HOW TIGHT IS TIGHT ENOUGH?

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Abstract

The topic of air leakage in buildings is discussed. Reasons for minimizing air leakage are presented. Measured values from tests of the air leakage of groups of both detached residences and larger buildings are given. For detached residences, air leakage measurements vary from less than 0.5 air changes per hour at 50 Pa, to more than 50 air changes per hour at 50 Pa. For larger buildings, a small sample of measurements indicated that the air leakage rate per unit surface area of the buildings ranged from 0.6 to 5 L/s·m^2 at 75 Pa. Care must be taken when sealing a building to ensure that adequate levels of ventilation are maintained. Most often this is accomplished by providing mechanical ventilation.

Introduction

There is general agreement among building scientists that it is desirable to build tight building envelopes, that is, envelopes with a low air leakage rate. Considerable disagreement, however, can still be found on the question "How tight is tight enough?"

In the latter part of this paper the question of the appropriate level of airtightness will be discussed in some detail. The following related topics are also dealt with:

1. Reasons for airtightness.
2. Different methods of reporting air leakage of buildings.
3. Comparative air leakage values for detached residences.
4. Comparative air leakage values for larger buildings.

Reasons For Airtightness

A number of reasons are usually cited for building a low leakage envelope. Usually the only reason one might choose not to have a tight envelope is to provide natural cooling in a structure. The usual reasons for providing a tight envelope include the following:

1. Damage to the envelope from condensation effects of air-borne convective flow of moisture can be minimized.

2. Energy consumption can be reduced by limiting the amount of bot sensible and latent heat that must be provided to temper th incoming air.
3. Heat recovery devices can be used effectively on the ventilation air if the envelope is tight.
4. Noise transmission through the envelope can be reduced.

Yet another advantage of providing a tight envelope is that th tight envelope can limit the entry of dust, pollen, and other air-born allergens and pollutants. In a tight building, the air supply for th structure can be controlled more readily, and if desired, the outside ai can be treated before it enters the occupied space.

Air Leakage Measurements Over the Years

Measurements have been made on the air leakage of envelopes an building components for many years. The Air Infiltration and Ventilatio Centre (AIVC) has produced a subject index (1) of papers on the ai leakage of buildings. In the index, there are 238 papers on the ai leakage of buildings, spanning the years from 1924 to 1986. A grap showing the number of papers written over the years on this subject i shown in figure 1. As can be seen, the recent years have seen a ver large amount of interest in this topic, with a peak of 38 paper published in 1980. In the AIVC subject index database there is also breakdown of technical papers on the air leakage of various buildin components. A pie chart summarizing the data is given in figure 2. A can be seen, the subject of windows has been the most popular topic, wit 55% of all the papers.

Measuring Airtightness

There are many different ways that the air leakage of buildings hav been reported. A summary of different standards for measuring the ai leakage of buildings and building components is contained in a 198 document by Thompson (2). Values of air leakage at 1 pascal, 4 pascals 10 pascals, 50 pascals, and 75 pascals can all be found in th literature. Leakages have been reported in equivalent leakage areas at 1 pascals, effective leakage areas at 4 pascals, air flows, air flows pe unit surface area, and air flows per unit volume.

Generally, pressure tests of whole buildings are most frequentl done on smaller buildings such as detached residences. An equation c the following form can be used to describe the air leakage:

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

where

Q = volumetric air flow (m^3/s)
C = constant depending on size of the openings ($m^3/s \cdot Pa^n$)
Δp = pressure difference (Pa)
n = exponent, ranging between 0.5 and 1.0

On most pressure tests done on buildings, the index of determination (R^2) on the best fit linear regression of equation (1) can be measured to 0.98 or better. Readings are usually taken over the range from about 5 pascals to about 100 pascals. Care must be taken during a pressure test of a component not to induce too great a positive or negative pressure on the building, as some components can distort or fail under higher pressure levels.

Perhaps the most common air leakage parameter that is reported for houses and small buildings is the air changes per hour at 50 pascals. Researchers in Sweden appear to have been the first to popularize this number. This number is convenient in that it is an air leakage number normalized by the building volume. Comparisons between one building and another can be readily made. A second advantage is the air leakage at 50 Pa is readily achievable in houses; a fan with a capacity of about 3 m^3/s can pressure test most houses to the 50 Pa level. Another advantage of the 50 pascal number is that it can be used to estimate the approximate air change of the building under natural conditions. Liddament(3) makes the following observation: "Numerous experimental tests have shown that the approximate air infiltration rate (in the absence of mechanical ventilation) will be of the order of one twentieth of the measured air change rate at 50 Pa...This provides a useful 'rule of thumb' should pressurization test data be available."

