THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION STANDARDS IN BUILDINGS

5th AIC Conference, October 1-4 1984, Reno, Nevada, USA

PAPER 5

BETTER AIRTIGHTNESS: BETTER OR WORSE VENTILATION?

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SYNOPSIS

In Finland there are not yet any regulations or standards concerning the airtightness of buildings. Drafts have caused discussions: would a controlled airtightness increase the building costs too much, and would improved airtightness worsen the indoor air quality?

In modern Finnish buildings, a good or satisfactory airtightness can be achieved with a normal careful workmanship. To secure a good indoor air quality, a functioning ventilation system is also necessary. There seems to be no return to traditional "breathing" structures and natural ventilation.

Airtightness standards are still being discussed in Finland. A draft one, including also proposed requirements for a functioning ventilation system and its operation, is reported here.

1. INTRODUCTION

This paper is mainly based on several research and experimental projects carried out by the Technical Research Centre of Finland (VTT).

Airtightness standards have been discussed in Finland since about 1976. At that time some calculations were presented showing significant energy losses due to air infiltration. Since then, the airtightness of buildings has been improved, without standards, and with practically no extra costs, though leaky houses are still being built due to bad workmanship.

Traditionally, detached houses and row houses have been generally provided with natural ventilation plus (recently) a kitchen hood fan, but mechanical systems are gaining in popularity. In blocks of flats mechanical exhaust systems are dominant, with only a few exceptions with also a mechanical supply. Non-residential buildings are generally provided with a mechanical supply and exhaust ventilation system.

In natural or exhaust ventilation systems, as a rule, no attention has been paid to the supply air intake. In new airtight buildings, many air quality problems have been reported, especially in bedrooms.

Thus if any airtightness standards were given, they should also include guidelines for ventilation arrangements. Attitude among builders and designers should also be developed: the traditionally separate structural and HVAC designs are interrelated. The main aspects to be considered in developing the standards are: first, health and air quality, second, thermal comfort, third, energy effectiveness.

2. REPORTED RISKS ON AIR QUALITY

2.1 General

Several factors may affect the indoor air quality. Risks have been increased because of many reasons:

- improved airtightness
- increased energy prices - reduced ventilation rates
- declining outdoor air quality especially in cities
- new building and furnishing materials
- no internal fireplaces providing a good air change.

2.2 Common impurities

Carbon dioxide concentrations can become high - even up to a hazardous level - in bedrooms not provided with any ventilation arrangements.

High humidity seldom occurs in the Finnish climate with a few exceptions in extremely poorly ventilated occupied rooms. Moisture problems, e.g. condensation and mould growth have been reported.

The spreading of cooking fumes can be prevented with a properly used kitchen hood plus fan. Dusty exhaust air terminal devices are still very common and cause complaints especially in older buildings.

Tobacco smoke is considered one of the most common and harmful impurities. The official guidelines give higher design air flows for rooms where smoking is allowed.

Radon is a local problem in Finland. In certain smaller regions the soil is exceptionally radioactive. In underground spaces with low ventilation rates, radon can still cause health risks in other regions as well.

Formaldehyde may be the most common reason for complaints concerning air quality. It can be smelled in almost every new house expecially if ventilation is minimized. In many cases harmful, irritative concentrations remain even after the first one or two years.

2.3 The "bedroom problem"

At the time when the airtightness was not good, the natural ventilation and mechanical exhaust system worked well with no severe problems in air supply - there were enough leakage routes. New buildings are airtight, but they seldom have any supply air arrangements in the building envelope. The risks for the "bedroom problem" are evident.

This problem can be prevented, of course. But it requires a new way of thinking, a cooperation between the structural and ventilation consultants and the builders.

"The bedroom problem" has been presented at many occasions /1/. In table 1, experimental results are presented showing low measured air change rates in rooms without any ventilation arrangements. An extreme "energy-saving" effort can thus cause discomfort and even health problems!

TABLE 1

The breakdown of outdoor air flows and air change rates measured in various ventilation systems. (The PIKO experiment project, Helsinki, winter 1983-84)

Test flat no.	1	2	3	4
Ventilation system	Mechanical (plus warm-air heating)	Mechanical exhaust	Mechanical exhaust	Natural exhaust
% of outdoor air into:				
bedroom 1 (u)	20	11	4	1
bedroom 2 (u)	12	12	4	18
bedroom 3 (u)	12	11	-	8
living room (g)	16	15	6	7
kitchen (g)	15	28	18	34
corridor (u)	2	3	16	0
hall (g)	10	9	12	20
sauna, bathroom	13	11	40	12
Total	100 %	100 %	100 %	100 %
Air change rates in bedrooms				
bedroom 1	0,80	0,58	0,23	0,07
bedroom 2	0,42	0,55	0,23	0,68
bedroom 3	0,61	0,73		0,34
Total air change rate ac/h	0,5 h^{-1}	0,66 h^{-1}	0,72 h^{-1}	0,61 h^{-1}
Average pressure difference (-=internal underpressure)				
upper floor	0 Pa	-28 Pa	-9 Pa	0 Pa
ground floor	-5 Pa	-24 Pa	-6 Pa	-3 Pa
Airtightness	good	good	satis-factory	poor
Weather during measurements:				
Outdoor temp.	3 °C	0 °C	0 °C	0 °C
Wind velocity	6 m/s	4 m/s	4 m/s	6 m/s

u = upper floor, g = ground floor

2.4 Problems caused by the use of small local fan

A kitchen hood fan is very common in detached houses, and also in renovated flats provided with a natural ventilation. In airtight buildings, while the kitchen hood fan is on, the supply air flows in through the natural exhaust ducts from bathrooms and toilets. In winter the walls of these (generally masonry) ducts turn cold and it becomes difficult to change the air flow direction even after the fan is turned off.

