CONTRIBUTING TO A FLAGSHIP PROJECT OF THE STRATEGY

Baltic Sea Region
Programme 2007–2013

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$Co_2olBricks$

WP5 Education and Economic Promotion

Improving building air-tightness

Educational product: New lecture material for training modules dealing with knowledge and skills how to apply suitable methods of energy efficient refurbishment of historic constructions and how innovation can be combined with cultural heritage

Improving building air-tightness

Target group: construction, energy audit students

Educational objectives: To give the understanding of leakage points in building envelope, to show the importance and possibilities to increase air-tightness in historic buildings.

This measure can help to save up to 8% of total energy used in building

Lecture course: 2 academic hours

References:

Zhivov, Alexander, and Wagdi Anis. "Building Air tightness and Air Barrier Continuity Requirements." *Energy and Water Conservation Design Requirements for Sustainment, Restoration and Modernization (SRM) Projects| US Army Corps of Engineers* (2010).

Kim, Min-Hwi, Jae-Hoon Jo, and Jae-Weon Jeong. "Feasibility of building envelope air leakage measurement using combination of air-handler and blower door." *Energy and Buildings* (2013).

Sadineni, Suresh B., Srikanth Madala, and Robert F. Boehm. "Passive building energy savings: A review of building envelope components." *Renewable and Sustainable Energy Reviews* 15.8 (2011): 3617-3631.

Staepels, Liesbeth, et al. "Do ventilation systems accomplish the necessary indoor air quality in low energy houses." *Clima*. Vol. 2013. 2013.

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Air tightness is the property of building envelopes most important to understanding ventilation. Air tightness is the fundamental building property that impacts infiltration.

Infiltration and Air tightness

Infiltration is defined as the movement of air into the building envelope through cracks, leaks, other opening in the building envelope etc. Exfiltration is defined as the movement of air from the building to the outside because of leaks, cracks and other openings in the building envelope etc. Air tightness measure is based on the building structure. If there are no changes to the building structure and measurements are taken correctly then the air tightness should reflect the same result every time. Whereas, infiltration is not constant as it depends on various parameters such as building orientation, wind direction, internal and external temperatures, occupant behavior.

Factors affecting Infiltration

Infiltration in a building envelope is mainly governed stack effect, wind movement and operation of mechanical devices. Infiltration rate also depends on building age, surroundings, building construction characteristics and climatic factors. During indoor cooling, the air tends to infiltrate through the leaks high in the building envelope and exfiltrate from the leaks low in the building envelope. The direction of air flow is reversed during indoor heating. Wind pressure of approximately 25 Pa or more can be generated by higher wind speeds.

Infiltration due to pollutant

Ventilation in building is due to three main reasons:

(a) Infiltration through cracks and leaks

(b) Natural ventilation through fenestrations due to wind and buoyancy forces and

(c) Mechanical ventilation due to fans and blowers. In mechanical ventilated buildings the performance of the filters guard the dispersion of the surrounding particles.

Whereas, in naturally ventilated buildings the openings of the air exchange are large and thus the particle penetration approaches to unity. In buildings with infiltration the penetration of the air depends on the air leakage path geometry, pressure difference and particle transport properties.

Pollutants include products such as carbon monoxide, particle matter, diesel soot, asbestos, lead, molds, pesticides, etc. The more the concentration of particle in the indoor air the more harmful it is for the occupants.

“Airtight building“ and „Thermal bridge free design“ are the concepts used in Passive Houses. But it is possible to transfer the planning principles for the new construction of Passive Houses to modernisations of old buildings.

“Thermal bridge free design” can be applied in the case of old buildings but there are some exceptions where a completely thermal bridge free implementation is not possible with justifiable effort (e.g. basement plinth, projecting balcony slabs etc). During the planning of these details the principles of thermal bridge free design can be of help.

