AIRTIGHTNESS OF OFFICE AND EDUCATIONAL BUILDINGS IN SWEDEN – MEASUREMENTS AND ANALYSES

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ABSTRACT

The airtightness of office and educational buildings influences energy use and thermal comfort. A leaky building is likely to have a high use of energy and thermal discomfort. The knowledge of real airtightness levels of entire buildings and their impact on the energy use is very low, except for a study carried out in the USA. Therefore two different methods of airtightness testing were applied to six entire Swedish office and educational buildings built since 2000. The first method involves using the ventilation system of the building and the second one to use a number of blower doors. Information on 30 other airtight tests was collected. During the airtightness testing the air leakage paths were detected using infrared scanning and smoke sticks.

The two methods are useful for testing entire office buildings, apartment buildings, industrial buildings and other premises.

The thirty-six tested buildings show a very good airtightness level, close to the Swedish passivehouse requirements. All previously tested office buildings in the USA, Canada and the UK are much leakier. The tested buildings showed some leakage paths, which could easily have been taken care of during construction, but are rather difficult to stop now.

The paper describes and evaluates the airtightness tests of thirty-six Swedish office and educational buildings and their implication for energy use.

KEYWORDS

Airtightness, blower door, energy, measurement, office building, pressurisation, school.

INTRODUCTION

It is well-known that the building sector plays an important role in the work towards sustainable development. The sector represents extensive economic, social and cultural values, at the same time as it causes extensive environmental impact due to its high use of energy and materials. An important part of the energy use within the building sector is related to office and educational buildings. The total energy use of an average Swedish office building is 220 kWh/(m²year) (heated usable floor area) of which electricity stands for 108 kWh/(m²year). Of this 108 kWh/(m²year), 57 kWh/(m²year) is due to office equipment, of which 23 kWh/(m²year) is lighting. This was shown in a study of 123 office and administrative buildings of different ages [1]. Of the floor area in all office buildings, 69 % is heated by district heating and the average use of district heating energy is 110 kWh/(m²year) [2]. Both new and old office buildings have a substantial potential for energy savings and improvement of indoor climate. While many new office buildings may have a low energy use for heating compared with older office buildings, they may have a higher electricity use. This is due to a high use of electricity for ventilation, cooling, lighting and office equipment. An important parameter affecting the energy use for space heating and cooling, and thus the indoor climate, is the airtightness of the building envelope. In a leaky building the energy use increases due to uncontrolled infiltration/exfiltration. The air leaking in and out through the building envelope increases the energy use as it, for example, does not pass through a heat recovery unit. The uncontrolled air leakage can contribute to discomfort such as draught, which can result in the indoor temperature being raised to improve the comfort, causing an increased energy use from the user's behaviour.

Unfortunately, there is no simple and accurate method of relating the airtightness of a building to the air leakage for an office or educational building in operation. This is due to difficulties in determining the location and characteristics of all leakage paths and determining the wind pressure coefficients [3].

The aim of this project [4] was:

- To use different measuring methods for determining the airtightness of educational and office buildings,
- to determine the airtightness for modern educational and office buildings,
- to determine the influence of airtightness on the energy use for space heating.

METHOD

The hypothesis is that, in many cases, the airtightness can be measured using the ventilation system of the building. Two different methods were used:

- Airtightness testing using a number of blower doors (portable fans), www.energyconservatory.com. European standard 13829, Method B was applied [5].
- Airtightness testing using the ventilation system of the building. Canadian standards were applied [6, 7].

The measurements involve pressurizing or depressurizing the entire building and measuring the corresponding air flow to maintain the different pressure differences between inside and outside. Ventilation openings and lead-throughs are sealed before the measurements. Thus the airtightness of the building envelope is determined. The location of leakage paths are determined using thermography and smoke.

When using the ventilation system of the building the following has to be investigated before:

- Exploring the building automation system to ensure that the ventilation air flows can be controlled and that it is likely to arrive at the necessary air flows. It is usually easier if the building has a demand controlled ventilation system.
- Ensuring that the air flows can be measured and that it can be done with adequate accuracy.

Within this project three schools and three office buildings were tested. An additional 31 tests had been carried out before by other Swedish organizations.

