Airtightness of single-family houses and apartments

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SUMMARY*:*
Airtightness of Finnish single-family houses and apartments have been studied during the past five years in two large-scale research projects by the Department of Civil Engineering at Tampere University of Technology and HVAC-laboratory at Helsinki University of Technology. The mean air change rate at 50 Pa, measured with fan pressurisation method, was in 100 timber-framed houses 3.9 1/h, in 10 houses built from AAC blocks 1.5 1/h, in 10 houses built from LWAC blocks 3.2 1/h, in 10 houses built from bricks 2.8 1/h, in 10 houses built from shuttering concrete blocks 1.6 1/h, in 10 houses built from concrete elements 2.6 1/h and in 20 log houses 6.0 1/h. The mean n_{50}*-value of 20 apartments in multi-storey houses built from concrete elements was 1.6 1/h. In concrete-built multi-storey houses, in which the intermediate floor was cast on site, the mean* n_{50}*-value of 23 apartments was 0.7 1/h. 16 apartments in timber-framed multi-storey houses had a mean* n_{50}*-value 2.9 1/h. Different factors (construction method and the insulation material in timber-framed houses, seam insulation material in log houses, ceiling structure in heavyweight houses among others) were noticed to have an effect on the average values of air change rates. Most important result, however, is that good airtightness was reached with all house types and with all kind of structures and methods of construction.*

1. Introduction

The Department of Civil Engineering at Tampere University of Technology and HVAC-laboratory at Helsinki University of Technology have carried out a co-operation project “Airtightness, indoor climate and energy efficiency of residential buildings”, in which the indoor and outdoor climates, indoor moisture excess, ventilation performance, energy consumption and airtightness in 70 Finnish heavyweight single-family houses and 56 apartments were studied. This research project is closely related to a previous study “Moisture-proof healthy detached house”, in which the same field measurements were carried out in 100 timber-framed dwellings.

In this paper the measurement results of 70 heavyweight single-family houses and 59 apartments are presented. In addition, a comparison to the results from 100 timber-framed houses is presented. The results from timber-framed houses have been presented previously and more detailed by Korpi et al. (2004). The results are and will be published in Finnish by Vinha et al. (2005) and (2008).

2. Studied houses

2.1 Timber-framed single family houses

The 100 timber-framed 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, for instance, as to age, ventilation type and structural solutions. Three of the dwellings were not detached (one semi-detached, two terrace houses) and some of the two-storey houses had a first storey built of concrete or LWAC blocks. 48 percent of the houses had only one storey. 60% of the houses had a mechanical supply and exhaust ventilation system with heat recovery. 30% houses had a mechanical exhaust ventilation system and 10% had passive stack ventilation. Half of the houses were constructed on site, one fourth of the houses were built from large prefabricated elements and the rest of the houses were built from either small prefabricated elements or with pre-cut -method.

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.

2.2 Heavyweight single-family houses

The group of 70 heavyweight houses consists of 20 log houses, 10 houses built from blocks of autoclaved aerated concrete (AAC), 10 houses built from lightweight aggregate concrete (LWAC), 10 houses built from bricks (5 from calcium silicate brick, 5 from burnt clay brick), 10 houses built from shuttering concrete blocks and 10 houses built from concrete elements. The material named above describes the main exterior wall material used. Three log houses were built with inner and one with external supplementary insulation. In all the rest of the log houses and AAC houses the external wall was of a solid material. Rest of the houses had a thermal insulation layer between the inner and outer shell. In houses made from LWAC and shuttering concrete blocks the insulation layer was in blocks themselves.

In most of the two-storey log houses upper storey was timber-framed. Also some of the two-storey houses had a first storey that was against ground and built from different material. The ceiling assembly in most of the cases was timber-framed. Only most of the AAC houses (9 out of 10) had a ceiling assembly made of reinforced AAC. Three houses with shuttering concrete block walls, two houses with concrete element and one house with LWAC exterior walls had a concrete hollow core slab as a ceiling structure.

The measured houses were received mainly from the databases of manufactures of the houses. Some of the houses were found by delivering brochures to the dwellers of suitable looking houses. The houses were situated mainly in the Tampere and Helsinki region. Nearly all of the houses had a mechanical supply and exhaust ventilation system with heat recovery. A few of the houses had a mechanical exhaust ventilation system. 44 percent of the log houses and 31 percent of the rest of the houses had only one storey. The average internal volume used in pressurisation test results was in log houses 483 m^3 and in the rest of the houses 554 m^3. All of the houses were relatively new; the oldest house was built 10 years prior to measurements. The mean age of the houses was 3 years and the median 2 years. Measurements were done in two sets, in the years 2005…2007.

