Timber building technology – a way to increase energy efficiency in buildings

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Abstract

Timber frame buildings usually have very good thermal insulation. Their construction is generally suited to meet high standards in respect to low energy consumption. Heat bridges are more easily avoided in timber frame buildings than in buildings with solid construction. Still, care needs to be taken to avoid such heat bridges which may lead to moisture problems.

Achieving a high level of airtightness of the building envelope is an important aspect for energy efficient buildings. Airtightness of the building envelope is a basic requirement to avoid rot through moisture in the construction. Measurements show the level of building envelope airtightness of German timber frame buildings. Typical leakage paths found during building airtightness tests of 87 timber frame buildings are discussed.

1 Introduction

The need to reduce energy consumption used for the heating of buildings is generally accepted. Timber frame buildings traditionally have a high standard of thermal insulation. Heat bridges are avoided more easily in timber frame constructions compared to solid constructions. The heat loss due to heat bridges is negligible for good timber frame constructions [1]. Reduction of the danger of moisture problems due to heat bridges is a different matter. Much care needs to be taken to avoid even only punctual low surface temperatures. Otherwise, steam condensation and, as a result thereof, rot can occur.

An airtight building envelope is paramount in avoiding rot through excess moisture, also. Every leakage in the building envelope can lead to large amounts of vapour migration into the construction.

In buildings with low overall energy consumption the heat loss due to ventilation and/or infiltration can be a considerable part of the whole. The need to reduce ventilation heat loss, apart from other aspects, often leads to the installation of ventilation systems. Other aspects, which make a ventilation system desirable can be air quality, noise or allergies to environmental pollution. Ventilation systems require an airtight building envelope.

In the following, an example of a typical and critical heat bridge in timber frame buildings is given. However, focus is set on building envelope airtightness of timber frame buildings. Results of recent pressurization tests of 87 timber frame buildings all over germany are presented [2].

2 Heat bridges

The total heat loss due to heat bridges does not change significantly with increasing insulation. The relativ heat loss does. Figure 1 shows the order of magnitude of heat loss due to heat bridges for

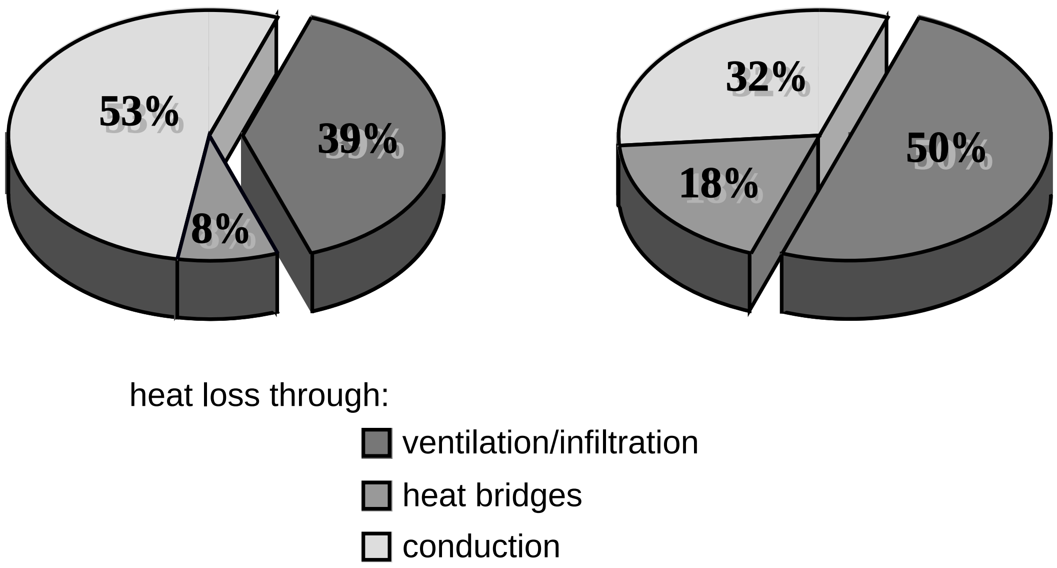

Figure 1: Comparison of the heat loss due to heat bridges for buildings with a low (on the left) and high insulation standard (on the right) [3].

two buildings, on the left a low standard of insulation with an annual heat load of approx. 60 kWh/(m^2 a). On the right a standard of insulation currently viewed as sufficient for a 'low energy building' (approx. 60 kWh/(m^2 a) [3]. The figures refer to a building of solid construction.

