Airtightness of Timber-Framed Houses with Different Structural Solutions

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ABSTRACT

Timber-framed buildings are being studied in Finland in a large-scale study by Tampere University of Technology and Helsinki University of Technology. This paper is based on the measurements of airtightness done in 100 Finnish single-family houses by the fan pressurization method in the years 2002 and 2003.

The mean air change rate at 50 Pa (0.201 in. of water) of the 100 dwellings was 3.9 1/h. It was noticed that the method of construction and the materials used in wall and ceiling assemblies had at least some influence on the level of airtightness. It was also noticed that the airtightness of buildings with a mechanical supply and exhaust ventilation system does not satisfy the recommended level of airtightness in Finland. In addition to structural solutions, airtightness depends on construction quality. In this study, good airtightness was achieved with many different structural solutions.

INTRODUCTION

Tampere University of Technology and Helsinki University of Technology started a study, "Moisture-Proof Detached House," in spring 2002, which was funded by Tekes (The National Technology Agency of Finland) and 13 Finnish companies and associations. The project is a large-scale field study in which the indoor and outdoor climates, indoor moisture supply, ventilation rates, and airtightness in 100 Finnish timber-framed buildings are studied. The project is due to end at the end of 2004.

In 2003, the revised National Building Code of Finland introduced a recommendation for airtightness. The n_{50}-value, i.e., air change rate at 50 Pa (0.201 in. of water), is recommended to be as near as possible to the value of one air change per hour in order to guarantee a proper function of ventilation devices (Suomen rakentamismääräyskokoelma part C3 2003). Finnish single-family houses have been studied on a large scale, mainly at the beginning of 1980s. One aim of this study was to determine the current level of airtightness in modern timber-framed houses. This paper is based on the measurements of airtightness done in the project mentioned above.

The purpose of this research was to study the impact of different structural solutions and other factors on airtightness. In typical Finnish houses, the air seals used are a plastic film, which also acts as a vapor barrier, and a paper sheet. Some of the houses built have no additional air seal. In those houses, the inner board (usually gypsum board panel) acts as an air barrier. In a few of the houses, the thermal insulation material also acts as an air barrier.

It was also studied whether the prefabricated houses or the houses constructed on site have some difference in the level of airtightness. In studies done earlier in Finland (for example, Perkkiö and Ryynänen 2001), the houses built from prefabricated units seemed to be more airtight than those built on site.

In most modern Finnish dwellings, the required ventilation is arranged with mechanical ventilation. Natural ventilation is used mainly in the older houses. Natural ventilation systems are based on air movements caused by temperature differences and wind pressure. Natural ventilation systems are conditional on weather conditions. Systems work most effectively on windy days and in winters when the temperature differences between inside and outside air are greater. A

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mechanical extract ventilation system is a ventilation system in which air is extracted from the house by a fan. In a mechanical supply and exhaust ventilation system, mechanical fans both supply air to and exhaust air from the building. A mechanical supply and exhaust ventilation can be provided with a heat recovery system, which recovers heat energy from outgoing air for re-use to preheat the incoming cold supply air. The airtight envelope of a building is important, especially for a mechanical supply and exhaust ventilation system. When no air leaks through the envelope, ventilation and heat recovery systems work effectively and have positive effects on energy savings.

The level of airtightness might decline over the years. Such a change might be due to changes in materials' moisture content. Also, the one-layer air barrier is quite vulnerable for holes that may come, for example, from hanging paintings on the wall. Also, the methods of construction in different times could cause differences. Therefore, it was also studied whether the age of the building has an effect on the level of airtightness. In some of the studies, no evident connection between age and air change rate was found (in commercial and institutional buildings by Persily [1998]). On the other hand, in a Swedish study, the airtightness values of 50 houses showed that the newer houses were less leaky than the older ones (Kronvall and Boman 1993).