A disadvantage of the air changes per hour at 50 pascal number is that the parameter is not a very useful one for larger buildings. In a large building, the volume to surface area ratio is much larger than in a detached residence, and the envelope leakage parameter that is of greater value is the air leakage per unit surface area of the building. A more popular parameter that has been used to report the air leakage of larger buildings is the air flow per unit surface area at a pressure difference of 75 Pa.

Is There a Universal Goal for Air Leakage for Buildings?

In this paper the author will not argue for a universal goal for air leakage for buildings. Differing energy prices and climates often make it impossible to suggest a single standard for one country, let alone for all countries. Yet another confounding variable is the use to which the building is put. Buildings with moderate to high interior relative humidities in cold climates need to be much better sealed to limit condensation problems than do buildings with low interior humidities.

Instead of suggesting a universal goal of airtightness, the author will present some measured values of air leakage for both houses and larger buildings, and from these measurements one can get a feeling for the air leakage values that are achievable under field conditions.

Air Leakage Values for Residences

For detached residences, a large number of air leakage measurements have been made. Persily (4) presents pressure test results from 11 different groups of houses tested in three countries in the Northern Hemisphere. The values are shown in figure 3. As mentioned earlier, the values are commonly reported as air changes per hour at 50 Pa (n_{50}). As may be seen from the figure, the n_{50} values range from less than 0.5 to more than 50 air changes per hour at 50 Pa. (It should be noted that 50 pascals is a large pressure compared to the pressure that is exerted on a low-rise building by wind and stack effects. For average conditions the pressure difference across the envelope of a detached house is usually less than about 5 pascals.) As can be seen from the figure, most of the groups of houses have average values less than about 15 air changes per hour at 50 Pa, with the exception of the group of 204 "low-income" houses in the United States. Houses in the samples of Swedish and Canadian houses both exhibit much lower values of air leakage. Since 1977, new detached houses in Sweden have had a maximum allowable air leakage rate of 3.0 air changes per hour at 50 pascals. In Canada, a federal government sponsored voluntary program (the R-2000 program) for energy-efficient new houses has a maximum allowable air leakage rate of 1.5 air changes per hour at 50 Pa. For program control purposes, each individual house in the Canadian R-2000 program is checked for compliance to the air leakage standard by having a pressure test done.

As illustrated by these test results, it is possible to reduce residential air leakage values to less than 3 air changes per hour at 50 Pa on a widespread basis, as is the case in Sweden. Under a program of training and quality control, it is possible to further reduce the air leakage values to less than 1.5 air changes per hour at 50 Pa.

It should be noted that in both the newer Swedish houses and in the Canadian R-2000 programs that the use of controlled mechanical ventilation for residences is also mandated. A house with an n_{50} value of 1.5 would typically have a natural air change rate less than about 0.1 air changes per hour, and this is about 1/3 to 1/5 of the recommended ventilation rate for dwellings. In the absence of mechanical ventilation, such tight houses would be seriously under-ventilated.

An argument that has been advanced for not building very well sealed detached houses is that such houses will be under-ventilated if mechanical ventilation is not used. Although continuous mechanical ventilation of larger buildings is very common in most countries these days, continuous mechanical ventilation is not widespread in detached residences in most countries.

For well-sealed houses that use a balanced mechanical ventilation system with a heat recovery device such as an air to air heat exchanger, it would seem prudent for energy conservation reasons to limit the amount of uncontrolled air flow through the envelope. If the envelope is tightened to an n_{50} value of 1.0, the approximate value of the uncontrolled infiltration will be about 0.05 air changes per hour, or approximately 1/10 of the total ventilation rate supplied (usually about 0.5 air changes per hour) by the heat recovery ventilator system. An unbalanced heat recovery ventilator system as used in Swedish houses also requires that the building envelope be tightly sealed. The slot vents that are used on the windows rely on a relatively uniform negative pressure throughout the house. If the envelope is leaky, under-ventilation of some rooms can occur.

Air Leakage Values for Commercial Buildings

Far fewer measurements have been made of the air leakage rates of buildings larger than detached residences. The U.S. National Association of Architectural Metal Manufacturers specifies a maximum leakage rate of 0.3 L/s·m^2 at a pressure difference of 75 Pa for wall systems, exclusive of leakage through operable windows. Such a low rate has rarely been measured in actual buildings. Measured air leakage in eight Canadian office buildings (5) with sealed windows (assuming a flow exponent of 0.65 in equation 1) ranged from 0.61 to 2.4 L/s·m^2 at 75 Pa. More recent measurements (6) in eight U.S. office buildings ranged from 1.1 to 5 L/s·m^2 at 75 Pa.