In general, the additional heat loss due to heat bridges in a carefully planned timber frame building is small [1]. Very good constructions can result in a reduction of heat loss through reduction of heat bridges in the order of 2 % in buildings with low energy consumption. An additional heat loss due to heat bridges in the order of 10 % can occur, if very unsuited constructions are chosen [4].

Heat bridges can be characterized by the dimensionless surface temperature

$$\Psi = \frac{\vartheta_{\text{surface, inside}} - \vartheta_{\text{amb.}}}{\vartheta_{\text{air, inside}} - \vartheta_{\text{amb.}}} \qquad (1)$$

To avoid condensation of steam, the dimensionless surface temperature must satisfy following inequation:

$$\Psi > \frac{(109.8 + \vartheta_{a,i})\,\varphi^{0.1247} - 109.8 - \vartheta_{amb.}}{\vartheta_{a,i} - \vartheta_{amb.}} \qquad (2)$$

For example, with $\vartheta_{a,i} = 20$ °C , $\varphi = 0.5$% (50 % relativ humidity) and $\vartheta_{amb.} = -10$ °C the above inequation gives $\Psi > 0.642$.

Keep in mind, that surface temperatures at 75 to 80 % of the equilibrium temperature for condensation can already lead to fungus [5].

So, care needs to be taken to avoid heat bridges which can result in moisture problems. Figure 2 shows a typical detail of the joint between a timber frame wall and the concrete floor of a building. The low, dimensionless surface temperature of Ψ = 0.610 indicates that this construction can lead to moisture-induced rot and fungus in the vicinity of the steel angles.

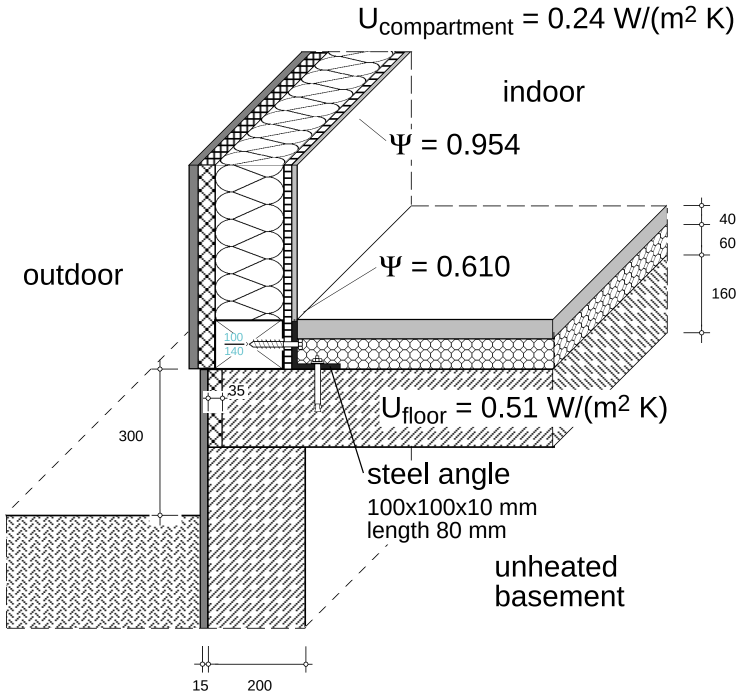

Figure 2: Example of heat bridge in typical joint between timber frame wall and concrete floor.

3 Building envelope airtightness

The airtightness of the building envelope is very important in two respects. One, the reduction of energy consumption for the heating of buildings involves taking ventilation and infiltration heat losses into account. Two, much care needs to be taken to achieve an airtight building envelope to reduce possible vapour migration and resulting moisture rot. Figure 3 shows an example of how much vapour can migrate into the cross section of a timber frame building through a crack of one meter length. In comparison, vapour diffusion leads to vapour migration orders of magnitude lower [6].