Basically, the details with improved insulation on the outside have higher interior surface temperatures. The risk of moisture damage is reduced everywhere with the improved insulation. Some details in old buildings have such enormous thermal bridges that only insulation to the Passive House level can ensure sufficiently high interior surface temperatures in the winter, so that there is no risk of mould growth even behind furniture placed against walls.

To protect building from moisture related problems it is imperative to also insulate the exterior walls of the building with adequate insulation thicknesses if new airtight windows are installed. With the Passive House level of insulation on the outside, one can be sure to remain on the safe side for all details. In order to achieve a good standard of airtightness, the same rules apply as for a new construction, but specific solutions needs to be worked out for a number of the details in old buildings. One of these is to position the airtight envelope at the level of the old interior plaster. Without careful airtight connection of each of the individual component layers to each other, it will not be possible to achieve an adequate standard of airtightness.

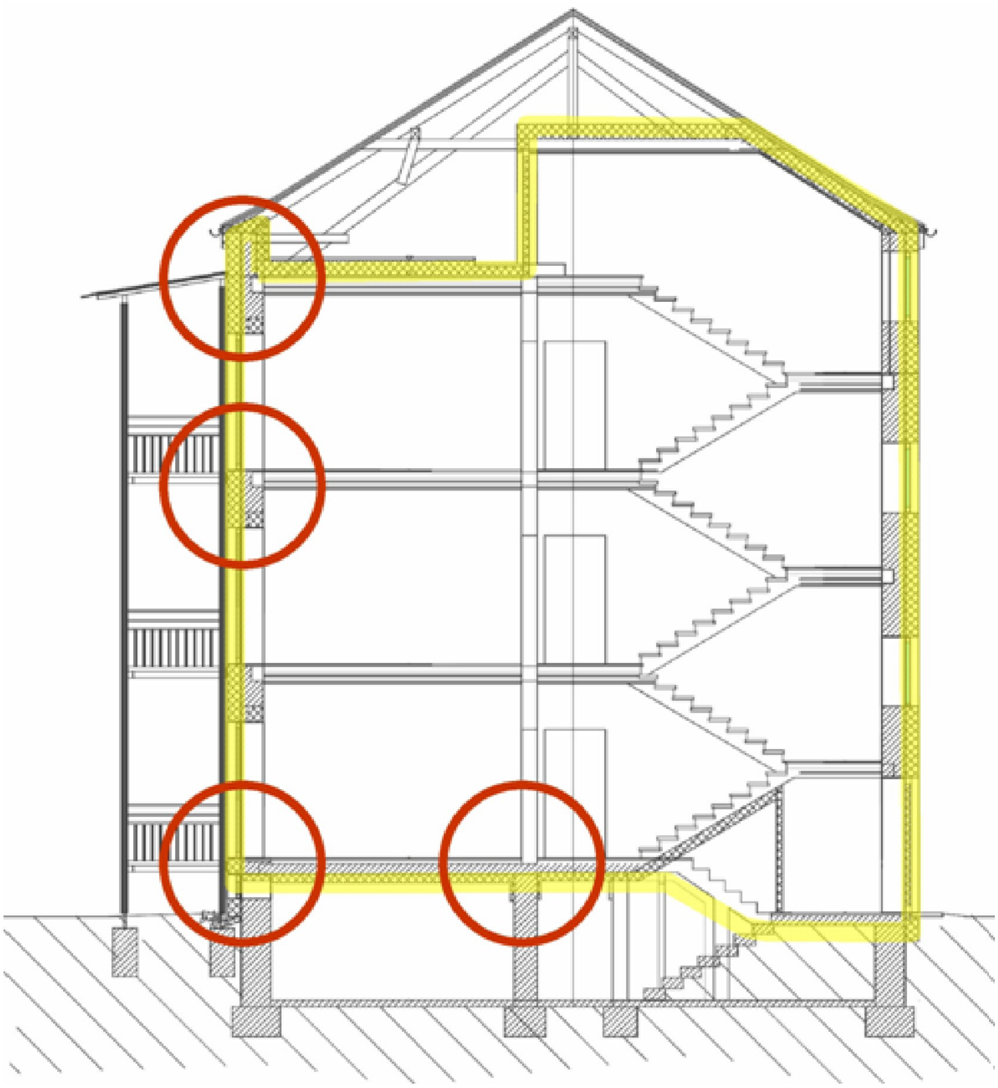

Figure 1. An uninterrupted building envelope and the places thermal bridges can appear in old building

