and drawings.

Tests on air leakage strictly follow DS/EN13829 and the results provided for the owner, normally in report form stating the result and whether in accordance with the Building Regulations. The fact that only few building owners are able to comprehend the test result as well as understand the test, somewhat underline the need for independent general information on building air tightness; a future task for KLIMASKAERM.

**Problems identified**

In connection with surveys done in Denmark it is our experience that leakages in general occur in all types of buildings regardless of whether they are erected in concrete, tile or timber. Leakages are also detected in different types of cladding, steel and glass structures. Joints are usually the weakest link.

At present our top ten lists of leakages found in new Danish buildings are:

1. Windows and doors, hereunder perimeter joints, embrasures, panels, flashings and sectional overhead doors
2. Plinths or bases for windows and doors
3. Joints between walls and ceiling and between walls and floors
4. Non sealed joints/junctions e.g. within damp proof course (DPC) or damp proof membrane (DPM)
5. Steel pipes for ovens, wood burning stoves etc that penetrate the building envelope
6. Installation shafts and inspection hatches
7. Halogen spots built into ceilings
8. Sockets
9. Pipes, ventilation service ducts and electrical services penetrating the damp proof course /membrane or the backing cavity wall
10. Floor joists, especially in connection with roofs

It is well known that windows and doors in some cases allow air to penetrate preformed gaskets, especially in the corners but also if the frame is not properly fitted. Though windows are tested by the manufacturer to withstand a wind pressure of at least 600 Pa, especially windows constructed with gaskets between actual window frame and aluminum sash frame fittings often need to be adjusted or supported by additional fittings to achieve the appropriate air tightness.

Perimeter joints and joints within the envelope in form of sealed joints are often installed with no regard to the adjacent materials ability to allow air to penetrate. In addition to improper sealant selection some surfaces are not specified nor prepared properly. Too many joints are elastic fillet joints with triangular shape with no ability to take up movement in the joint and inferior to those which have a rectangular (timeglass) shape. Also backing and tooling lack attention by the installer.

Many precompressed sealing tapes are installed with very little compression or the actual materials lack sufficient airtightness. As with sealants the surface is not smooth and seldom prepared properly. This is seen both in poorly functioning 2-step joints and where the sealing...
tape is used to seal between damp proof course and e.g. a wall.

Plinths and bases for windows, but also for doors are wrongly thought to be airtight. Also considerations for the position of a window or door in connection with such a device as well as the material used lack attention both in design and installment. Especially lightweight blocks (exclay or similar products) should be plastered or sealed properly vertical as horizontal to prevent airflow through the block or below e.g. wooden flooring.

Panels and embrasures in combination with windows and doors are often fitted in such a way that air can penetrate through insulation and on to joints and corners. Depending on how the window or door are fitted and where the frame is located within the envelope many cases show air penetration. Here there is clearly a need for new air tight solutions as traditional methods do not seem to be working properly. In some cases a damp proof courses are installed, but air can still penetrate through the corners. Windows are manufactured in such a way that it is almost impossible to fold and make corners airtight. Even though some products addressing the airtightness have proven themselves useful and many inventive solutions are also in progress, there seems to be a trend to build in heavy recesses around windows and doors.

Where a damp proof course (DPC) or a damp proof membrane (DPM) is used joints and overlaps are not correctly joined together and taped. If tape is used many problems with the quality of material used and poor workmanship is seen. Tapes are normally not specified and if low quality tape is used, usually due to cost parameters, many problems with drying out of the adhesive giving low adherence to substrate and low or non existing durability often rapidly lead to poor airtightness, convection of moisture and damp or even wet insulation. The worst example of this encountered so far is brown paper packing tape used to seal of polyethylene damp proof course in the attic.

Also a strong belief amongst designers as well as builders is that any kind of sealant can be used in the sealing of overlaps, slots etc., even between damp proof course/membrane and wall. In our experience no elastic sealant based on silicone, polyurethane, MS or similar will provide an everlasting bond on polyethylene. Polyurethane foam is not suitable as it does not bond to polyethylene and is often too stiff. Here several suppliers have developed more agreeable and durable sealantlike adhesives, which provide a more appropriate contact angle which is able to bond on polyethylene, sandy surfaces and plaster. Still there is something “magic” in sealant layers of less than 10 microns and how huge a load they can carry.