3.1 Airtightness standard

To date there is no fixed upper or lower requirement to the level of building airtightness in Germany. The new German standard 'DIN V 4108, part 7' [7] gives 'suggestions', how airtight the building envelope should be. All figures given are upper limits. Lower limits are not being considered in Germany. Table 1 shows the current level of airtightness taken as sufficient for different ventilation strategies. The ACH_{50} of naturally ventilated buildings (ventilation through windows and doors) should not exceed 3.0 h^{-1}. The ACH_{50} of buildings with ventilation system should not exceed 1.0 h^{-1}.

The determination of the volume of reference for the calculation of ACH_{50}-values is cumbersome and prone to error. Therefor, a different characteristic value to describe airtightness of buildings is proposed. It is defined as

$$\text{NBV}_{(50)} = \frac{\text{volumetric flow rate at 50 Pa pressure difference}}{\text{net floor area of building}}. \quad (3)$$

The calculation of the net floor area is well defined (in Germany, at least) and thus less prone to error [8]. By assuming a mean room height of 2.5 m and transforming the building airtightness limits given in terms of ACH_{50} it is possible to express the above mentioned limits for building airtightness in terms of NBV. See table 1 for these limit values.

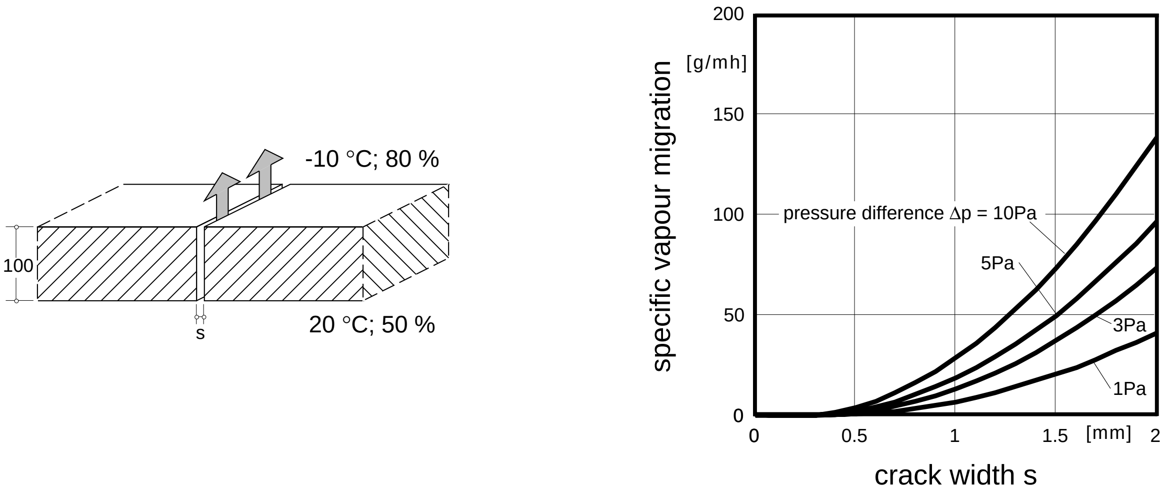

Figure 3: Example of vapour migration through a crack due to pressure difference [6].

Table 1: Characteristic values for the description of building airtightness. Upper limits according to DIN V 4108-7 [7].

ventilation strategy	ACH_{50}	NBV
natural ventilation	$\leq 3.0\ h^{-1}$	$\leq 7.5\ \frac{m^3}{h\ m^2}$
ventilation system	$\leq 1.0\ h^{-1}$	$\leq 2.5\ \frac{m^3}{h\ m^2}$

3.2 Measurement results

The results of pressurization tests of 87 timber frame buildings are presented in the following sections. With the exception of a comparison of own test-results with results given by other authors, building airtightness levels are discussed by reference to NBV-values. For the discussion or comparison of mean values given, the number of buildings tested (see table 2) should be taken into account.

3.2.1 Overview

Figure 4 shows a comparison of air change rates at 50 Pa pressure difference (ACH_{50}) from various publications [9, 10, 11, 2]. The results given in [10] refer to low energy buildings (LEB) only, most of which were built with support by experts in the field of building airtightness. Data from [2] is given in more detail below.