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Measurement fundamentals

From a measurement standpoint, air tightness means measuring the flow through the building envelope as a function of the pressure across the building envelope. This relationship often fits a power law, which is the most common way of expressing the data.

The power law relationship has the form:

$$Q = C\Delta Pn$$

where C $[m_3/sPa_n]$ is the flow coefficient and n is the pressure exponent.

The pressure exponent is normally found to be in the vicinity of 0.65 but has the limiting values of 0.5 and 1 from simple physical considerations. Because of the nonlinear nature of this expression there are some interesting challenges in understanding any measured data;

In her general study of air flow measurement, McWilliams (2002) reviews of the techniques for measuring air tightness. The vast majority of techniques fall into the category of "fan pressurization" in which a fan (or blower) is used to create a steady state pressure difference across the envelope. The flow through the fan is measured at a variety of pressures. The most common incarnation of fan pressurization technique for dwellings and small buildings is known as a blower door. Although other methods for measuring air tightness have been examined we shall concern ourselves principally with fan pressurization techniques.

BLOWER DOOR BACKGROUND

"*Blower Door*" is the popular name for a device that is capable of pressurizing or depressurizing a building and measuring the resultant air flow and pressure. The name comes from the fact that in the common utilization of the technology there is a fan (i.e. blower) mounted in a door; the generic term is "Fan Pressurization". Blower-Door technology was first used in Sweden around 1977 as a window-mounted fan (as reported by Kronvall, 1980) and to test the tightness of building envelopes (Blomsterberg, 1977). That same technology was being pursued by Caffey (1979) in Texas (again as a window unit) and by Harrje, Blomsterberg and Persily (1979) at Princeton University (in the form of a Blower *Door*) to help find and fix the leaks.

During this period the diagnostic potentials of Blower Doors began to become apparent. Blower Doors helped Harrje, Dutt and Beya (1979) to uncover hidden *bypasses* that accounted for a much greater percentage of building leakage than did the presumed culprits of window, door, and electrical outlet leakage. The use of Blower Doors as part of retrofitting and weatherization became known as *House Doctoring* both by Harrje and Dutt (1981) and the east coast and Diamond et al. (1982) on the west coast. This in turn led Harrje (1981) to the creation of instrumented audits to computerized optimizations.

While it was well understood that Blower Doors could be used to measure air tightness, the use of Blower-Door data could not be generally used to estimate real-time air flows under natural conditions or to estimate the behavior of complex ventilation systems. When compared with tracer-gas measurements, early modeling work by Caffey (1979) was found wanting. There was a rule of thumb, which Sherman (1988) attributes to Kronvall and Persily that seemed to relate Blower-Door data to seasonal air change data in spite of its simplicity. Modeling of infiltration, however, is discussed elsewhere.

Norms and normalization

The metrics above all refer to the total amount of leakage of the tested envelope. For setting norms or standards, or for comparing one structure to another it is often desirable to normalize this total by something that scales with the size of building. In that way buildings of different sizes can be evaluated to the same norm.

There are three quantities commonly used to normalize the air leakage: building volume, envelope area, and floor area. Each has advantages and disadvantages and each is useful for evaluating different issues:

Building volume is particularly useful when normalizing air flows. When building volume is used to normalize such data the result is normally expressed in air changes per hour at the reference pressure; ACH_{50} is probably the most common air tightness metric reported. Many people find this metric convenient since infiltration and ventilation rates are often quoted in air changes per hour.

