Airtightness requirements for high performance buildings

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ABSTRACT

International building legislation is setting stronger and stronger requirements for the energy performance of buildings. The most recent example is the Energy Performance of Buildings Directive in the European Union. The improved energy performance of buildings can't be achieved by additional insulation or more effective building systems only. A major influence factor on the energy quality is the ventilation technology and also the airtightness of the building. Some countries include in their energy decree already maximum air exchange 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 infiltration losses become a significant factor to the energy performance. The paper presents a short overview on the existing airtightness requirements in different European countries and especially for high performance buildings as well as insights in how strong the impact of improved airtightness can be regarding the net, final and primary energy demand of a building.

KEYWORDS

Airtightness, building envelope, high performance buildings, energy demand

1. INTRODUCTION

The implementation of the Energy Performance of Buildings Directive (EPBD) (European Union, 2003) has caused in most of the EU Member States more severe requirements for the energy demand of buildings. In order to meet these requirements, not only buildings components with better U-values and more efficient building systems have to be used, also the ventilation losses have to be reduced. A contribution to this necessary reduction is the improvement of the building airtightness, mainly the airtightness of building components and joints. With the EPBD implementation or even before some of the countries have included minimum airtightness requirements in their building codes.

Buildings that do not only fulfill the national requirements, but are designed to use considerable less energy, are often called high performance buildings. There are different terms used in this area, from low energy building over passive houses and 3-litre houses to zero energy or zero emission buildings and many more. An information paper (Erhorn-Kluttig and Erhorn, 2008) soon available on the *Buildings Platform* (www.buildingsplatform.org) summarises the used terms and definitions as well as the currently realised number of high performance buildings in the EU Member States. Though the definitions of the various types of high performance buildings differ from each other, the very most of them imply a building airtightness that is better than for regular buildings.

An European project called *ASIEPI* (Assessment and Improvement of the EPBD Impact (for new buildings and building renovation), www.asiepi.eu) has as objective of one of the work packages to give policy makers a clear picture of the way better envelope and ductwork airtightness is stimulated in the member states, including indications -where available- on the impact of the measures taken to transform the market. This paper is partly based on the work done in the ASIEPI project.

2. EXISTING BUILDING SURFACE AIR-TIGHTNESS REQUIREMENTS IN THE EU MEMBER STATES

According to an investigation in the ASIEPI project (Carrié, et al. 2008) 5 of 13 EU Member States have minimum requirements regarding the building envelope integrated in their building codes. These are: the Czech Republic, Germany, Denmark, the Netherlands and Norway. Spain has partial requirements focussing on windows. The existing minimum requirements that refer to new buildings (residentials and non-residentials) differ from country to country and are presented in table 1.

Table 1: Airtightness requirements in European Union Member States

EU Member State	Air tightness requirements at 50 Pa pressure	
	Natural ventilation	Mechanical ventilation
Czech Republic	4.5 1/h	w/o recuperation: 1.5 1/h with recuperation.: 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 area
Leakage rate per façade area	3.0 m^3/m^2h	
Denmark	1.5 l/s per m^2 floor area	
Norway	3.0 1/h	

It has to be stated though that in all of the 5 countries with air tightness requirements there is no generally required compliance test. However in Germany and Denmark there are in some cases pressure tests required. 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 of a building 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 with a lower resulting value has been made.

3. AIR TIGHTNESS REQUIREMENTS FOR HIGH PERFORMANCE BUILDINGS

As stated in the introduction high performance buildings require in general an improved airtightness of the building envelope. Otherwise the aspired low energy demands can't be achieved. Most of the various high performance buildings however have not specified values that have to be fulfilled.

An exemption is the so-called passive house. Passive houses are calculated with a calculation procedure that differs from the national German energy performance calculation standard, mostly in the area of the ventilation losses. The net heating energy demand of these houses has to be 15 kWh/m^2a or lower and the primary energy demand for heating, ventilation, domestic hot water and household electricity shall not exceed 120 kWh/m^2a. In the definitions set by a private organisation in Germany, which are applied in some other middle-European countries as well, the infiltration rate at 50 Pa overpressure is set to 0.6 1/h.

As the passive houses generally include a mechanical ventilation system which is also used for heating purposes this value has to be compared to German air tightness requirements for buildings with mechanical ventilation systems: 1,5 1/h. The airtightness of a passive house is supposed to more than double as good as for a regular house.

Experiences from many pressure tests at the Fraunhofer Institute for Building Physics show that values below 1.0 1/h are difficult to achieve. However the institute has tested some building, also some passive houses, which do meet this requirement in practice. Figures 1 shows an exemplary photo of a series of row houses built according to the passive house definitions in Stuttgart which were monitored by the Fraunhofer Institute for Building Physics (Reiss, Erhorn, 2003). The results of the Blower-Door tests made right after the construction phase (2000) and two years later are presented in figure 2.