2.3 Apartments

Apartments measured in this study represent three different types of multi-storey buildings. In concrete element buildings the external walls were of concrete element and the intermediate walls of hollow core slab. One group of apartments were in buildings, in which the intermediate floor was concrete cast on site. In most of these buildings exterior walls were of concrete element. The only exception was building number 6200 which also had non-bearing timber-framed external walls. Third group of apartments were in timber-framed multi-storey houses.

Three to five apartments were chosen to be studied from the same building. When possible, the apartments were chosen from different stories so that one apartment was from the ground floor, one from the upper stories and one from a storey in between. Altogether 59 apartments were measured in 17 buildings. Studied buildings were mainly built a couple of years ago. Nearly all of the apartments had mechanical supply and exhaust ventilation system with heat recovery. A few apartments had mechanical ventilation system. The average floor area of the apartments was 72 m^2, range from 35 m^2 to 138 m^2.

3. Pressurisation method

The airtightness of the houses was tested using a fan pressurisation method (described in European standard EN 13829 2000). The fan pressurisation 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 pressurisation test, a series of pressure differences and the corresponding airflows through the fan are received. A so-called building leakage curve, 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 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, ACH50, n_{50}-value), and by using it, the airtightness values of different buildings can be compared. Airflow measured in a pressurisation test can also be normalised by the area of the envelope (air permeability at 50 Pa, also called air leakage index and q_{50}-value). 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.

The inner volume of a house was calculated including the partition walls, fixture and fittings but excluding the intermediate floors. In apartments the intermediate walls were not included to the volume. The area of the building envelope was calculated using also the measures from the inside of envelope assemblies. This internal surface area included walls, ceiling and floors.

The results of single-family houses are given as the mean value of depressurisation and pressurisation tests. Airtightness of the apartments is the result of depressurisation test. 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 final result of a pressurisation test to be within ± 10 % (SIS 1987). The EN-standard estimates that in most cases in calm conditions the overall uncertainty will be less than ± 15 % and in windy conditions ± 40 % (EN 13829 2000).

4. Results and discussion

4.1 Single-family houses

Distribution of the results from timber-framed houses is presented in Figure 1. The mean air change rate of the houses was 3.9 1/h and the standard deviation 1.8 1/h. 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/sm^2.

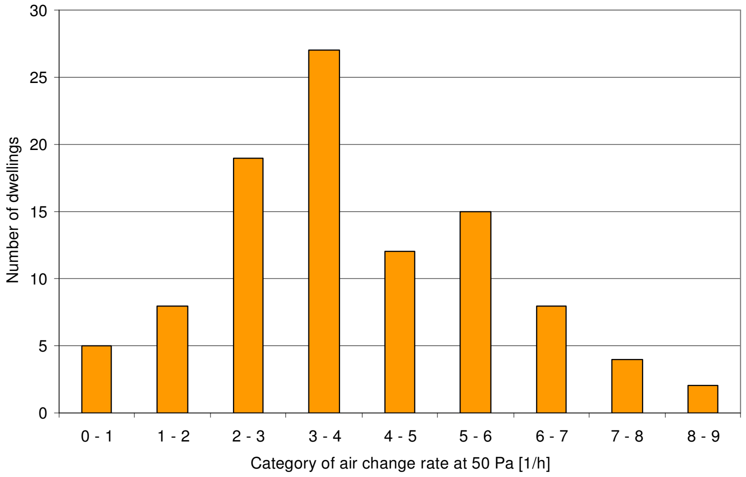

FIG. 1: Distribution of n_{50}-values [1/h] of 100 timber-framed single-family houses.

Timber-framed houses constructed on site (avg 4.5 1/h) were not as airtight as houses built from timber-framed prefabricated elements (large elements 3.3 1/h, small elements 3.2 1/h, pre-cut 3.5 1/h). The group of houses in which the thermal insulation was polyurethane were on average more airtight than houses with other insulation materials or vapour barriers. In this study the one-storey houses (average 3.7 1/h) didn't appear to be significantly tighter than the two-storey houses (average 4.1 1/h). The volume of the dwellings didn't have an effect on the results. In addition, no clear correlation between the energy consumption of the houses and air change rate at 50 Pa was found.