Envelope area is particularly useful if one is looking to define the quality of the envelope as a uniform "fabric". Dividing (especially a leakage area) by the envelope area makes the normalized quantity a kind of porosity. Although this normalization can sometimes be the hardest to use, it can be particularly useful in attached buildings were some walls are exposed to the outdoors and some are not.

Floor area can often be the easiest to determine from a practical standpoint. Because usable living space scales most closely to floor area, this normalization is sometimes viewed as being more equitable. This normalization is used most often with ELA measurements and can be converted to a different kind of dimensionless leakage, such as the normalized leakage used by ASHRAE (2001).

Air tightness data

Air tightness data can be expensive to collect. The larger and more complex the building, the more difficult and time-consuming it is to collect the data. Furthermore, air tightness in large buildings was not thought to be as important a consideration as for dwellings. Thus, the majority of existing data is for dwellings and more specifically for single-family homes. We shall review those first and then move on to the other kinds of data.

The air tightness of low energy buildings is particularly important when the buildings are equipped with heat recovery ventilation system in order to achieve energy-efficiency.

Key leakage pathways

The types of leakage problems have much to do with the construction of the buildings.

One of the most important factors is the method used to construct the walls.

Load-bearing masonry walls with timber-framed are common forms of construction in the Historic buildings in BSR. If for inside finishing plasterboard-on-dabs are used, all the leakage paths in the house will become interconnected which makes air sealing difficult.

Wet plastered masonry wall can potentially be several orders of magnitude more air tight.

The use of polyethylene air barrier is a common practice to reduce air leakage at walls.

Buildings with polyethylene wrap are on average 13% tighter than their counterparts.

The technique of using housewrap over untapped extruded polystyrene foam sheathing has the highest flow resistance among the different materials studied. However, a longevity study by Air-Ins Inc. (1998b) showed that spun bounded olefin paper can fail to stretch around joints under high temperature and

break away.

There are alternatives to the use of plastic film as air barrier in buildings – diffusion permitting polymer-based fiber sheets (sometimes known as 'windproof' sheets) and gypsum board panels. Measurements showed that it is possible to meet the Sweden Building Regulations provided if the technical designs and quality of contractor work are of high standard.

Some types of perforated polyethylene are permeable to air. After a test period of five months at some pressure and temperature differentials, improvement in air tightness was noted due to dust which blocked the holes.

A longevity study on the behavior of various air barrier connection techniques submitted to pressure and temperature differentials showed that silicone base sealant and adhesive tape are the most durable. On the other hand, open cell gaskets, mineral wool, and perforated polyethylene should not be used due to their high permeability. Spun bonded olefin and acrylic sealant can exhibit problems at high temperatures.

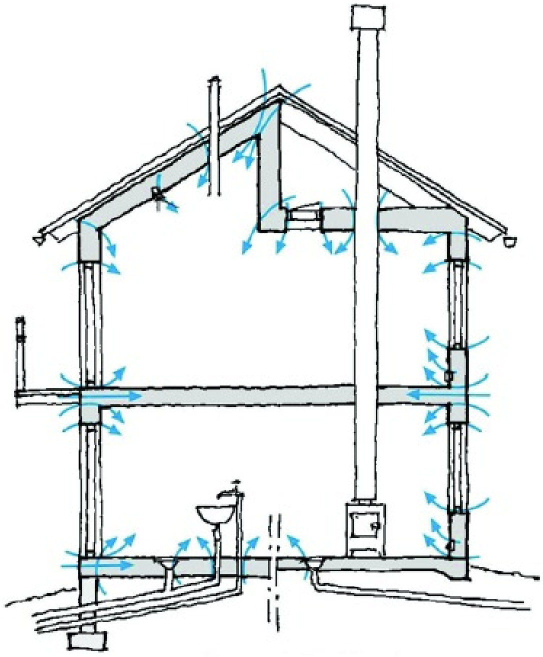

Figure 2. Common air leakages in a building envelope
(Eric Verner AB)

Apart from leakage through wall, other important components contributing to air leakage include windows and doors, flue and fireplace, heating ducts, and the connections to attic, basement.

