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International Energy Agency
Energy Conservation in Buildings
and Community Systems Programme

Air Infiltration and Ventilation Centre

Airtightness of buildings

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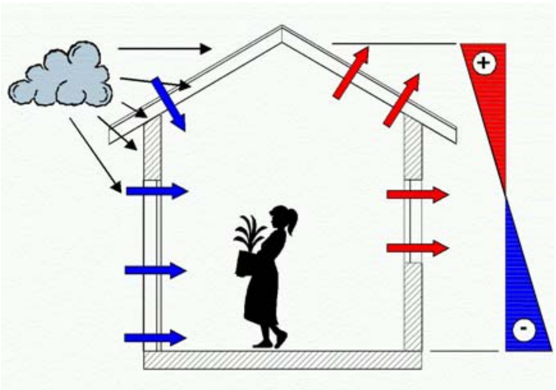


1 Introduction

If the building envelope is not airtight enough, significant amounts of energy may be lost due to exfiltrating air, or damage to structural elements may occur due to condensation. Air leakage can be avoided by appropriate design and careful construction. Test methods to check the quality of airtightness and to locate the individual leakages are available and are increasingly used.

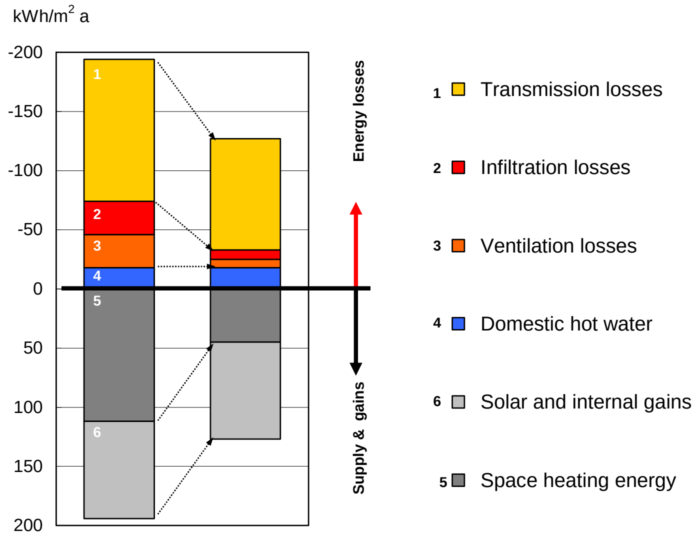
2 Importance of airtightness of building envelope

Since ancient times, it has been common knowledge that sealing cracks and joints, in the past with moss and clay, prevent cooling of the building and reduces draft risk, thus providing better thermal comfort. In the envelopes of today's new buildings, the critical spots are often just small hidden leaks which do not show their negative effects until some time after the dwelling has been occupied.

Warm air escaping through many small leaks in the building envelope produces, exactly like an open window, a permanent energy loss. Depending on building location, building type and leakage type, the space heat demand is increased up to 50% in order to compensate for this energy loss (Figure 1). As boilers and heat distribution systems of today are rather strictly dimensioned to the nominal demand, unaccounted-for leakages may lead to the situation that the designed room air temperature is no longer reached during cold days. Similarly, excess energy demand will also occur in summer conditions if the indoor air is conditioned.

There are other problems related to insufficient airtightness: In winter, escaping warm room air cools down on its way through the wall or roof leak. This leads to condensation in the construction. The condensed water may trickle its way downwards and drip somewhere from the ceiling. Even worse, stagnant water or high moisture may rot the construction without being discovered in due time. (Example: Through a leak of 1 cm^2, at 4 Pa pressure difference, up to 30 l of condensed water may be accumulated per winter period in Zurich climate). In multi family houses, odours or indoor pollutants, affecting indoor air quality or even health, may be spread from dwelling to dwelling through internal leakages. Finally outdoor noise and air pollution can penetrate the rooms through leaky windows or door joints or cracks (Figure 2).

Therefore, airtightness requirements for the building envelope are stipulated in building standards and codes, to prevent energy loss, structural damage, draught risk and immission problems.



Left: Single family house, with assumed airtightness level $n_{50} = 4.5\ h^{-1}$. (definition of n_{50} see chapter 3)

Right: House with increased insulation and airtightness level ($n_{50} \cong 1.5\ h^{-1}$) and mechanical ventilation with heat recovery.