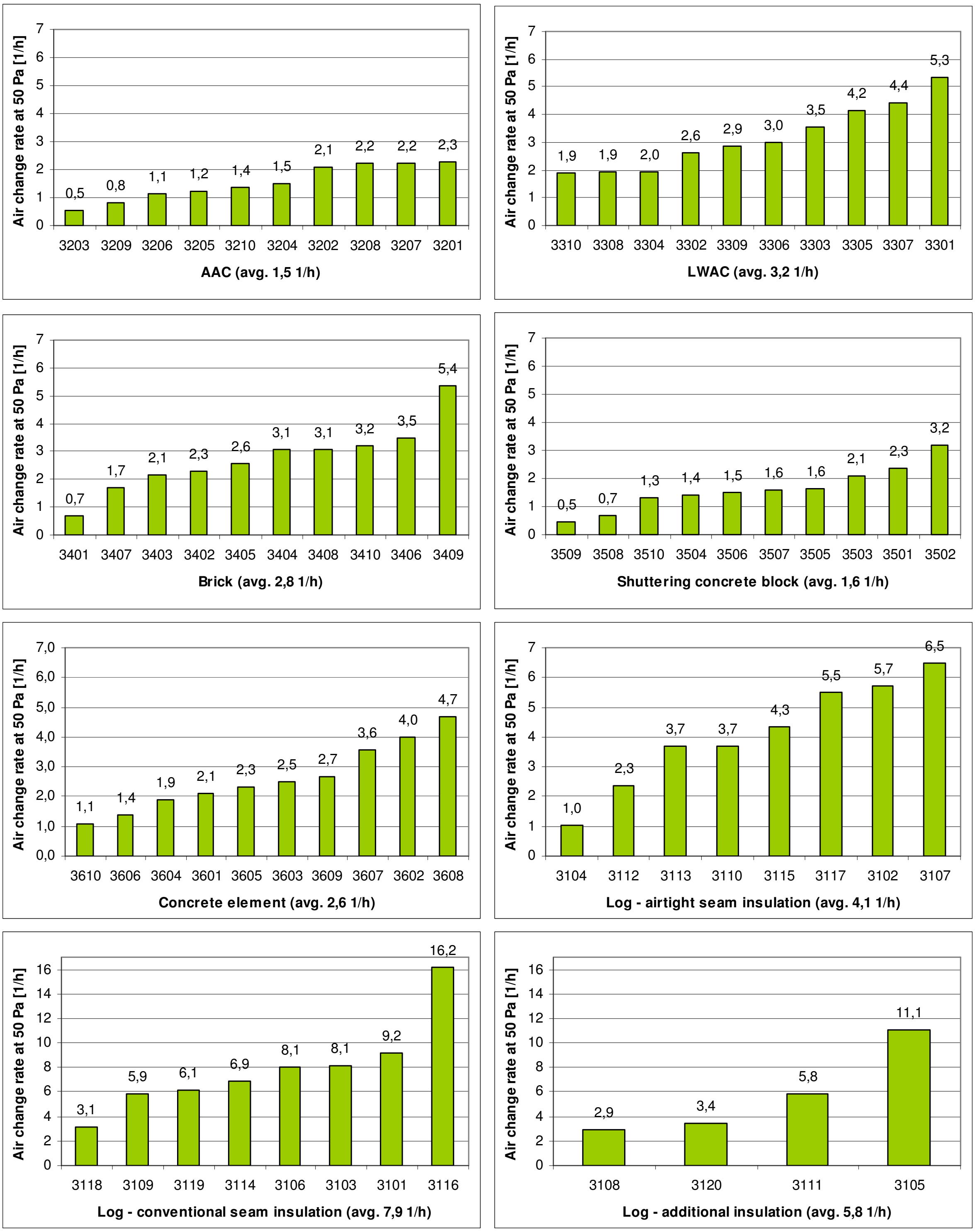

FIG. 2: Results of air change rate at 50 Pa [1/h] grouped by the type of house. The four-digit number is the code of the studied house. Notice different scale in the two lowest graphs.