PRESSURIZATION TESTS

The 100 houses measured were chosen to be a wide selection of different timber-framed dwellings. The whole group of houses is not a random sample of Finnish houses because the purpose was to gather proper subgroups of different types of houses. Dwellings differed from each other in, among other things, age, ventilation type and structural solutions. Three of the dwellings were not detached (one semi-detached, two terrace houses), and some of the two-story houses had a first story built of concrete or stone. Also, a few of the houses weren't yet completely finished. Most of the buildings were built in the recent years. The mean age of the dwellings was five years, and the median was three years. Half of the houses were situated in the Tampere region, and half in the Helsinki region. Measurements were done in two sets, in the summers of 2002 and 2003.

The airtightness of the houses was tested using a fan pressurization method (described in European standard EN 13829 [2000] and more closely for this study in Korpi [2003]). The fan pressurization method is a widely used method and a relatively simple way of getting a comparison value of airtightness. Tests were done with a commercial computer-controlled blower-door system. During a blower-door test, all openings in the envelope are closed and sealed when needed. A fan is mounted tight on one of the building's door or window frames. The pressure difference between the inside and the outside and the airflow through the fan, which is needed to maintain a certain pressure difference, are then measured.

As a result of the pressurization test, a series of pressure differences and the corresponding airflows through the fan are received. A so-called building leakage curve,

$$Q = C\Delta p^n , \tag{1}$$

where Q is the airflow required to maintain a pressure difference Δp and C and n are coefficients, is then fitted to these results. In the blower-door equipment, the curve was fitted to the results automatically by the blower-door software. Airflow corresponding to a pressure difference of 50 Pa (0.201 in. of water) can be divided by the inner volume of the measured building. This quantity is called air change rate at 50 Pa (or air leakage rate at 50 Pa, ACH_{50}, n_{50}-value) and by using it, the airtightness values of different buildings can be compared. Airflow measured in a pressurization test can also be normalized by the area of the envelope (air permeability at 50 Pa, also called air leakage index). The latter has also become a common way of reporting airtightness, especially in Europe. The results in this paper are mainly reported as air change rates, although both values were calculated for all of the houses.

The inner volume of a house was calculated, including the partition walls, fixture, and fittings, but excluding the intermediate floors. The area of the building envelope was calculated also using the measures from the inside of envelope assemblies. This internal surface area included the walls, ceiling, and floors.

In most of the cases, the airtightness of a dwelling was tested with both pressurization and depressurization tests. Normally an appropriate way to give the result would be to give the mean value of these tests. The results in this paper are expressed as results of the depressurization test as it was done to all of the houses. In the group of all the houses, the difference of the mean values of depressurization and pressurization tests and merely depressurization tests was insignificant. The results are expressed to an accuracy of one decimal even though the accuracy of the measurements might not quite reach that level. A former Swedish standard estimates the accuracy of the final result of a pressurization test to be within ±10% (SIS 1987).

RESULTS AND DISCUSSION

The mean air change rate of the houses was 3.9 1/h, with 1.8 1/h standard deviation. The lowest value was 0.5 1/h, and the highest 8.9 1/h. The mean air permeability at 50 Pa was 1.1 L/s m^2 (1.6 gpm/ft^2). Distribution of the results is presented in Figure 1, which shows that over a quarter of the houses had an air change rate between 3 to 4 1/h. The results correspond quite well to results received from tests made in new Finnish dwellings. Eleven timber-framed houses had an air change rate of approximately 3.4 1/h (Perkkiö and Ryynänen 2001). VTT Technical Research Centre of Finland has measured the airtightness of 56 single-family houses (not necessarily