Figure 1 : Energy demand for space heating and domestic hot water, and respective coverage by the heating system and by passive gains (in kWh per m^2 floor area and year)

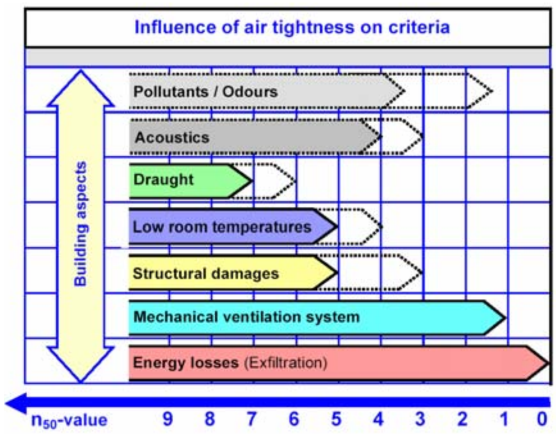


Figure 2: Influence of airtightness on the different building aspects (based on empirical experience in Switzerland)

3 How is airtightness quantified?

The measured leakage flow is normalized to a reference pressure difference and to a factor which accounts for the building size (floor area, envelope area, volume). Many approaches for normalization and reference pressures are used [Ref. 1].

3.1 Volume related leakage air flow

The leakage flow at 50 Pa pressure difference across the envelope divided by the volume of the building (net volume of measured zone) results in the so called n_{50}-value, which can be used to compare the airtightness of different buildings.

3.2 Envelope area related leakage air flow

Many countries express leakage flow rates as an air flow per m² envelope area, related to the reference pressure difference (4 Pa in France and Switzerland). The envelope area is defined in several ways. In most countries, the envelope area does not include the ground floor, whereas this is the case in Sweden and Belgium.

3.3 Effective leakage area (ELA)

The measured leakage volume flow rate at the reference pressure difference is related to an equivalent orifice area with the same flow rate at this reference pressure difference. ELA are defined for pressure differences of 4 Pa (US) or 10 Pa, and for different orifice discharge coefficients.

4 Interaction of infiltration with ventilation system

Driven by pressure forces due to wind and stack (pressure due to different densities of cold and warm air) air infiltrates through the leaks in the building. Thus, the amount of infiltration is dependent on the indoor-outdoor temperature difference, the wind pressure, the building type, and the distribution of air leakage and internal partitions (Figure 3). Different models (simple or complex) exist to calculate the infiltration depending on these parameters.

Today's building design philosophy is to keep the building as airtight as possible and to provide air by windows and other purpose provided openings, and/or by mechanical ventilation.

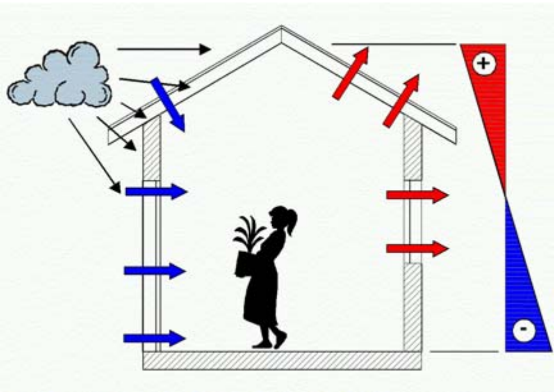


Figure 3: Infiltration is governed by wind and stack pressures and the size and distribution of leaks

For buildings with mechanical extract ventilation systems, infiltration may contribute as much as 30 % to the total outdoor air supply flow, even for good airtightness (n_{50}=1.0 h^{-1}) and outdoor air inlets dimensioned for low pressure differences (Figure 4).

Also in buildings with mechanical supply and extract systems, supply/extract flow imbalances and the resulting pressure differences across the façade may lead to significant infiltration or exfiltration flows respectively.

5 Airtightness requirements

Most national buildings standards and codes include requirements for airtightness of the building envelope. An overview is given in AIVC TN 55 [Ref. 1].