Tamura and Shaw (5) list typical air leakage values as follows:

	L/s·m^2 at 75 Pa
Tight	0.51
Average	1.5
Loose	3.1

For comparison purposes, a detached residence of size 8 x 12.5 x 5 m (volume = 500 m^3; surface area = 405 m^2) with an air change rate of 1.0 air changes per hour at 50 Pa would have a leakage rate of 0.44 L/s m^2 at 75 Pa. (assuming an exponent of 0.65 in equation 1.) Such a residence would be considered very well sealed, and it is interesting to note that the envelope would also be considered tight using the above criteria suggested by Tamura and Shaw (5).

Summary

Measurements indicate that large variations exist in the measured air leakage rates of buildings.

For detached residences, the most commonly quoted value is the air changes per hour at 50 pascal value. Measured values of n_{50} range from less than 0.5 to more than 50. Programs in Sweden have shown that it is possible to produce detached houses on a widespread basis that have n_{50} values less than 3.0.

For larger buildings, a relatively common value that is quoted is the air leakage per unit surface area at 75 pascals. Measurements on a small sample of buildings in Canada and the United States have been in the range from 0.6 to 5 L/s·m^2 at 75 Pa.

Care must be taken with tight buildings to ensure that adequate ventilation is maintained. In well sealed buildings, some form of mechanical ventilation is normally required. In such buildings, heat recovery and treatment of the ventilation air is possible.

List of References

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4. Persily, A.K. "Measurements of air infiltration and airtightness in passive solar homes." Measured Air Leakage of Buildings, ASTM STP 904, H.R. Trechsel and P.L. Lagus, ed. Philadelphia: American Society for Testing and Materials, p.46, 1986.
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6. Grot, R.A. and Persily, A.K., " Measured air infiltration and ventilation rates in eight large office buildings." Measured Air Leakage of Buildings, ASTM STP 904, H.R.Trechsel and P.L. Lagus, ed Philadelphia: American Society for Testing and Materials, p. 151 1986.