To determine the air infiltration/exfiltration rate from the results of pressurization tests there are different ventilation models. The ventilation models can be divided into: "air change" methods, reduction of pressurization test data, regression techniques, theoretical network methods, simplified theoretical methods [8]. The first three models are empirical techniques, which tend to be loosely based on the physical principles of air flow. The other models are theoretical models, which are based on a much more fundamental approach involving the solution of the equations of flow for air movement through openings in the building envelope. Empirical methods are usually straightforward to use, but tend to be unreliable and have a limited field of application. On the other hand, theoretical models have a potentially unrestricted applicability but are often demanding in terms of data and computer execution time. Theoretical calculation techniques can divided into: single zone network models, multi zone network models and simplified theoretical techniques. These models require a lot of information e.g. wind pressure coefficients, air leakage distribution for the building envelope, local wind speed, geometry of the building. Due to the limited amount of information on the tested buildings the method using reduction of pressurization test data was chosen in order to determine an order of magnitude for the average infiltration/exfiltration rate.

The reduction of pressurization test data method does nevertheless provide valuable information concerning the average infiltration performance of the building. The artificial pressurisation/depressurisation of a building to determine air leakage performance is now fairly common practice. The test only provides data regarding the “leakiness” of the building. The result provides no information on the distribution of openings or on how infiltration will be affected by wind, temperature, terrain, or shielding. However, several experimental results have shown that the approximate air infiltration rate will be of the order of one twentieth of the measured air change rate at 50 Pa [9], i.e.:

$$Q_{inf} = Q_{50} / 20 \qquad (1)$$

where Q_{inf} = infiltration rate (h^{-1})
Q_{50} = air change rate at 50 Pa.

Calculations have shown that the ratio can vary between 6 and 40 depending upon the house, the climate and the shielding [3].

To determine the energy use caused by air infiltration/exfiltration the infiltration/exfiltration rate was first calculated from the pressurization tests and then the energy use was calculated using degree days for Stockholm. For most of the buildings the only available information was the floor area, the volume, type of ventilation system and type of building technology, the results of a pressurization test.

TESTED BUILDING

The aim was to test educational and office buildings built after the year 2000 with a floor area preferably larger than 1000 m². It should be a mix of buildings with specific airtightness requirements and without.

Outside this project

31 buildings had been tested by different organisations e.g. the Technical Research Institute of Sweden, Akademiska Hus, Skanska, WSP. All the buildings were built between 2007 and 2012. The buildings are mainly schools and offices, but also homes for the elderly, shops, and sports centres (see table 1). The smallest building has an floor area of 800 m² and the biggest 17 000 m². All buildings have balanced mechanical ventilation with heat recovery. The building envelopes vary, ranging from prefabricated concrete to stud walls.

Type of building	Year	Number of storeys above ground	Floor area, m²	Volume, m³	Building envelope
Shop	2011	1-2	8,221	61,090	Prefabricated concrete/stud wall
Sport Centre	2011	1-2			Prefabricated concrete/stud wall
Office	2008		1,950	5,250	Sheet metal/expanded plastics elements
Office	2010		3,905		Prefabricated concrete
Office	2010	6	4,094	15,171	Some kind of facade system, TRP
Office	2010	5	17,000		
Office	2007	5	8,574	25,722	Prefabricated glass façade/stud wall
Office/industry	2009		379/1,269		Plannjaelement/stud wall
Storage/workshop /office	2011	1-2			Stud wall, TRP
Food store	2011		1,540	8,000	Concrete PPM, plaster expanded clay, TRP plastic foil
School	2009				
School	2011	1-2			Stud wall
School	2008	1-2			Stud wall
School	2008	1	1,840		Stud wall
School	2009	1-2	1,134		Stud wall, TRP
School	2008	1-2			
School	2010	1-2	973		Stud wall
School	2010	1-2	973		Stud wall
School	2010	2-3			Concrete/stud wall
School	2010	1-2	761		Stud wall
School	2010	2	3,425	13,500	Infill wall, loft ceiling beams of HDF
School	2011	1-2	959		Stud wall
School	2011	1-2	2,250	8,995	Stud wall, TRP
School	2007	2			
School	2011		880	3,300	PPM, stud wall, plasict foil,
School	2010		800	3,190	Prefabricated concrete/infill wall
School	2011		2,950	11,500	PPM, stud wall, TRP tak, plastic foil
School	2010		3,340	14,000	PPM, stud wall /TRP, plastic foil
Home for the elderly	2012	7	4,762	14,800	Prefabricated concrete
Home for the elderly	2011		4,200	11,000	Infill walls, concrete roof

Table 1. Description of tested buildings. Year refers to year of construction.

Within this project

Five buildings were tested for the purpose of this project, three office and three educational buildings. All the buildings were built between 200x and 2011 (see table 2). The smallest building has an floor area of 800 m² and the biggest 20 000 m². All buildings have balanced mechanical ventilation with heat recovery. The building envelopes vary, ranging from prefabricated concrete to stud walls.