Figure 1: North view (above) and South view (below) of the passive houses buildings monitored by the Fraunhofer Institute for Building Physics.

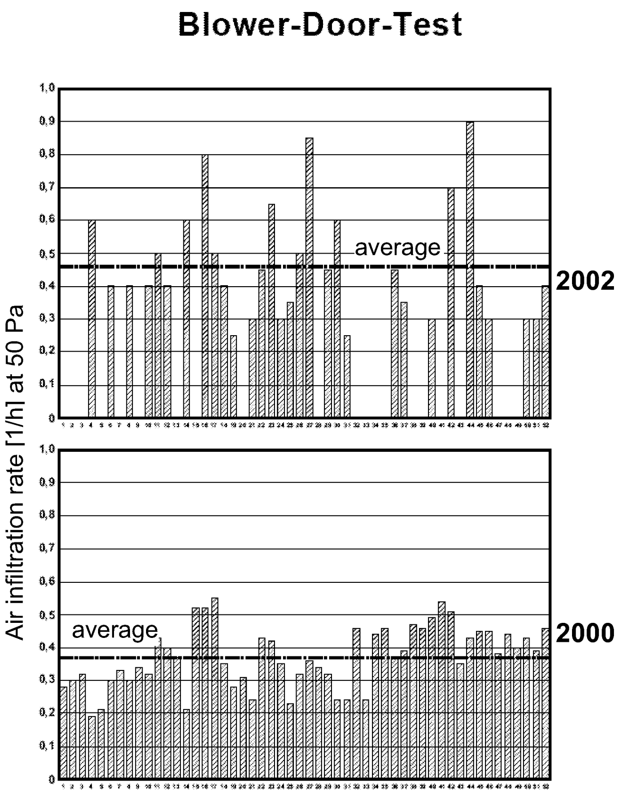

Figure 2: Blower door test made at several passive houses in 2000 and 2002.

The results of the air leakage test show that the average infiltration rate of all 52 row houses measured right after the construction phase was 0.37 1/h and the average value of 31 of the houses measured two years later was 0.46 1/h. That proves not only that the very low leakage rates are possible, but also that they were only slightly worse after two years of building use. Yet in 5 of 31 buildings measured in 2002, the original goal of 0.6 1/h which was met at the end of the construction period could no longer be achieved.

4. THE INFLUENCE OF AIR LEAKAGES ON THE ENERGY CONSUMPTION OF HIGH PERFORMANCE BUILDINGS

4.1 The 3-litre houses in Celle

In the demonstration project *3-Litre Houses Celle* (Kluttig, Erhorn, Reiß, 2001) concepts for 11 different high performance buildings have been developed and 4 of them have been realised. The primary energy demand for heating, ventilation and auxiliary of the buildings was calculated to less than 34 kWh/m²a which can be transferred with German primary energy factors to 3 litres oil per m² floor area and year. Therefore this type of high performance buildings got the name “3-litre house” similar to the first so-called 3-litre cars that have been sold at the start of 2000. Figure 3 presents a photo of the “Ziegel-Aktiv-Haus”, a double house, which was planned according to the 3-litre-house requirements and realised in Celle, Germany.

Figure 3: Photo of two of the realised 3-litre houses: the “Ziegel-Aktiv-Haus” (brick active house).

For the two houses presented in figure 3, the influence of the construction details on the ventilation heat losses (infiltration losses) and the transmission heat losses (thermal bridge effect) have been analysed in comparison with measures like improved U-values of components or energy efficient building systems e.g. solar thermal panels.

Both buildings were equipped with high efficient building systems and very good insulated building components. A speciality of the external wall was that it had no insulation level, but was built out of a special light brick so that the 42,5 cm masonry resulted in a U-value of 0,24 W/m²K. Windows with 3 pane glazing and 20 cm insulation between the rafters plus a 10 cm insulation below the rafters in the roof and 10 cm insulation below the slab made it possible to reach an average U-value of the building surface of 0,24 W/m²K.

The used heating system for house A) was a gas condensing boiler supported by a solar thermal panel for both heating and domestic hot water and photovoltaic for the auxiliary energy. House B) had a gas condensing boiler with a solar thermal panel for domestic hot water only (therefore no influence on the presented results) and a ventilation system with 90 % heat recovery rate.