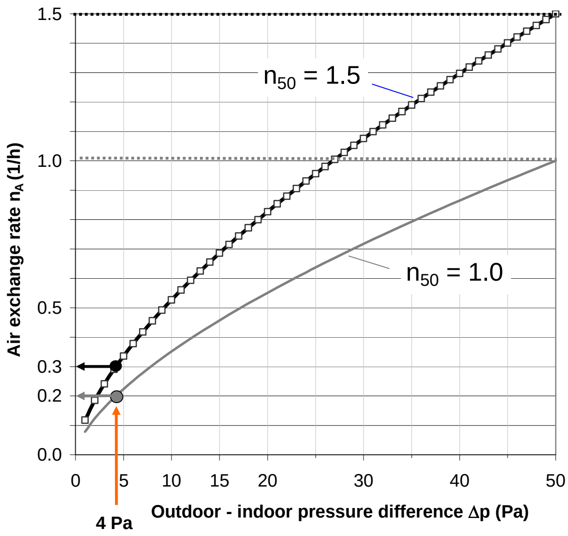


Figure 4: Infiltration contributes significantly to the total outdoor air flow of extract ventilation systems, even when dimensioned to low pressures differences (e.g. 4 Pa)

6 How is airtightness measured?

6.1 Pressurisation tests

The airtightness of a building envelope is measured by the so called blower door technique, according to EN 13829 [Ref. 2] or ASTM-E1827-96 [Ref. 3]. A fan is inserted into a door (Figure 5) or window frame and the building is pressurized or depressurized, enough to minimize the influence of stack and wind pressures on the results. The measured flow through the fan corresponds to the flow through the leakages (Figure 6).

For an entire measurement a characteristic of the leakage air flow rate q_V as a function of the pressure difference Δp from 0 to 100 Pa is taken. The measurement points are fitted to a characteristic which is based on the flow equation (1).

$$q_V = C \cdot \Delta p^n \qquad (1)$$

C : leakage coefficient *n : flow exponent*

From the leakage flow characteristic plot, the respective values for the leakage criteria and parameter are derived.

Figure 5: Minneapolis blower door

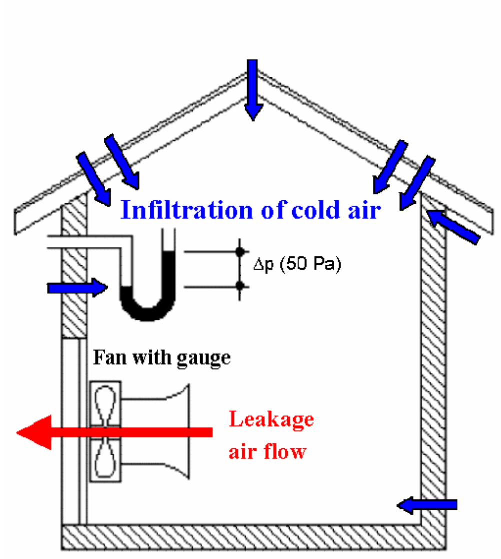


Figure 6: Fan-pressurization test

Table 1: Sources for uncertainties in fan-pressurization tests and respective error bands, based on empirical experience

Parameter	Error band	Errors stem from
Flow rate measurement equipment	± 5 - 10 %	Uncertainty of measuring instrument
Under- /overpressure	± 0 - 20 %	Object and surrounding related uncertainty
Determination of reference volume or envelope area	± 5 - 15 %	Level of expertise and experience
Size and geometry of building	± 5 - 15 %	Critical are very large buildings
Outdoor climate (wind, stack)	± 0 - 40 %	Object and surrounding related uncertainty
Season (winter, summer)	± 0 - 30 %	Object and surrounding related uncertainty
Construction phase (new building)	± 0 - 20 %	Level of finalization of air tightening
Age of building	± 0 - 10 %	Level of expertise and experience
Leakage of ventilation system	± 0 - 50 %	Sealing of air inlets/outlets, duct leakage, measuring zone, measurement time

Many boundary condition parameters influence the result of the measurement. Depending on the point in time of the measurement (building under construction, inhabited building), season (summer or winter), position of fan (stack effects!) or preparation of the building for the measurement (sealing and taping of openings), the uncertainties can be relatively high (see Table 1).

For the calculation of ventilation losses due to infiltration, EN 832 stipulates n_{50}-values for the building in its normal use (thus with air inlets open) while many airtightness requirements are related to the quality of the building envelope only, thus requiring measurements with all air inlets/outlets carefully sealed.

Figure 7 shows as an example the influence of a kitchen hood which was not sealed for the measurement. The uncertainties due to the measuring instruments are rather small, but the uncertainties related to the building and the surrounding as well as the methodology and the procedures for the set up of the building for the measurements might be high.

Many specific topics are not specified in enough detail in EN 13829 [Ref. 2]. A detailed operation procedure, worked out as an amendment to EN 13829, is therefore crucial for reliable results [Ref. 4]. Reference pressures of 4 and 10 Pa are closer to the natural driving pressures inducing infiltration, but as they are outside the pressure range for measurement, the air flow rates at 4 and 10 Pa, predicted by extrapolation, may be subject to significant uncertainties (Figure 8).