Type of building	Year	Number of storeys above ground	Floor area, m^2	Volume, m^3	Building envelope
Exhibition/office	2011	1-2	20,000	204,000	Prefabricated concrete sandwich elements, HDF-floor structure
Office	2009	6	12,000	48,000	Façade bricks and glass
Office	2009	10			Prefabricated glass facade
School	2007	2	2,628	8,600	Light-weight concrete block wall
School	2011	1	1,030	2,967	Wood-framed wall
School	2009	2	2,098	7,148	Wood-framed wall

Table 2. Description of tested buildings. Year refers to year of construction.

RESULTS

All the buildings tested outside the project are very airtight (see table 3). The average airtightness was 0.3 l/sm² @ 50 Pa which is equivalent to the voluntary Swedish requirement for passive houses [10]. The best building had a value of 0.1. For most of the buildings airtightness requirements were made ranging from 0.2 to 0.8 l/sm² @ 50 Pa, which can be compared with the requirement of the previous Swedish building code (before year 2006), 1.6 l/sm² @ 50 Pa. Only two buildings did not meet their requirement. The current building code does not have any specific requirement. All previously tested office buildings in the USA, Canada and the UK are much leakier [11]. Common leakage paths were exterior doors and connections between façade elements and floors/roofs, most of which would be difficult to tighten afterwards. Most buildings were tested with blowerdoors covering most of the buildings. Some were tested with the ventilation system.

Type of building	Year of construction	Test method	Envelope area, m^2	Airtightness requirement, l/sm² @ 50 Pa	Measured air tightness, l/sm² @ 50 Pa	Main leakage paths
Shop	2011	Blowerdoors, three fans, the whole building	18,721		0.18	Concrete element joints, exterior doors
Sport Centre	2011	Blowerdoors, two fans, the whole building	6,616	0.4	0.44	Exterior doors etc.
Office	2008	Ventilation system	2,580		0.34	Entrance parts/windows /exterior doors
Office	2010	Ventilation system		0.4	0.27	

Office	2010	Blowerdoors, one fan, the whole building	4,237	0.5	0.43	Connections between floor and wall
Office	2010	Blowerdoors, three storeys, one at a time	14,610	0.6	0.55	
Office	2007	Ventilation system/two blowerdoors		0.8	0.7	Connection between facade elements, facade and roof elements
Office/industry	2009	Ventilation system	4,560	0.25	0.26	Connection between ceiling and wall/workshop – exterior doors
Storage/ workshop /office	2011	Blowerdoors, two fans, the whole building	10,034	0.3	0.29	Exterior doors
Food store	2011	Blowerdoors, two fans, the whole building	3,995	0.8	0.62	TRP/expanded clay, windows, Entrance parts
School	2009	Ventilation system, the whole building excl. basement	4,912	0.5	0.36	
School	2011	Blowerdoors, one fan, the whole building	2,607	0.2	0.13	
School	2008	Blowerdoors, one fan, the whole building	3,335	0.45	0.41	
School	2008	Blowerdoors, one fan, the whole building	5,180	0.4	0.21	
School	2009	Blowerdoors, one fan, the whole building	2,832	0.6	0.27	Exterior doors
School	2008	Blowerdoors, one fan, the whole building	2,414	0.3	0.26	
School	2010	Blowerdoors, one fan, the whole building	2,460	0.6	0.23	Exterior doors and windows
School	2010	Blowerdoors, one fan, the whole building	2,460	0.6	0.19	Exterior doors and windows
School	2010	Blowerdoors, one fan, the whole building	2,182	0.6	0.57	
School	2010	Blowerdoors, one fan, the whole building	2,054	0.5	0.38	Exterior doors

School	2010	Blowerdoors, one fan, the whole building	5,513	0.2	0.09	No major leakage paths
School	2011	Blowerdoors, one fan, the whole building	2,520	0.40	0.28	Exterior doors
School	2011	Blowerdoors, one fan, the whole building	4,973	0.25	0.17	Exterior doors
School	2007	Blowerdoors, one fan, the whole building	3,941	0.4	0.45	Exterior doors etc.
School	2011	Blowerdoors, one fan, the whole building	2,261	0.6	0.48	Roof, windows and doors
School	2010	Blowerdoors, one fan, the whole building	2,295	0.3	0.4	Connection wall-ceiling, exterior door
School	2011	Blowerdoors, one fan, the whole building	4,822	0.2	0.16	
School	2010	Blowerdoors, three fans, the whole building	5,641	0.8	0.88	
Home for the elderly	2012	Blowerdoors, one fan, the whole building	4,081	0.3	0.20	Exterior doors
Home for the elderly	2011	Blowerdoors, x fans, the whole building	3,900	0.2	0.14	
Average				0.44	0.30	

Table 3. Measured air leakage and leakage paths.