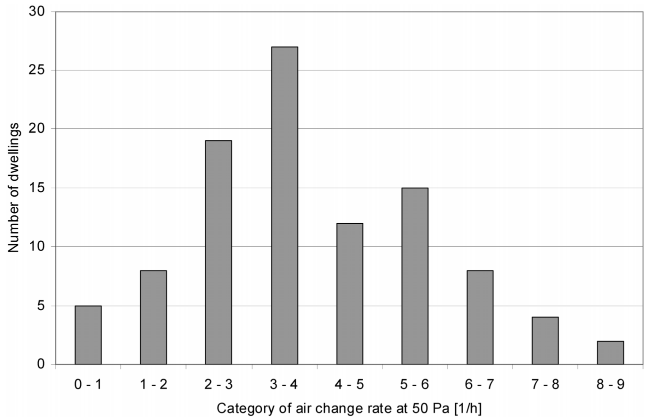

Figure 1 *Distribution of air change rates at 50 Pa (0.201 in. of water) (1/h).*

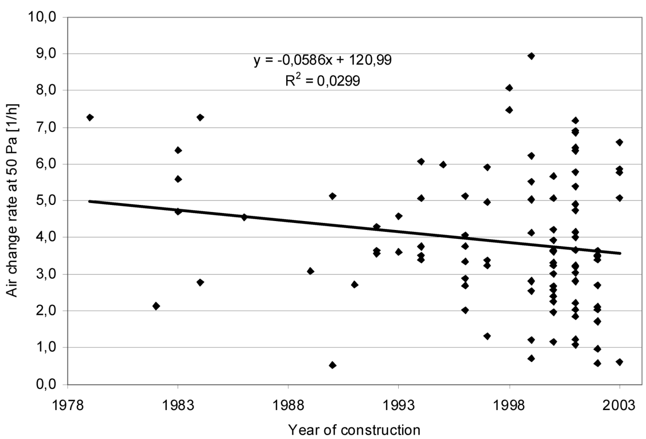

Figure 2 *Air change rate at 50 Pa (0.201 in. of water) (1/h) versus the year of construction.*

timber-framed) over the years 1981-1998. The average result was 5.3 1/h. Most of the houses measured were cases of reclamation and, for that reason, the measured average might be higher than the actual average (Kauppinen and Rantamäki 1999).

Figure 2 is a plot of airtightness results versus the year of construction. There is a slight but not a significant trend of newer houses being more airtight than the older ones. The number of older houses is relatively small for definite conclusions.

Most of the houses had a mechanical ventilation system. In those houses, the average air change rate at 50 Pa was also smaller than in houses with natural ventilation, as presented in Figure 3. The age of the dwellings might have some effect on these results. The mean age of houses with natural ventilation was 11 years, with mechanical extract ventilation 5 years, and with mechanical supply and exhaust ventilation 4 years. The

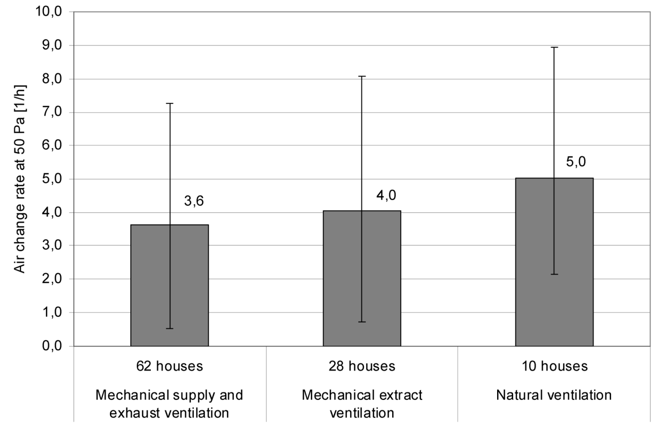

Figure 3 *Air change rate at 50 Pa (0.201 in. of water) (1/h) grouped by ventilation system (average result and the range of results).*

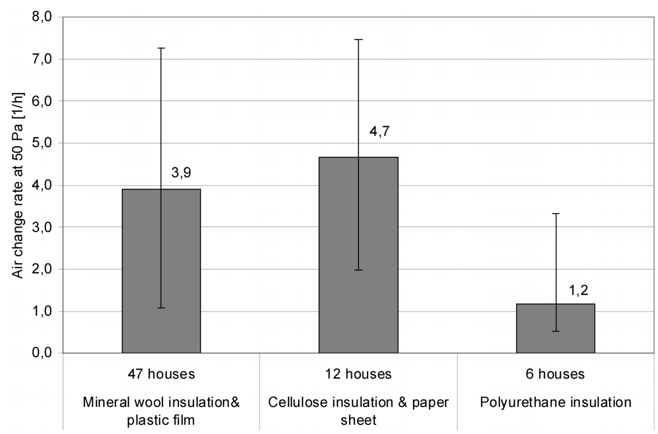

Figure 4 *Air change rate at 50 Pa (0.201 in. of water) (1/h) grouped by combinations of insulation and air barrier materials (average result and the range of results).*

mean air change rate of houses with mechanical supply and exhaust ventilation was 3.6 1/h. There is still need for improvement so that the houses with mechanical supply and exhaust ventilation reach a lower level of airtightness that is important for the proper function of ventilation devices.