Also the influence of the duct leakage of the mechanical ventilation system may be significant when measuring highly airtight buildings, even if the openings and air intake are sealed. Figure 9 shows a situation where air can flow through the ducts to outside, leading to erroneous envelope leakage values. Figure 10 gives some results from recent measurements in low energy buildings with balanced mechanical ventilation and heat recovery.

The sealing of the ventilation system in the airtightness measurement can have a large impact on the results.

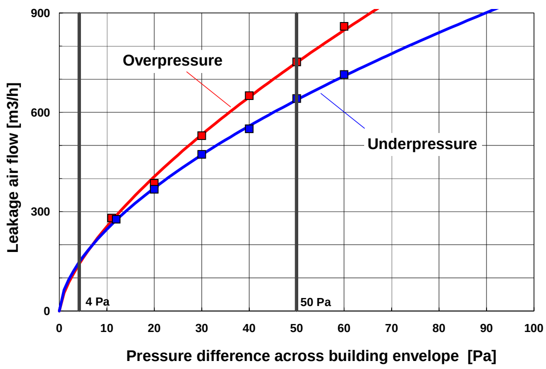


Figure 7: Characteristic of building leakage. In this case the leakage for overpressure (red) is higher than the leakage for negative pressure because the flap trap of the unsealed kitchen fan opened with increased overpressure.

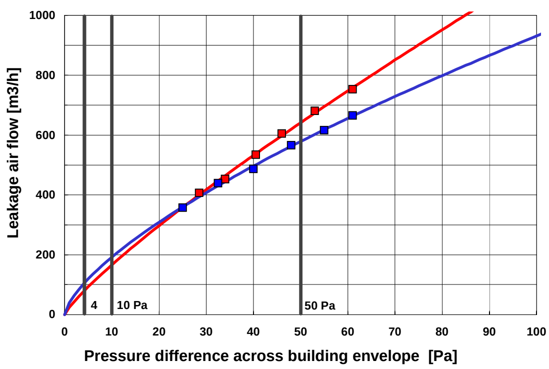


Figure 8: Characteristic of building leakage An extrapolation of the characteristic to pressure values below the effectively measured values is problematic because small uncertainties of the readings might influence the shape of the characteristic considerably.

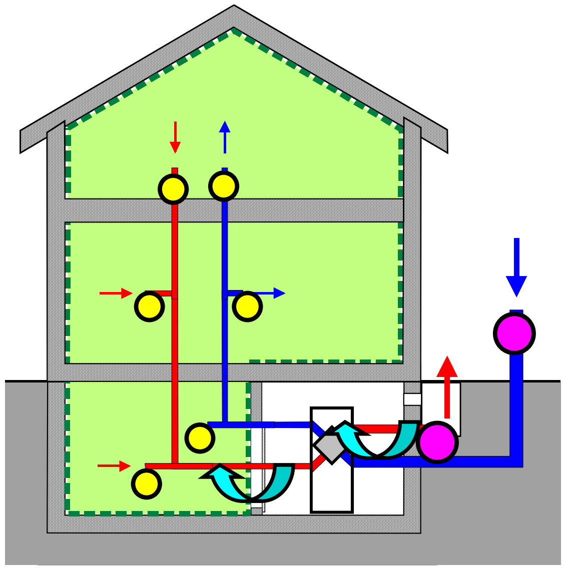
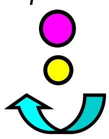


Figure 9: Air may pass through leakage in the ducts of the ventilation system, thus leading to too high envelope leakage values for the reference volume zone (green).



External sealing
Internal sealing
Unintentionally measured flows due to duct leakage

6.2 Leakage distribution measurements

The leakage of individual parts of a building can be determined by applying “guarded zone” techniques, where one or several fans are used to balance the pressure between boundaries (walls) not to be measured, and one fan is used to build up the pressure difference across the façade element to be measured, see [Ref. 5].