For twelwe of the buildings information on the volume was available and the airtightness could be recalculated to ach @ 50 Pa (see table 4). A comparison of the buildings is now different due to different ratios between volume and envelope area. Using a simple method of calculating the infiltration (see Method) an average infiltration rate was estimated. The result was an average air infiltration rate during the heating season of 0.03 ach (air changes per hour), varying between 0.01 and 0.06. This is equivalent to an energy use for space heating of 4 kWh/m²year. If the buildings would have only met the requirements of the previous building code the energy use might have been five times higher i.e. 20 kWh/ m²year.

Type of building	Year	Measured airtightness l/sm² @ 50 Pa	Measured airtightness ach @ 50 Pa	Infiltration/ex filtration, ach	Energy use for heating infiltration, kWh/m²year
Shop	2011	0.18	0.20	0.01	2
Office	2008	0.34	0.60	0.03	3
Office	2010	0.43	0.43	0.02	3
Food store	2011	0.62	1.11	0.06	10
School	2010	0.09	0.13	0.01	1
School	2011	0.17	0.34	0.02	2
School	2011	0.48	1.18	0.06	7
School	2010	0.4	1.04	0.05	7
School	2011	0.16	0.24	0.01	2
School	2010	0.88	1.28	0.06	9
Home for the elderly	2012	0.20	0.20	0.01	1
Home for the elderly	2011	0.14	0.18	0.01	1
Average		0.34	0.58	0.03	4

Table 4. Measured air leakage and calculated energy use for heating infiltrating air.

Also the recently tested five buildings were fairly airtight, but not as airtight as the previously tested buildings (see table 5). For the sixth building the result was not available at the time of writing this report. One contributing factor might be that there were only two buildings which had a specified airtightness requirement.

Type of building	Year of construction	Test method	Envelope area, m²	Airtightness require-ment, l/sm² @ 50 Pa	Measured air tightness, l/sm² @ 50 Pa	Main leakage paths
Exhibition/ office	2011	Ventilation system, the whole building	40 400	0,4	0,39	Connection between façade elements and columns, between facade and roof, exterior doors.
Office	2009	Ventilation system, storey 3, back pressure storey 2, 4, atrium and staircase	5 600		0,85	Connection between infill walls and steel columns, windows
School	2007	Blower Door	3 923	-	0,87	Lead-throughs, windows
School	2011	Blower Door	2 775	-	0,45	Doors, windows
School	2009	Blower Door	4 307	-	0,62	Lead-throughs, windows, doors.
Average					0,64	

Table 5. Measured air leakage and leakage paths.

For the recently tested buildings, information on the volume was available and the airtightness could be recalculated to ach @ 50 Pa (see table 6). The comparison of the buildings is now different due to different ratios between volume and envelope area. Using a simple method of calculating the infiltration (see Method) an average infiltration rate was estimated. The result was an average air infiltration rate during the heating season of 0.05 ach (air changes per hour), varying between 0.01 and 0.08. This is equivalent to an energy use for space heating of 6 kWh/m²year. If the buildings would have only met the requirements of the previous building code, the energy use might have been three times higher 20 kWh/ m²year.

Type of building	Year	Measured airtightness l/sm² @ 50 Pa	Measured airtightness ach @ 50 Pa	Infiltration/exfiltration, ach	Energy use for heating infiltration, kWh/m²year
Exhibition/office	2011	0,39	0,28	0,01	5
Office	2009	0,85	0,36	0,02	2
Office	2009				
Education	2007	0,87	1,44	0,07	8
Education	2011	0,45	1,51	0,08	7
Education	2009	0,62	1,34	0,07	8
		0,64	0,99	0,04	6

Table 6. Measured air leakage and calculated energy use for heating infiltrating air.

CONCLUSION

This study clearly shows that it is possible to build very airtight educational and office buildings. Most likely, the energy use for infiltration in these buildings are almost negligible i.e. in the order of magnitude of a couple of kWh/m²year. This number can be compared with the total energy use for space heating for a typical average Swedish office building of 110 kWh/ m²year, where infiltration might account for 10-20 kWh/m²year if only the airtightness requirement of the previous building code is fulfilled, which is likely.

Two different methods of measuring the airtightness of entire buildings have been used, using the building's ventilation systems and using a number of blower doors. Both methods can be used and combined. The choice of method depends on the prerequisites of the test object. For big buildings using the ventilation system can be preferable. Tests during construction, which are recommended to ensure good airtightness, can often only be carried out using blower doors. The two methods can be applied to office buildings, apartment buildings, industrial buildings and other premises. For apartment buildings the blower door technique is often the only method as the ventilation system often has insufficient capacity, unless the building is very airtight. Complete testing includes determination of the location of leakage paths.

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