4.2 Introduction into the German calculation standard for the energy performance of residential buildings

The analysis of the influence of the construction details has been made using the German energy performance calculation standard *DIN V 4108-6* and *DIN V 4701-10*. For the air leakage study the ventilation heat loss with different infiltration rates was assessed. The main equations for the ventilation loss calculation and the default values used in the standard are presented below:

$$H_V = n * V * (\rho_L * c_{pL}) \qquad (1)$$

with:
H_V: ventilation heat loss
n: ventilation rate (window opening and infiltration)
V: air volume, here: 401 m³
ρ_L: density of air
c_{pL}: heat capacity of air
$(\rho_L * c_{pL}) = 0.34$ Wh/Km³

In case of natural ventilation only the standard sets the following default values for the ventilation rate:
n = 0.70 1/h for not pressure tested buildings
n = 0.60 1/h for pressure tested buildings with $n_{L50} \leq 3$ 1/h

In case of mechanical ventilation the ventilation rate is defined as shown in equation (2):

$$n = n_A * (1-\eta_V) + n_x \qquad (2)$$

with:
n_A: air change rate of the mechanical ventilation system, here: 0.40 1/h
η_V: heat recovery rate
n_x: additional air change rate due to (reduced) window opening and infiltration
n_x = 0.20 1/h for balanced systems
n_x = 0.15 1/h for exhaust systems

Note: The air change rate given for n and n_x can’t be compared to those measured in the blower door tests in paragraph 3 and required by the national standards in paragraph 2. The air change rates for window opening and infiltration in paragraph 4 are not under 50 Pa overpressure but under the average pressure difference between inside of the house and outside over the whole heating period in Germany. The transfer from an infiltration measurement by blower door test to the average air change rate by infiltration during the heating period can be approximated by dividing the blower door value by 10 to 15. That would mean for example a blower door test value of 1.0 would lead to an infiltration air change rate during the heating period of about 0.07 to 0.10 1/h.

4.3 Analysis of the influence of infiltration losses to the energy performance of the 3-litre house

As one half of the double house was designed with a balanced mechanical ventilation system and the other half with natural ventilation only but more efficient building systems, the calculation was made for the mean German climate with 2900 Kd as heating degree days for the following variations:

A) natural ventilation only:
A1) as built: improved and exactly calculated thermal bridges (ΔU_{TB} = 0.019 W/m²K),

building with passed blower door test, ventilation rate n = 0.70 1/h

A2) standard value for normally designed joints (ΔU_{TB} = 0.10 W/m²K), building with passed blower door test, ventilation rate n = 0.60 1/h

A3) standard value for normally designed joints (ΔU_{TB} = 0.10 W/m²K), building without passed blower door test, ventilation rate n = 0.70 1/h

B) balanced mechanical ventilation system:

B1) as built: improved and exactly calculated thermal bridges (ΔU_{TB} = 0.019 W/m²K), building with passed blower door test, infiltration rate n_x = 0.20 1/h

B2) standard value for normally designed joints (ΔU_{TB} = 0.10 W/m²K), building with passed blower door test, ventilation rate n_x = 0.20 1/h

B3) standard value for normally designed joints (ΔU_{TB} = 0.10 W/m²K), increased ventilation rate n_x = 0.30 1/h (same difference of infiltration rate between B2) and B3) as between A2 and A3: 0.10 1/h)

The variations A1) and B1) do each meet the 3-litre house requirements and are only included as proof to that. Table 2 presents the resulting heat energy demands, the primary energy demands and the oil equivalent calculated for the 6 variants.

Table 2: Results of the analysis of the influence of different ventilation rates on the energy consumption of high performance buildings.

Variant	Thermal bridge surcharge ΔU_{TB}	Ventilation rate n resp. Infiltration rate n_x: n	Ventilation rate n resp. Infiltration rate n_x: n_x	Heating energy demand	Primary energy demand (heating, ventilation, auxiliary)	Oil equivalent
	W/m²K	1/h	1/h	kWh/m²a	kWh/m²a	l/m²a
A1	0.019	0.60		32.1	32.2	2.9
A2	0.10	0.60		43.5	42.1	3.8
A3	0.10	0.70		48.5	46.9	4.2
B1	0.019		0.20	12.9	27.3	2.5
B2	0.10		0.20	24.3	39.9	3.6
B3	0.10		0.30	29.6	45.8	4.2

The difference in the infiltration rate of 0.1 1/h in both variants A and B shall represent a house either with passed pressure test (≤ 1,5 1/h at 50 Pa) or without. The calculations show that the heating energy demand is increased through the 0.1 1/h difference in the infiltration rate by 5.0 respectively 5.3 kWh/m²a. The primary energy demands rise by 4.8 kWh/m²a or 5.9 kWh/m²a. Taken into account that the heating energy demands are in the range of 43 and 24 kWh/m²a the difference due to the infiltration rates are 11 % for the naturally ventilated house and 22 % for the mechanically ventilated house. The relative increase of primary energy is 11 % and 15 %. Also with houses at the level of 3-litre heating oil equivalent primary energy increases of 5 kWh/m²a and higher can't be easily balanced by better U-values or system efficiencies as the included systems and technologies are already of very high quality.