Figure 4 is a plot of the average air change rate grouped by different combinations of insulation materials and air barriers. This closer study was done to houses with the same insulation material and air barrier used in both ceiling and wall assemblies. The most common combination of insulation material and air barrier was mineral, i.e., a rock or glass wool and a plastic film. The second most common combination was cellulose (loose fill) insulation and paper sheet air barrier. The third category included houses with aluminium-covered polyurethane insulation, which also functions as an air barrier. In

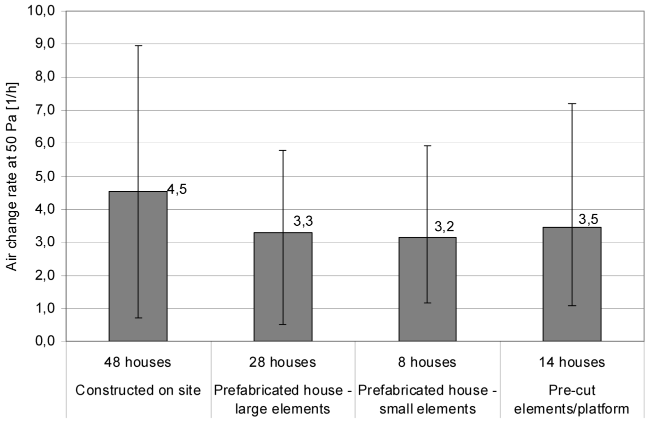

Figure 5 *Air change rate at 50 Pa (0.201 in. of water) (1/h) grouped by construction type (average result and the range of results).*

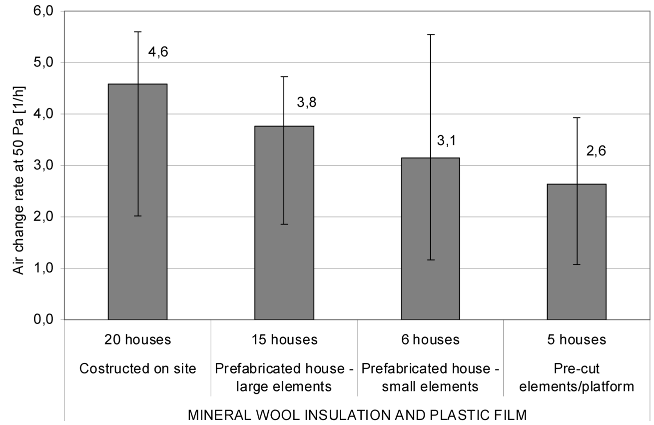

Figure 6 *Air change rate at 50 Pa (0.201 in. of water) (1/h) in houses with mineral wool and plastic film grouped by ventilation system (average result and the range of results).*

over one-third of the total 100 houses, a mixture of different insulation materials and air barriers had been used.

From these groups, clearly the lowest air change rates were received with polyurethane insulation. There was also a slight but not significant difference between the combinations of mineral wool insulation + plastic film and cellulose insulation + paper sheet air barrier.

Figure 5 is a plot of average airtightness versus method of construction. In this study, the houses built on site were slightly more leaky than those built from prefabricated units.

In Figures 6 and 7 the dwellings with mineral wool insulation and plastic film air barrier are grouped by ventilation system and method of construction. This comparison gives a better idea of the impact of ventilation system and construction type because the impact of different insulation and air seal materials is eliminated. On the other hand, in these comparisons, the amount of some of the subgroups is very small. The difference between different ventilation systems is minor compared to differences in the whole group of houses (Figure 3). Also, the difference between houses constructed on site and prefabricated with large units is a bit smaller than in Figure 5. In this comparison, a small group of houses made by a precut technique appeared to be more airtight than they were in the whole group of houses.