3.2.2 Timber frame buildings

A summary of construction types, number of buildings tested, mean age of timber frame buildings tested and results of the tests is given in table 2. Figure 5 shows the mean NBV-values for a selection of timber frame construction types in comparison with solid buildings also tested by the author. All buildings referenced in figure 5 were less than one year old when tested. Table 3 and fig. 6 show the test results in respect to building age.

Figure 7 gives a frequency distribution of NBV-values for 87 tested timber frame buildings. In addition, the upper limits for NBV-values for buildings ventilated naturally and with ventilation systems (see table 1) are shown. NBV-values left of the NBV=2.5-line are O.K., NBV-values right of the NBV=7.5-line are considered to high.

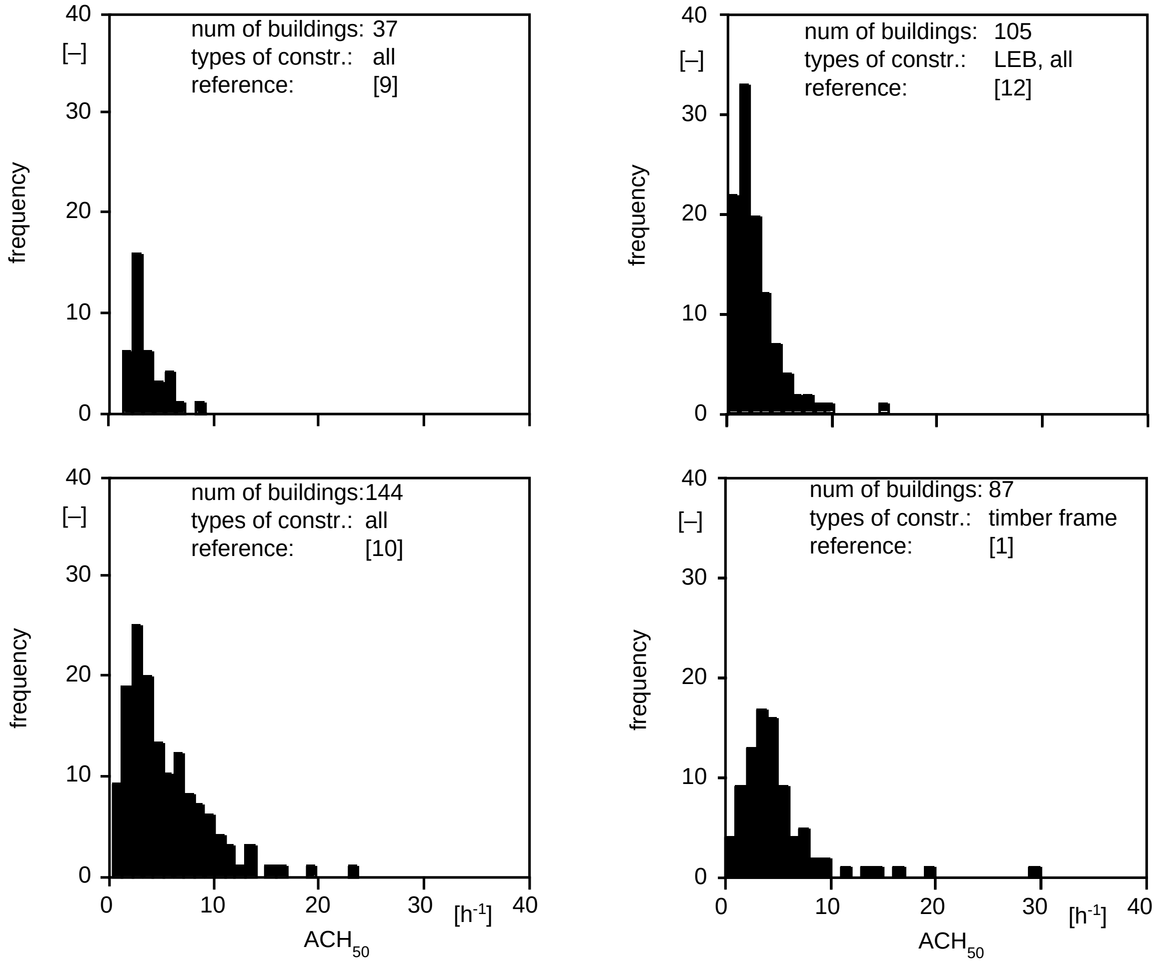

Figure 4: A comparison of results of building airtightness tests in Germany [10, 2], Sweden [11] and Switzerland [9].