Figure 2 shows the results of measured air change rates at 50 Pa in heavyweight houses. In the group of log houses different kind of seam insulation materials were used. The seam insulation materials were grouped to conventional and to airtight. Group of conventional seam insulation materials included for example mineral wool, polypropylene and flax insulation. To the group of airtight seam materials different erectile seam insulation materials and cellular rubber seam insulations were included. House was included to the group of houses with airtight seam insulation, if airtight insulation was used between the logs either in the wall part or in the corner structure or in both. On average, houses with airtight seam insulation were clearly more airtight than houses with conventional seam insulation materials (Figure 2). In three of these log houses (3104, 3113 and 3115) polyurethane insulation was used in ceiling structure, which also might have affected to lower n_{50}-value. Log house 3108 had external additional insulation, while the rest of the log houses with additional insulation had interior insulation layer.

The ceiling structure of the houses seems to have an effect on the results. Infra-red camera measurements in this project reveal that the joint between exterior wall and ceiling is the most common source of air leakage. The joint between solid wall and the thin air barrier layer in timber-framed ceiling is difficult to make airtight. In Table 1 the results of house-groups, in which houses with both concrete and timber-framed ceiling structure occurred, are shown. In all of the groups the amount of houses in different subgroups is very low, but still the average air change rate of houses with concrete element slab as ceiling structure is a bit lower than the ones that have timber-framed ceiling structure. In the group of all block and concrete element houses, the difference in air change rates between houses with concrete or timber-framed ceiling structure was significant.

TABLE. 1: Air change rates at 50 Pa [1/h] of houses with concrete or timber-framed ceiling structure.

	Houses with concrete ceiling structure			Houses with timber-framed ceiling structure		
	Amount of houses	Average n_{50}-value [1/h]	Average q_{50}-value [l/sm^2]	Amount of houses	Average n_{50}-value [1/h]	Average q_{50}-value [l/sm^2]
Autoclaved aerated concrete	9	1,5	0,45	1	2,3	0,57
Shuttering concrete block	3	1,2	0,45	7	1,8	0,61
Concrete element	2	1,2	0,45	8	3,0	0,84
Lightweight aggregate concrete	1	1,9	0,67	9	3,3	1,06

Figure 3 shows the summary of the results of single-family houses. The air change rate of combined group of masonry and concrete element houses (2.3 1/h) had a lower n_{50}-value than timber-framed (3.9 1/h) and log (6.0 1/h) houses. In Figure 3 the airtightness of the houses is compared with both n_{50}- and q_{50}-values. In a comparison with q_{50}-values the log and timber-framed houses perform better than in the comparison with n_{50}-values. This is because the relation between the volume and the area of building envelope is on average higher with masonry and concrete element houses than log and timber-framed houses. The group of masonry and concrete element houses were also larger by their volume (554 m^3) than log (483 m^3) and timber-framed houses (405 m^3). With timber-framed houses the n_{50}-value had no correlation to the volume of the house, but weak correlation to the volume was found with both log and the group of masonry and concrete element houses. Figure also shows that there is variation in the results with the same kind of houses and that good airtightness was achieved in all house groups.