NUMBER OF TECHNICAL PAPERS CONCERNING AIR LEAKAGE IN BUILDINGS

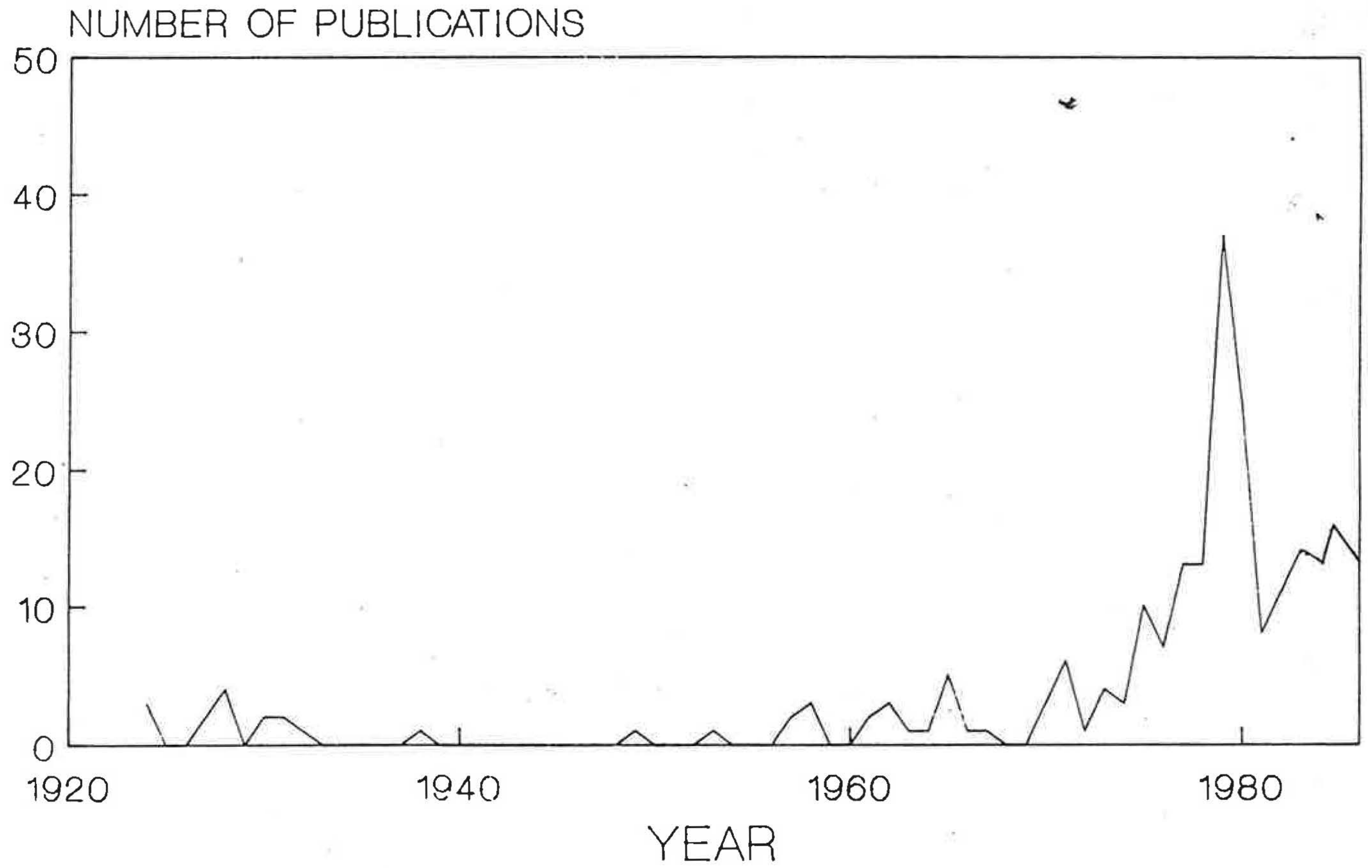
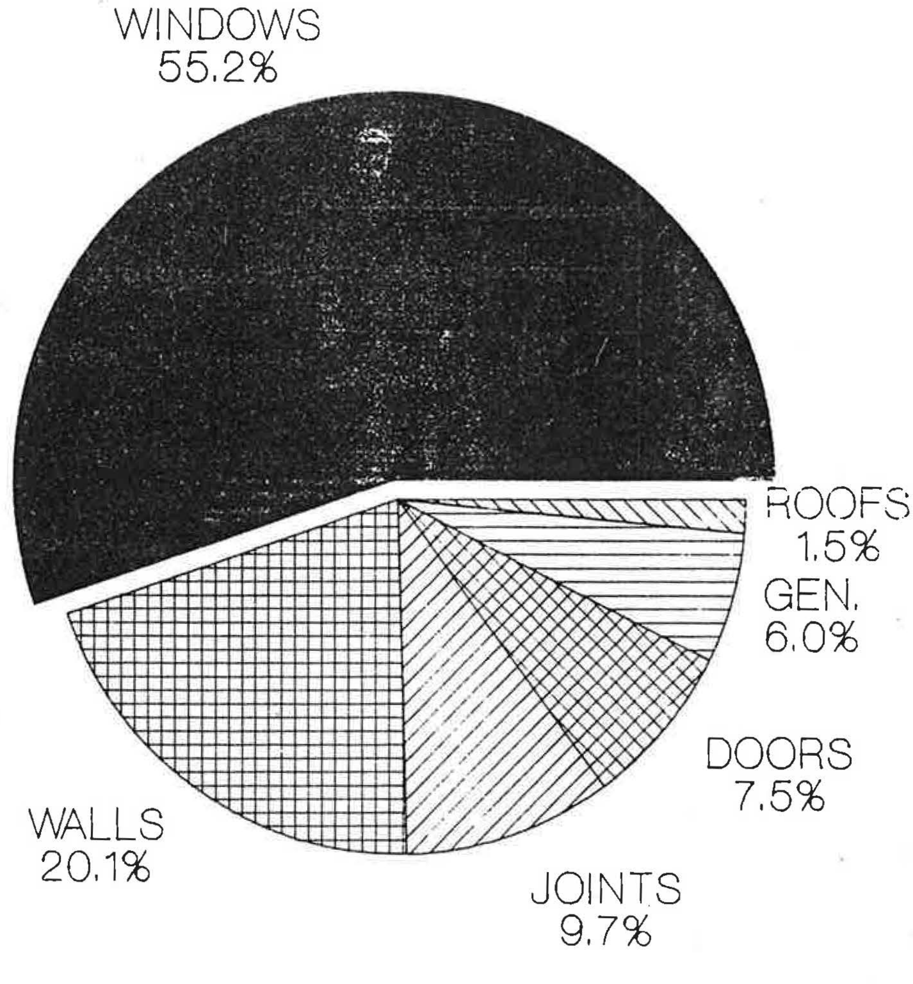


Figure 1. Publications over the years concerning air leakage in buildings

PERCENTAGES OF AIR LEAKAGE PAPERS ON VARIOUS BUILDING COMPONENTS



Total number of papers = 121

Figure 2. Percentages of air leakage papers on various building components.