In our opinion to fine a layer of sealant will not be able to cope with wind excessive pressures nor give sufficient bondage between the substrates. Blowerdoor testing can result in harmful damage leading to problems with moisture and mould.

Installation shaft and hatches, and omitted passive fire protection tend to appear with low or no airtightness especially vertically between apartments. Many builders and designers believe mineral wool is as airtight as sealants, plasters and coatings, this problem needs to be addressed throughout the industry as this is not the case.

In Denmark it is only recently that designers and builders have learned that around halogen spots, sockets, pipes, ventilation service ducts and electrical services penetrating the damp proof course /membrane or the backing cavity wall, but also joist floors, especially in
connection with roofs, that penetrating members need to be secured with an airtight and
durable solution. In most cases we would recommend solutions involving EPDM flashings
depending on the envelopes fire classification etc.

**The need for a better understanding of airtightness in the design**

Envelopes in Denmark are now specified to six fundamental performance criteria

- Structural behavior
- Water tightness
- Thermal performance
- Fire performance
- Acoustic performance
- Air tightness

Both air and watertightness are difficult to predict, but air tightness is the critical issue. Our
experience shows that the leakage of air usually increases as the pressure difference increases.
This should lead to more focus on any penetrations in the building envelope. However the key
to successful airtightness of a new building and achieving a long term airtight envelope is to
understand how structures and materials work. This applies for the design phase as well as the
building phase of a project.

Especially in the envelope design, basic building physics tends to be forgotten, and elementary
principles such as 1-step and 2-step constructions e.g. pressure equalized rainscreens where
principles often are mixed or left out tend to give problems in the development of the project
as well as in the phase of construction.

A closer detailing in the design is therefore necessary. The selection of adequate solution and
material is essential and should not be done on site but at the drawing table.

**Summary and outlook**

Legislation and regulations on airtightness have proven effective in Denmark. Focus on
envelope airtightness has had a synergy effect on envelope tightness in general, air and
watertightness, consumption of energy and indoor climate e.g. the prevention of mould, not
only within the building industry, but also among architects, engineers, planners as well as
builders and building authorities.

Envelope airtightness is essential in Danish buildings, even though there is still a lot be done
before we can see a solid result of the legislation and regulations made. Especially the joining
of materials, durability of materials and design detail need further investigation and research.

As Local Authorities in Denmark can withdraw the Planning Permission and demand a blower
door test an effort to assure the quality of the design details and building materials specified,
of the building work done and tests on airtightness performed is needed.

In addition to quality assurance on building air tightness, focus on how to secure obtained air
tightness is needed, due to the fact that the daily use of the building and its interior may have
effect on the airtightness of the building envelope.

If the building owner expects that the building’s airtightness is everlasting, the owner may
need to reconsider the quality of his envelope, as the airtightness of many details in the building may change during its lifetime. Some materials are not able to follow movement in junctions and joints. Many materials used may change in size and form, as movement, settlement, heat and moisture change the building. Many defects caused by rodents or even by the user himself e.g. if a nail perforates vapour barriers a hole is made and can lead to problems with moisture, mould and a rise in energy consumption. This should be taken into consideration by giving the end user of the building information on how to keep the building airtight, solve immediate problems and the revised design may lead to preventing problems later on during the buildings lifespan.

As any part of a building, floors, walls, ceilings, doors, windows, joints etc. should be inspected at least once a year to secure that airtightness is still effective. To uphold obtained airtightness the building owner should not only be instructed in the optimal use of the building and its facilities, but also encouraged to check and maintain the buildings airtightness. Perhaps we in the years to come will have a building user maintenance guide with information on how to secure this.

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BMT - Building Environment Consultants Ltd. is a small Consultant Engineering Company encompassing fields such as Indoor Air, Mould, Felt Roofing, the Building Envelope and Building Physics. The company is based north of Copenhagen, adjacent to the Danish Building Research Institute with whom we share laboratory and other facilities.