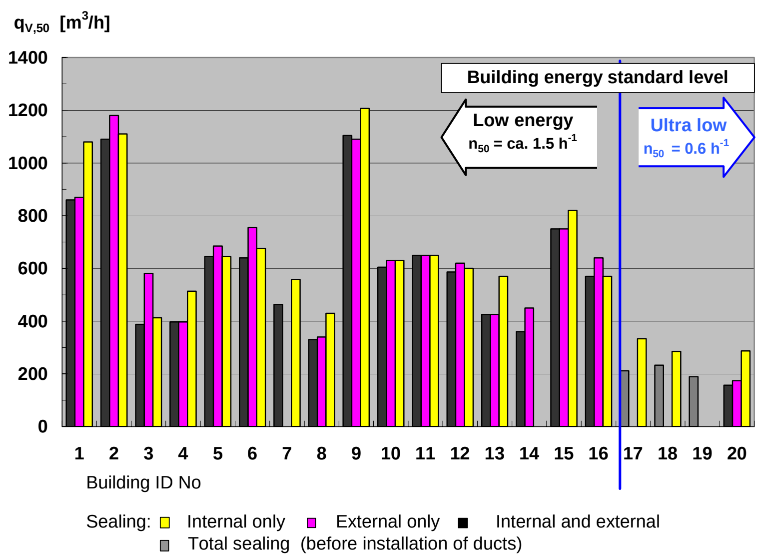


Figure 10 : Effects of different sealing techniques for the ventilation system on the result of airtightness measurements in a number of moderate low energy buildings (Swiss Minergie standard), and of ultra low energy buildings (acc. to German Passive House standard), where the discrepancies can amount up to 50% of the n_{50}- value! Internal = sealing of inlets/outlets in the rooms only. External = sealing of air intake and exhaust only.

7 How can air leakages be localized?

Blower door leakage tests do not indicate the location of the leakages. To find major leaks, critical locations (e.g. window, roof/wall joint, pipe penetrations etc.) several methods can be applied e.g. smoke detection, anemometer or hand sensation during the fan-depressurization [Ref. 6].

The most promising way of detecting and visualising leakages is infrared (IR)-thermography. This method is based on a fan-depressurization test in winter. The cold outdoor air entering the room through the leakages cools down the warm inner surface near the leakages. This can be observed with an IR-camera (Figure 11 to Figure 13). Differential images between the situations with and without fan-depressurization show only those cold spots caused by the entering cold outdoor air, and hide cold surface areas caused by cold bridges (Figure 14).

Air leaks can also be detected by IR-imaging only, without pressurisation, by scanning the building in winter from outside for warm spots caused by warm air leaking though the building (mostly in the upper part of the building due to stack effects) (Figure 15 and Figure 16).

Figure 11: Normal picture of the room.

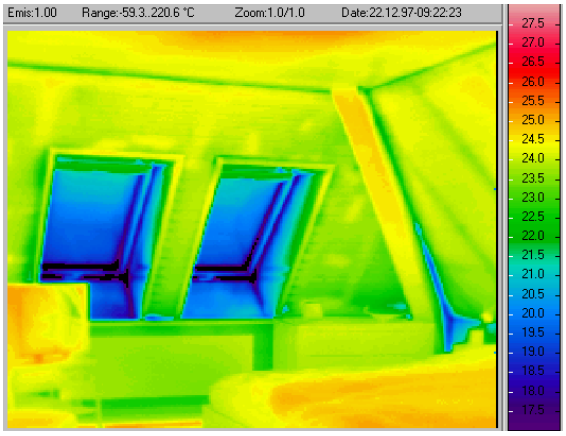


Figure 12: IR image of an attic room, without depressurization. The windows and the corner surfaces are rather cold (blue colour), as it is normally the case.

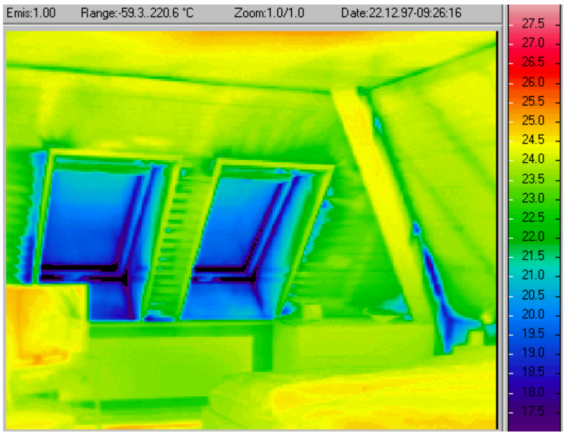


Figure 13: The same IR image as figure 12, but now with depressurization. After some minutes, the cold air infiltrates through various leaks.