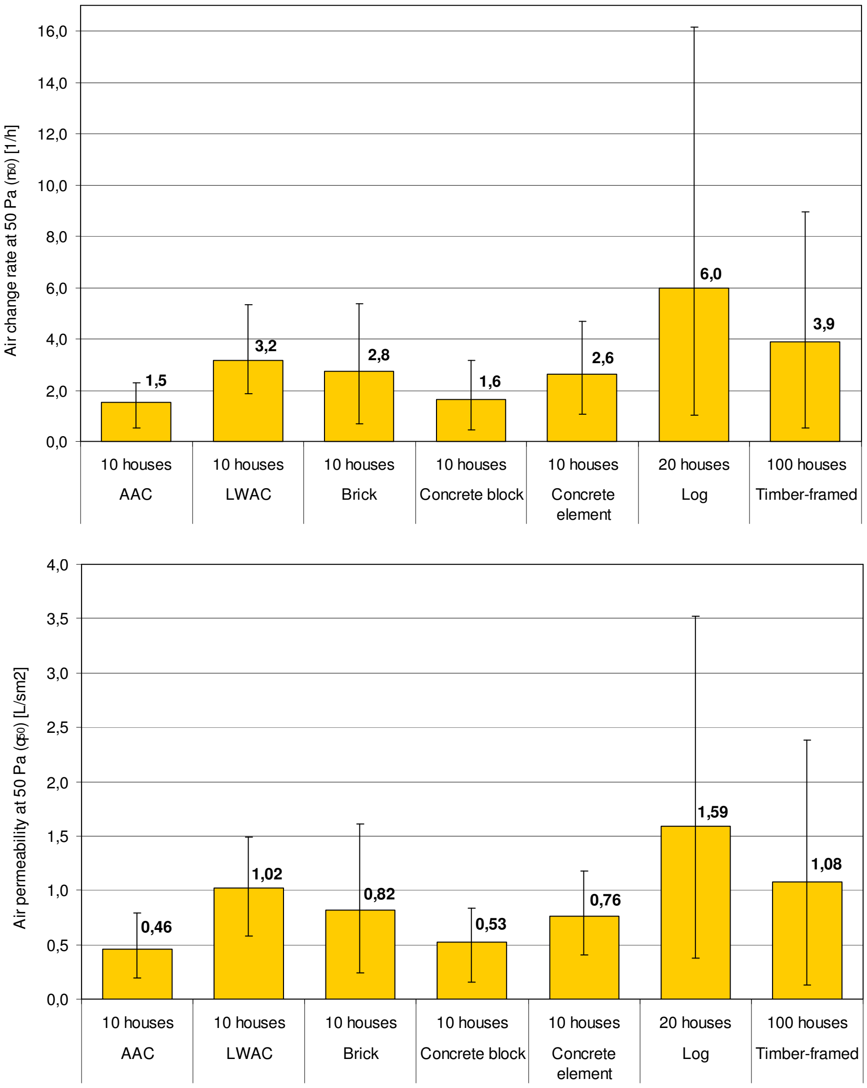

FIG. 3: Air change rates at 50 Pa [1/h] upper graph, air permeability rates at 50 Pa [L/sm^2] lower graph. (Average result and the range of results)

4.2 Apartments

The airtightness of apartments was better than that of single-family houses. Average air change rate at 50 Pa of all apartments was 1.6 1/h and range from 0.3 to 5.3 1/h. In 49% of the dwellings the n_{50}-value was lower than 1 1/h.

The airtightness of the apartments categorized by the building type is shown in Figures 4, 5 and 6. The lowest average n_{50}-values were received in concrete built houses with intermediate floors cast on site (0.7 1/h). The average n_{50}-value of apartments in concrete element houses was 1.6 1/h and in timber-framed multi-storey houses 2.9 1/h.

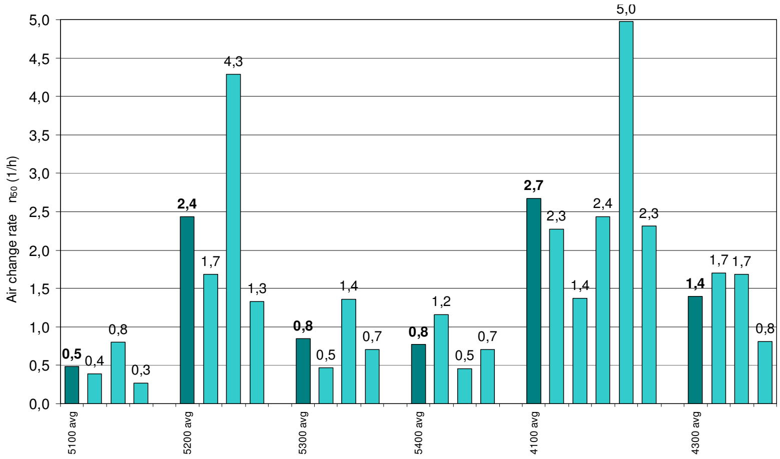

FIG. 4: Air change rates at 50 Pa [1/h] of apartments in concrete element multi-storey houses. The darkened column is the average of all apartments in the same building.