Current window testing standards do not include air leakage from the joint between window and wall assemblies or from the sides of the windows.

The air leakage of windows can be further reduced by 60% to 80% when an additional storm window is added.

Identify the Positions of Leaks/Positions for Improvements

There are often problems with air leaks around window and door openings, joints, connections to floors, ceilings or intermediate walls, and around duct and pipe penetrations. Typical weak points are shown in Figure 2 and can be summarized as:

- joints in air barrier sheet materials
- wall-to-floor connection
- wall-to-ceiling connection
- wall-to-window connection
- service penetrations

- Get a rough idea of the position and size of possible leaks by using your hand after starting the fan.
- Find the positions of leaks using smoke, an anemometer, or a thermal imaging camera.

When the leak is found, the necessary steps to reduce it or eliminate it entirely have to be taken.

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Thermal imaging camera. If the outdoor temperature is at least 5°C colder than indoors (and preferably 10°C), a thermal imaging camera can be used to find leaks. In some cases, the temperature in the test area has to be raised for at least twelve hours before carrying out the tests, in order to create a greater temperature difference. However, as air leaks can be confused with thermal bridges, the camera should be complemented by an anemometer.

Anemometer. The anemometer should be placed carefully next to the position where an air leak is found or suspected to be. It has to be aligned so that any air currents flow through it. All detected leaks shall be completely sealed since it can be difficult to interpret the results and determine the consequences of a leak.

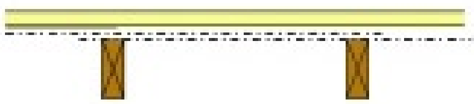

Figure 3. The polyethylene films overlap over two points

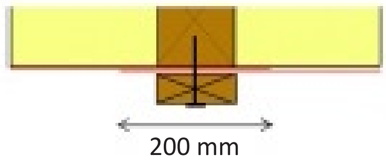

Figure 4. Clamped overlap

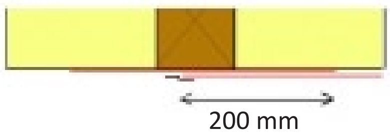

Figure 5. Taped overlap

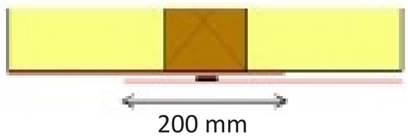

Figure 6. Butyl rubber strip

Figure 7. Damaged polyethylene film must be repaired in two layers

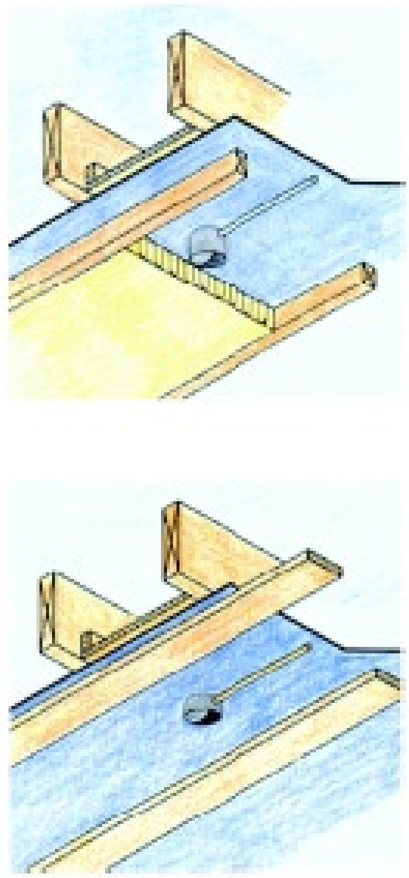

Figure 8. A gap for the services is created by pressing

There are several measures that can help to ensure high performance with an air barrier made of polyethylene film.