The influence of the details, that means an improved infiltration rate and details that are designed with thorough consideration of the thermal bridges, on the primary energy demand is about 15 kWh/m²a and is in therefore in the range of the contribution of a solar domestic hot water system (≅ 10 kWh/m²a). If thermal bridges can be reduced down to ΔU_{TB} = 0.0 W/m²K, they alone can replace a solar thermal system for domestic hot water by balancing the primary energy reduction.

4.3 What exactly means an increased infiltration loss of 0.1 1/h?

A difference in the infiltration loss of 0.1 1/h may sound either big or small, depending on what the standard infiltration loss is in country. As presented in paragraph 3, the goal for high performance buildings for a pressure test at 50 Pa can be set to about 0.60 to 1.0 1/h. Transferred to the average pressure difference during a heating period in middle Europe this would be about 1.0 1/h / 10 = 0.10 1/h (see also note in paragraph 4.2).

The 3-litre houses used here as example did not reach blower door value of lower than 1.0 1/h but met the national German requirements of 1.5 1/h. Therefore the best default ventilation rates of the calculation standard were used as base case and a slightly worse infiltration rate was assessed as worse case.

In order to show how small a leakage is that can cause an infiltration loss of 0.1 1/h during the heating period, figure 4 with a scheme of an open joint is introduced. The pressure difference of 6 Pa can be regarded as average pressure difference during the German heating period and results of an average wind speed of 3 m/s. The open joint has a length of 1 m, a width 2 mm and a depth of 10 cm. The resulting air flow through the joint is 15 m³/h/m.

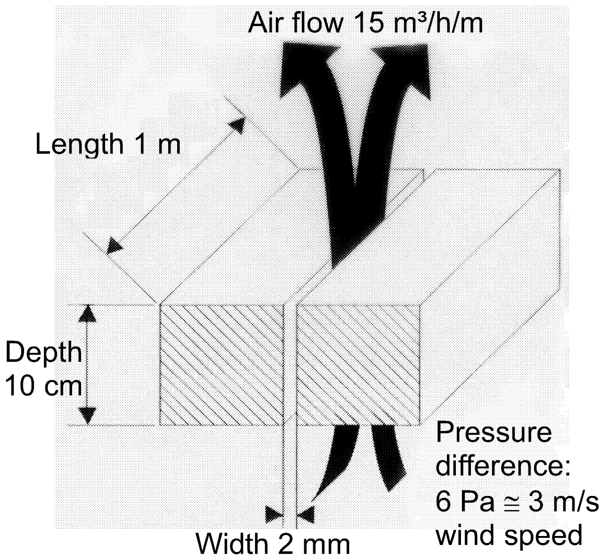

Figure 4: Scheme of an open joint resulting in an air flow of 15 m³/h/m.

The example house has an air volume of 401 m³. Therefore an air change rate of 0.1 1/h means an air volume of 40.1 m³/h. The necessary length of the open joint to produce this volume would be only 2.67 m. This emphasizes that rather small openings in joints can have a huge influence on the air tightness of a building.

5. CONCLUSIONS

In this paper the national requirements concerning airtightness in buildings in the European Union Member States were summarised. Airtightness requirements for high performance buildings, especially for so-called passive houses are stated and measured values for 52 exemplary passive houses are documented. Despite the experience made at Fraunhofer Institute, that blower door values of lower than 1.0 1/h at 50 Pa are difficult to achieve, the measured houses achieved an average value of about 0.5 1/h two years after the construction.

The last part of the paper presents the results of a study on the impact of construction details on the energy performance of high performance buildings with the focus on the part air tightness. It was shown that the influence of details can easily be as high as the primary energy demand reduction of a solar thermal plant for domestic hot water (≅ 10 kWh/m²a).

A small approximation of the size of an open joint that results in 0.1 1/h infiltration loss during the heating period in German climate completes the work presented.

5. REFERENCES

Carrié, Remie et al., 2008. Internal questionnaire in the EU project ASIEPI (Assessment and Improvement of the EPBD Impact, (for new buildings and building renovation)), Intelligent Energy Europe programme contract EIE/07/169/SI2.466278).

Erhorn-Kluttig, Heike and Erhorn, Hans, 2008. Terms and definitions used in the EU Member States for High Performance Buildings. Information Paper soon available on the Buildings Platform www.buildingsplatform.org.

European Union, 2003. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Official Journal L 001, 04/01/2003 P. 0065 – 0071.

Kluttig, Heike, Erhorn, Hans and Reiß, Johann, 2001. Demonstrationsvorhaben 3-Liter-Häuser in Celle. Summary report of the Fraunhofer Institute for Building Physics (IBP-Mitteilung) 394.

Reiss, Johann and Erhorn, Hans, 2003. Messtechnische Validierung des Energiekonzeptes einer großtechnischen umgesetzten Passivhausentwicklung in Stuttgart-Feuerbach. Report WB 117/2003 of the Fraunhofer Institute for Building Physics.