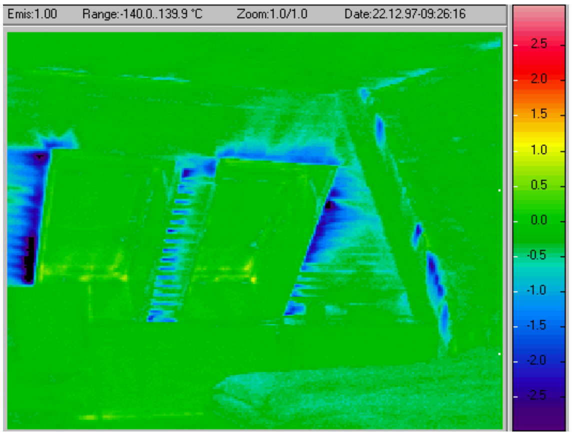


Figure 14: Differential image of figures 12 and 13. Such, the surfaces cooled down by the air entering trough the leaks are clearly visible

Conclusion: The connections between window frames and roof panels are very leaky. The window joints themselves are airtight. Additional leaks can be observed in the region of the rafter in the corner. The roof panels are tight.

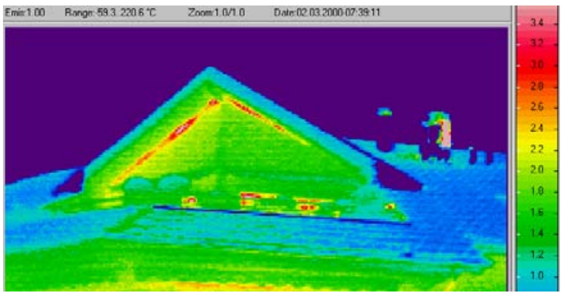


Figure 15: This external IR thermography image shows warm air exfiltrating due to stack forces at the roof – wall joint.

Figure 16: Exfiltrating warm and moist room air condenses at the roof panels and clearly discolour the wood.

8 Principles for airtight buildings

Walls of concrete plastered brickwork, plasterboards or plates of metal or glass are usually airtight. Joints of building components, penetrations (rafters, pipes, ducts) or cracks and joints (windows, doors) are potential locations for leakes. Especially buildings with timber frame constructions have many critical locations. Also a steep roof on top of a solid structure is a timber construction. Therefore airtightness is also an issue of concern for this type of building.

Airtightness in timber frame constructions can be achieved with proper placement of the wind barrier sheet. In certain countries, the wind and vapour barriers are combined in one single film layer. Overlaps of the layers have to be durably bonded together. Additionally the joints to adjacent components (e.g. walls, penetrations) have to be sealed with special adhesive tapes.

An airtight building envelope, which complies with today's requirements, can only be achieved if the airtightness is conceptually planned and the specific design principles are considered. These are in general: The simpler the geometries and the areas of the airtight layer are (no penetrations) and the simpler its installation, the smaller the risk for leakages. Certainly this includes the correct choice of material and a reliable workmanship, which is to be checked consistently during each construction phase, see also [Ref. 7].

In Central and Northern Europe, for low energy buildings, a fan-pressurization test is increasingly becoming a standard element in the commissioning procedures.

9 Available airtightness data

Data from over 2000 single and multi-family buildings are compiled in the AIVC Numerical Database [8]. A large data base on single-family dwellings is the LBNL Residential Diagnostics Database [9]. A comprehensive outline on all aspects of airtightness, including available data sources, also on non-residential buildings, is given in [10].

10 References and literature

[1] AIVC TN 55. A Review of International Ventilation, Airtightness, Thermal Insulation and Indoor Air Quality Criteria. 2001

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

[3] ASTM, Standard E1827-96, "Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door". 2002

[4] FLiB Amendment to DIN EN 13829-2. Issue 10 (in German). Fachverband Luftdichtheit im Bauwesen. 2002 (http://www.flib.de)

[5] AIVC TN 34: Air Flow Patterns within Buildings - Measurement Techniques. 1991

[6] ASTM, Standard E1186-98, "Air Leakage Site Detection in Building Envelopes and Air Retrader Systems". 1998.

[7] prEN 14134 Performance testing and installation checks of residential ventilation systems

[8] AIVC Guide 5, Ventilation Modelling Data Guide. 2002

[9] Chan R. et al. Analysis of the U.S. Residential Houses Air Leakage Database. Lawrence Berkeley National Laboratory Report 53367. 2003

[10] Sherman M H, Chan R. Building Airtightness: Research and Practice. Lawrence Berkeley National Laboratory Report 53356. 2004.

[11] ASHRAE Standard 119, "Air Leakage Performance for Detached Single-Family Residential Buildings". 1988.

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.