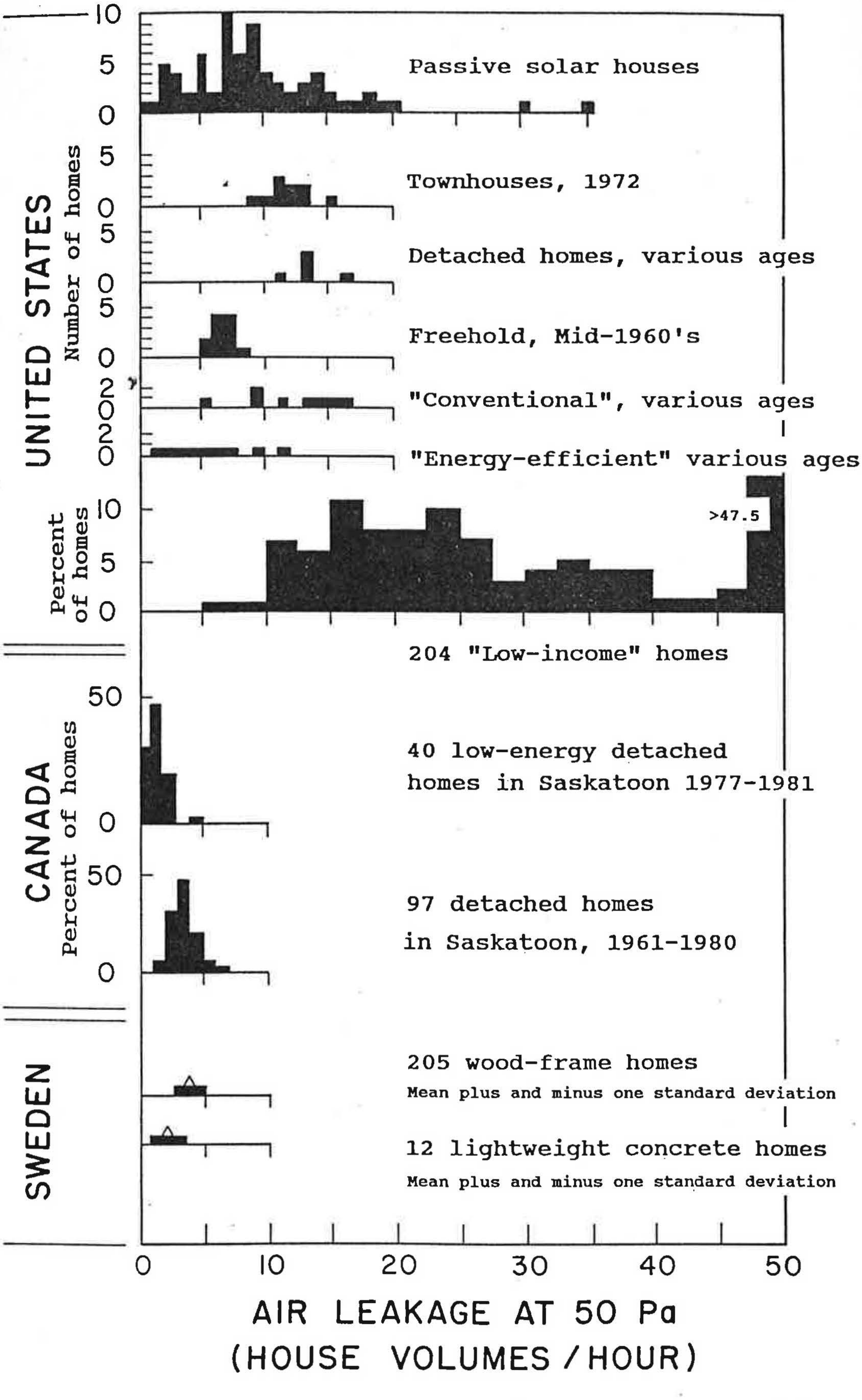


Figure 3. Air leakage test results for 11 groups of houses(4)