For achieving good airtightness, it is important to pay attention to joints, for example, in the ceiling, walls, intermediate floors, and windows. The air barrier is hard to make continuous, especially in the joint of intermediate floor and exterior wall. In this study, the one-story houses (average 3.7 1/h) didn't appear to be significantly tighter than the two-story houses (average 4.1 1/h). The same result was received by examining only houses with mineral wool insulation and plastic film air barrier. In houses constructed on site, the difference in airtightness between one-story houses (average 4.0 1/h) and two-story houses (average 5.0 1/h) was greater, but not significant. The volume of the dwellings didn't have any effect on the results.

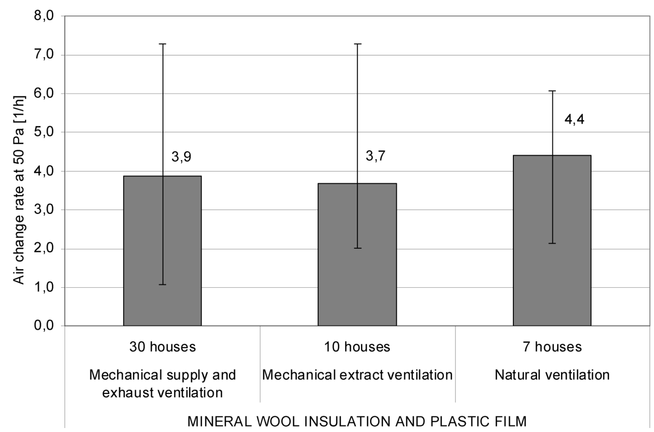

Figure 7 *Air change rate at 50 Pa (0.201 in. of water) (1/h) in houses with mineral wool and plastic film grouped by construction type (average result and the range of results).*

In Swedish regulations (Boverkets Byggregler BBR 1998), the requirement of airtightness for dwellings is 0.8 L/sm^2 (1.2 gpm/ft^2). Thirty-eight percent of the houses measured had a lower air permeability than that required in Sweden. Ten percent of the houses filled the requirement created by Natural Resources Canada (2001) in the R-2000 standard. The ten most airtight houses that had an air change rate at 50 Pa under 1.5 1/h are presented more specifically in Table 1.

Table 1. Ten Most Airtight Houses (Air Change Rate under 1.5 1/h)

House Code	ACH_{50} (1/h)	Insulation Material	Air Barrier	Construction Type	Ventilation System	Construction Year	Stories
1039	0.5	PU	-	PL	MSE	1990	1
1005	0.6	PU	-	PL	MSE	2002	2
2052	0.6	PU	-	PL	MSE	2003	1.5
1020	0.7	PU	-	CS	ME	1999	2
1023	1.0	CE	PF on ceiling, GB on walls	CS	MSE	2002	1.5
1012	1.1	MW	PF	PC	MSE	2001	1.5
1029	1.2	MW	PF	PS	MSE	2000	1
2039	1.2	MW	PF	PS	MSE	1999	1
2037	1.2	MW + CE + partly on ceiling also PU	PF	CS	MSE	2001	1
1038	1.3	PU	-	PS	MSE	1997	1.5

PU = polyurethane
MW = mineral wool
CE =cellulose
PF = plastic film
GB = gypsum board
PL = prefabricated – large elements
PS = prefabricated – small elements
CS = constructed on site
PC = pre-cut

MSE = mechanical supply and exhaust
ME = mechanical extract

It can be noted that, among the most airtight houses, there are houses with different properties. This and the variation of the results in the same kind of houses express the importance of construction quality in achieving good airtightness.

CONCLUSION

The results of this study indicate the level of airtightness of Finnish timber-framed houses. The average air change rate of 100 dwellings measured by the fan pressurization method at a 50 Pa (0.201 in. of water) pressure difference was 3.9 1/h. The result corresponds quite well to those few recent studies made in Finland. In a closer study, the impact of different properties was noticed but not always found significant.

Very good airtightness was reached with many different combinations of insulation and air barrier materials and with houses of different age, number of stories, and construction type. This and the range of results in the same kind of houses indicate the importance of construction quality in achieving good airtightness.

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