Only 30% of the 87 tested buildings were found to have a level of airtightness considered sufficient for buildings ventilated naturally. Five percent of the tested buildings showed the high level of airtightness ventilation systems require.

3.3 Typical leakage paths

Many discussions with architects and building professionals in connection with pressurization tests have shown that it is often difficult to convey the special problems related to making a timber frame building airtight. To date, many mistakes which could be avoided easily are repeated because of a lack of understanding leakage paths. The following figures 8 through 10 try to help understand possible leakage paths in timber frame buildings.

Figure 8 shows a jamb wall section of a timber frame building. The plastic sheet used as airtight layer is not fastened to the eaves purlin. Additionally, it is often neglected to fasten the sheet to the gable wall in an airtight manner. This leaves ample possibilities for leakages. As it is very usual to have utility piping in the space between jamb wall and roof, the whole building is connected to these leaks.

Very similar unsound constructions can be found in the basement as well. One typical leakage path leads through the slit between wing and lining of the door between the heated space to the basement

Table 2: Type of construction, number of tested buildings, mean age, mean ACH_{50} and mean NBV-values.

construction type	num [-]	mean age years	n_{50} h^{-1}	NBV $m^3/(hm^2)$
prefabricated	53	4.7	4.2	10
standard timber frame	16	2.4	4.4	10
skeleton framing	7	6.9	5.5	16
block houses	2	1.0	5.3	17
fitted out roofspace	4	5.3	4.4	13
framework houses*	5	20.0	12.6	28

(*the age was uniformly set to 20 years)

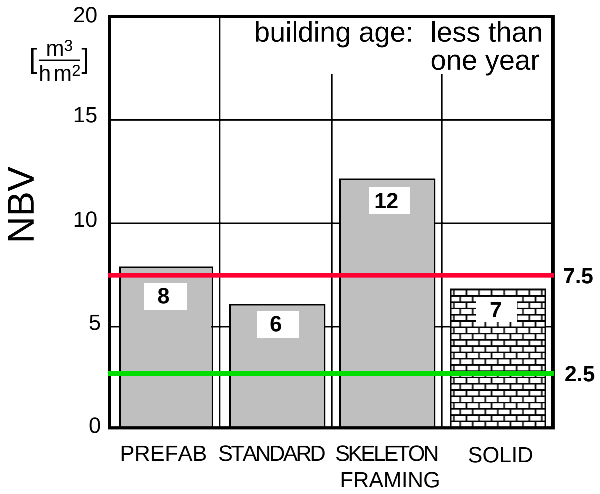

Figure 5: Results of timber frame building airtightness tests in Germany [2] compared with results of airtightness tests of solid construction buildings.

boiler room. The fire-resistant doors (draft stops) used here are usually made of steel and have a slot in which one could fit a gasket. More often than not, however, the gasket is missing.

Figure 9 shows another typical leakage path through the basement. Often, the basement is planned as unheated space. Simple windows with permanent ventilation openings are used. Utility piping leads to and from the basement rooms and if this piping is not sealed where it penetrates the ceiling of the basement, air can move into the heated part of the building via the hollow walls.

Figure 10 shows a further leakage path, which has shown to be typical for prefabricated timber frame buildings. The shutter box is integrated in the wall construction and does not actually comprise a 'box'. This leaves many leakages, through which air can enter the wall.

3.4 Frequency of leaks

During depressurization it is possible to detect places, in which air enters a building. With detailed knowledge of the construction, this information can sometimes give a fair idea of the path air takes through the construction. Some leakages can be viewed as more or less 'direct' and thus attributed to the location, where the air enters. Figure 11 shows the frequency of some typical leakages found in prefabricated timber frame buildings. The frequency is expressed as how often a certain leakage was found in respect to the number of buildings in which the corresponding detail was present.