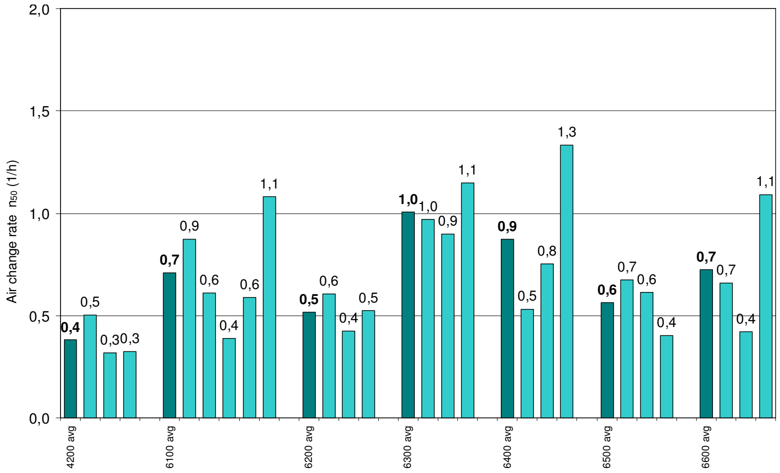

FIG. 5: Air change rates at 50 Pa [1/h] of apartments in concrete-built multi-storey houses, in which the intermediate floor is cast on site. The darkened column is the average of all apartments in the same building.

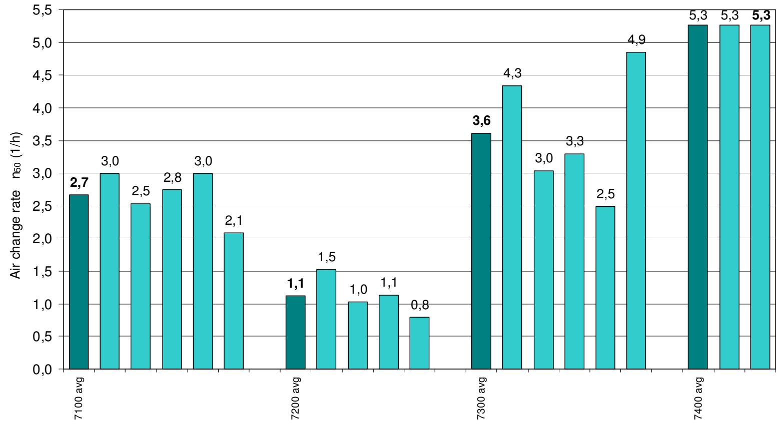

FIG. 6: Air change rates at 50 Pa [1/h] of apartments in timber-framed multi-storey houses. The darkened column is the average of all apartments in the same building.

5. Conclusions

Studies done during the past five years give a good conception of the level of airtightness in new Finnish single-family houses and apartments. The mean air change rate at 50 Pa in 100 timber-framed houses was 3.9 1/h, in 10 houses built from AAC blocks 1.5 1/h, in 10 houses built from LWAC blocks 3.2 1/h, in 10 houses built from bricks 2.8 1/h, in 10 houses built from shuttering concrete blocks 1.6 1/h, in 10 houses built from concrete elements 2.6 1/h and in 20 log houses 6.0 1/h. The mean n_{50}-value of 20 apartments in houses built from concrete elements was 1.6 1/h. In concrete-built multi-storey houses, in which the intermediate floor was cast on site, the mean n_{50}-value of 23 apartments was 0.7 1/h. 16 apartments in timber-framed multi-storey houses had a mean n_{50}-value of 2.9 1/h. Although it must be noticed, that the group of houses are not necessary a random sample because the purpose was to gather proper subgroups of different types of houses (for example the ceiling structure, seam insulation material in log houses and the insulation material in timber-framed houses).

The air change rate of combined group of masonry and concrete element houses (2.3 1/h) had a lower n_{50}-value than timber-framed (3.9 1/h) and log (6.0 1/h) houses. Timber-framed houses constructed on site were not as airtight as houses built from timber-framed prefabricated elements. The group of timber-framed houses in which the thermal insulation was polyurethane were on average more airtight than houses with other insulation materials or vapour barriers. On average, log houses with airtight seam insulation were more airtight than houses with conventional seam insulation materials, although other factors might have affected the good airtightness too. 15 of the measured houses had a concrete ceiling structure. In these houses, even thought the number of them is relatively small, the airtightness was a bit better than in houses with timber-framed ceiling structure. Most important result, however is, that good airtightness was reached with all house types and all kind of structures and methods of construction. This emphasises the importance of construction quality in reaching good airtightness.

6. Acknowledgements

This study is part of two larger field research projects carried out by Department of Civil Engineering at Tampere University of Technology and HVAC-Laboratory at Helsinki University of Technology. The researches have been financed by TEKES (National Technology Agency of Finland) and Finnish companies and associations. We extend our thanks to all assisting people, residents of the houses studied, and financiers of the research for their co-operation during the study.

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