1. Minimise the number of service penetrations.

2. Make sure that the joints in the polyethylene film overlap two joists, as shown in Figure 8. The polyethylene film should preferably be placed between two solid layers (mineral wool is sufficient), so that the joint is compressed over its entire length.

3. The polyethylene film joints should be placed in line with the joists if possible. If it is not possible to have an overlap of two joists, the overlap should be at least 200 mm. The joints can be clamped, taped, or secured with doublesided adhesive material, such as mastic or butyl rubber strip (Figures 9, 10, and 11, respectively). When adhesion is needed, care should be taken so that the polyethylene film is clean and not folded. In addition, the durability of the sealing materials must be considered. A clamped joint can lose its airtightness when wooden joists dry. Consequently, combining a clamped joint with a flexible or double adhesive material ensures a good result.

4. Use double layers of polyethylene film to improve airtightness.

5. Use extra-thick polyethylene film (0.4 instead of 0.2 mm). This is particularly important when there is a risk of damaging the polyethylene film.

6. Protect the polyethylene film during the construction phase. If the sheet is damaged, it must be repaired by first surrounding the damaged part with tape and then adding an extra piece of polyethylene film over the damage. The overlap must be at least 100 mm in all directions.

7. Finally, the polyethylene film should be recessed into the construction when possible. This way, the number of service penetrations is minimized and the polyethylene film is also protected. Care should be taken to ensure that the polyethylene film (and vapor barrier) is not located too close to the cold side of the structure, as this can result in moisture damage. Recessing the polyethylene film is common in exterior walls and is also a good idea for roofs.

Airtightness requirements

International building legislation is setting stronger and stronger requirements for the energy performance of buildings. An actual example is the impact of the Energy Performance of Buildings Directive in the European Union (EPBD) on the national requirements in the Member States. The improved energy performance of buildings can't be achieved by additional insulation or more effective buildings systems only. A major influence factor on the energy quality is the ventilation technology and also the airtightness of the building envelope. Some countries include in their energy decree already maximum air change rates, partly for all building types, partly only for those that include a mechanical ventilation system. Especially for high performance buildings which go beyond the national requirements, the infiltrations losses become a significant factor to the energy performance.

Table 1: Results of the German study on the impact of thermal bridges on the heating energy

EU Member State	Air tightness requirements at 50 Pa pressure	
	Natural ventilation	Mechanical ventilation
Czech Republic	4.5 1/h	w/o heat recovery: 1.5 1/h with heat recovery: 1.0 1/h
Germany	3.0 1/h or 7.8 m^3/h per m^2 floor area	1.5 1/h or 3.9 m^3/h per m^2 floor
	Leakage rate per facade area: 3.0 m^3/m^2h	
Denmark	1.5 l/s per m^2 floor area	
Norway	3.0 1/h	
The Netherlands	Dwellings: 200 dm^3/s (at 10 Pa) Non-residential buildings: 200 dm^3/s per 500 m^3 (at 10 Pa)	
United Kingdom of Great Britain	New dwellings and new commercial and public buildings over 500 m^2: 10 m^3/m^2h (stated as reasonable limit for the design air mermeability in building regulations 2000 L1A and L2A)	

It has to be stated though that in all BSR countries with air tightness requirements, there is no generally required compliance test.

However, in Germany and Denmark pressure tests are required in some cases.

In Denmark the pressure test is generally optional but can be required by building authorities.

In Germany the pressure test has to be made if a mechanical ventilation system is considered in the calculation of the energy performance certificate of a new building. The reduction of the ventilation losses can only be taken into account if the airtightness was proven.

In Finland the basic air leakage rate for calculation of the energy performance can be reduced if a pressure test or some other accepted method presents better performance.