Table 3: Mean ACH_{50} and mean NBV-values for different building ages.

building age (years)	num [-]	ACH_{50} h^{-1}	NBV $m^3/(hm^2)$
under 1	48	3.2	8
under 5	18	5.6	14
under 10	8	4.3	11
under 15	4	4.5	11
over 15	9	13.4	30

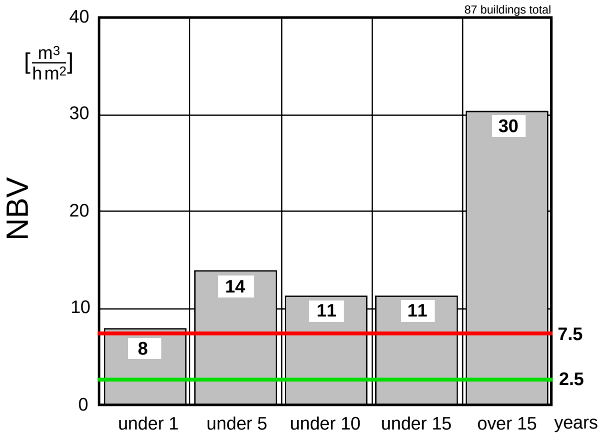

Figure 6: Results of timber frame building airtightness tests in germany [2].

Figures 8 through 10 should be kept in mind when discussing the leakages mentioned in figure 11.

3.5 Component leakage

It is desirable, to have information about the leakage rate of building components and parts of buildings. Table 4 gives orders of magnitude for leakage rates of fire-resistant doors and trap doors to the garret. Leakage rates given for shutter workers are taken from [12].

Furthermore, the pressurization tests made show that an average of 24 % of the overall leakage rate is due to leakages in the upper part of the building, usually roofspace and jamb walls. In some cases over 70 % of the total leakage can be attributed to this part of the building. A mean value of 20 % of the total leakage rate is found due to leaks in the basement.

Table 4: Order of magnitude of leaks through doors leading to unheated space, trap doors to the garret and shutter workers. All values refer to 50 Pa pressure difference across the separating component.

	typical value $\frac{m^3}{h}$	maximum value $\frac{m^3}{h}$
door to unheated space	150	300
trap door to garret	100	500
shutter worker	0.5 [12]	2.4 [12]

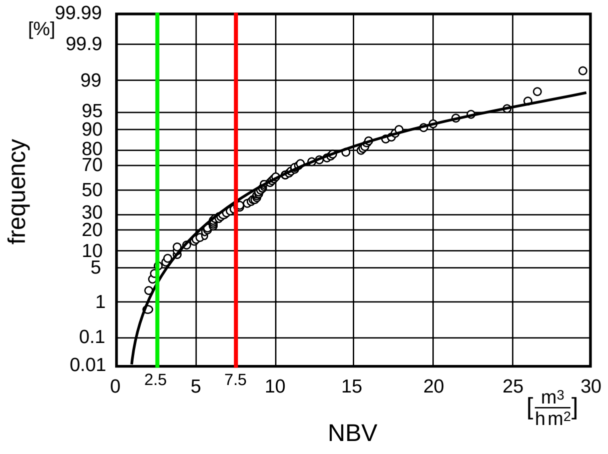

Figure 7: NBV-value frequency distribution of 87 tested timber frame buildings.

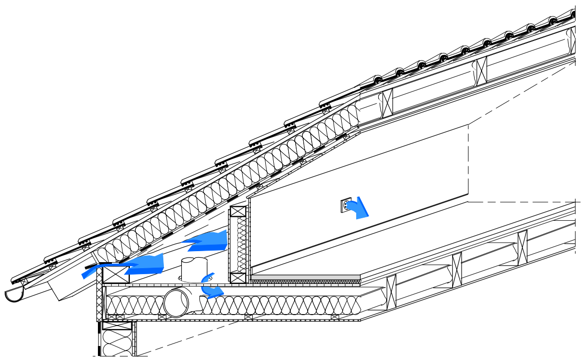

Figure 8: Leakgage path through roof and jamb wall.

How can one interpret the values given in table 4? Compare the given volumetric flows with the typical building volume of single family dwellings. Say approx. 300-500 m^3. One of the above mentioned leakages 'door to unheated space' or 'trap door to garret' results in an overall leakage rate and a NBV-value greater than the proposed standard for buildings with ventilation system will permit.

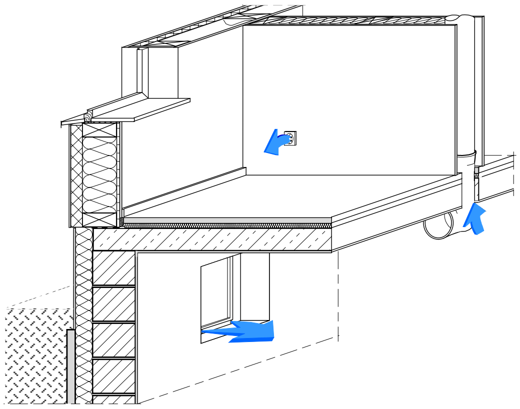

Figure 9: Leakage path through permanent ventilation openings in simple windows and unsealed penetration of basement ceiling.

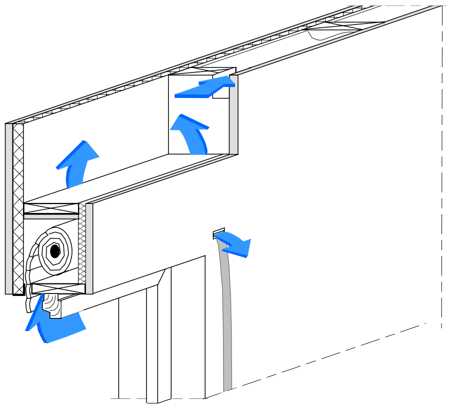

Figure 10: Possible leakage paths through the shutter box into the wall of timber frame buildings.

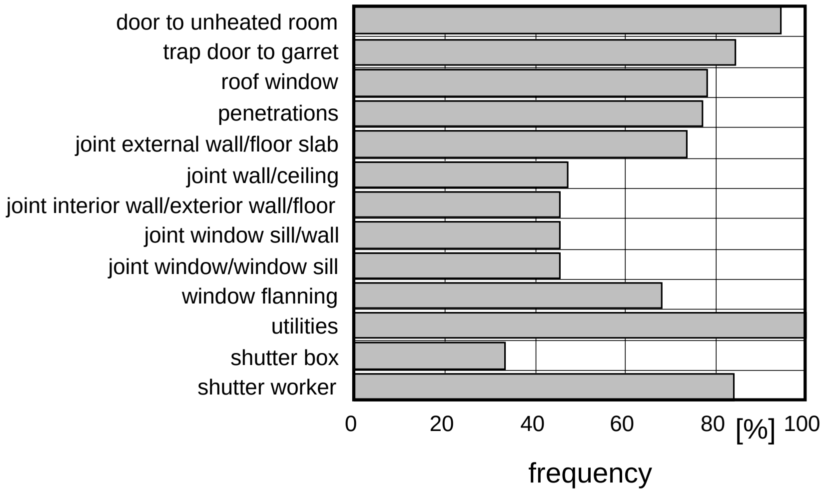

Figure 11: Frequency of leaks found during pressurization tests of 53 prefabricated timber frame buildings.

4 Summary

Timber frame buildings are well suited to meet low energy consumption standards. Care needs to be taken to avoid heat bridges which can cause moisture problems. Also, much care needs to be taken in order to achieve an airtight building envelope. This is important in respect to vapour migration and resulting moisture rot.

Low energy buildings increasingly feature ventilation systems. A basic requirement of such systems is an airtight building envelope. Results of recent pressurization tests of 87 timber frame buildings all over germany are presented. Typical leakages and leakage paths are discussed. It is found, that of the tested buildings only 30 % meet the limit suggested for buildings ventilated through windows and doors. Only 5 % meet the limit suggested for buildings with ventilation systems.

The tests also show that in some cases over 70 % of the total leakage is due to leaks in the upper part of the building, usually roofspace and jamb walls. A mean value of 20 % of the total leakage rate due to leaks in the basement is found.

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