3. PRINCIPLES OF AIRTIGHTNESS AND VENTILATION REQUIREMENTS

3.1 Existing regulations and guidelines for ventilation

Part "D2" (ventilation requirements and guidelines) of the Finnish Building Code, was published in 1978. /2/

The most essential part (in practice, i.e. among consultants and inspecting authorities) has been the table giving guidelines for airflows into (and in some cases from) various types of spaces. Parts of that airflow table are presented in table 2 (Residental buldings, offices). Corresponding values are included in e.g. ASHRAE Standard 62-1981 and British Standard BS 5720:1979.

It is also stated that an assumed infiltration of 0,1 or 0,2 ac/h can be included in minimum outdoor airflows. This detail has been widely criticised: in new airtight residential buildings the exhaust air ventilation is very often adjusted to give a mechanical ventilation rate of merely 0,3 ac/h.

TABLE 2

Recommended supply and return air volumes in different areas (According to the National Building Code)

Area	Ventilation quantities	Remarks
DWELLINGS		The units are $dm^3/s(m^3/h)$, if not otherwise stated
kitchen kitchenettes mini-kitchens	22(79)	12(43) is sufficient, if ventilation can be rendered more effective during food preparation or if the total ventilation rate in a small dwelling exceeds 1.5 air change per hour.
utility rooms	12(43)	
bathrooms	16(58)	8(29) is sufficient, if venting is possible through an easily openable window or ventilation can be rendered more effective after bathing.
toilets	8(29)	2(14) is sufficient, if ventilation can be rendered more effective after use. Toilet must be subjected to less pressure than the adjacent areas.
walk-in cupboards(>1 m^2	3(11)	An easily openable window or sash window replaces ventilation
OFFICE BUILDINGS		The units are dm^3/sm^2, if not stated otherwise
office rooms		
- smoking	1,6(5,8)	
- non-smoking	0,8(2,9)	
toilets	16(58)	$dm^3/s(m^3/h)$ per seat
conference rooms		
- smoking	10(36)	
- non-smoking	5(18)	
corridors and hallways.	0,8(2,9)	
storage areas and archives.	0,33(1,25)	
areas for the storage of cleaning equipment and materials.	3(11)	
common areas for smoking	16(58)	

3.2 Revising the requirements

A proposal for revised ventilation requirements have been worked on since September 1983. The purpose has been to develop requirements based on the best knowledge of today concerning principles rather than means.

Because the proposal is still being prepared for the Ministry of the Environment, no details can be published yet. The general contents are:

- definitions
- indoor climate
- principles for ventilation
- design, construction, commissioning
- operation and maintenance

Existing foreign standards are applied as reference material, e.g. ASHRAE 62-1981, BS 5920:1979 and the Nordic guidelines NKB 40(1981).

In the "Principles of Ventilation", a controlled supply air intake will probaly be required in buildings without mechanical supply air ventilation. Some guiding values for pressure conditions may be also given. Airtightness, as a structural property, is not determined in the ventilation requirements, and no numerical values would yet be stated for air infiltration, which in fact is a complicated result of structural and ventilation parameters.

3.3 Draft proposal for airtightness requirements

This preliminary proposal is reported in ref. /3/. It is mainly based on air quality and thermal comfort criteria rather than on energy aspects.

Entire buildings: a certain maximum air change is allowed to be verified in the building inspection with a pressure test. The main purpose is to secure the owner a certain quality of workmanship.

Parts of buildings: a certain airtightness should be achieved between flats etc. Numerous cases of leakage between flats, floors etc. via e.g. penetration and cracks have been reported lately -complaints about neighbours' tobacco smoke or cooking fumes are common.

Building elements: as in most countries airtightness standards are given for windows, in Finland as well. If the required airtightness is achieved, air leakages through the structures will remain a minor problem compared to those through structural joints.

Joints between structures: for comfort, cold leakage flows should be rather strictly limited. A suggested value will be about 0,2 litres per second and a meter of crack width. The airtightness of certain joints should be measured at the owner's request (see point 4.2).

Supply air intake: because of the reasons stated previously, this belongs to ventilation requirements in which it will probably be included (see 3.2). Recommended airflow -pressure difference characteristics shall, however, be included in the development of design guides and product standards.

The future development of airtightness standards - official and unofficial - is still an open question, because even moderate values raise a certain opposition.

4. MEASUREMENT METHODS

Measurements are necessary to verify the function of the ventilating system, including the tightness of the building envelope. In fact, infiltration itself is difficult to measure but the operating efficiency of the ventilating system can be measured with tracer gas methods.

4.1 Measurement of airtightness using the existing ventilation system for pressurization

There has been a lack of suitable methods for measuring the airtightness of large high-rise buildings. A new version of the pressure method has been developed in which the building's own mechanical ventilating system creates a suitable underpressure inside. In high-rise buildings, this method has proved successful.

Airflows in each supply or exhaust terminal device and pressure difference between outdoors and indoors as well as between apartments and stairwells are measured. Generally, the measuring procedure is quick and easy. The accuracy of the method is not high but adequate for practical purposes. It shows whether the building envelope is airtight enough (pressure differences high, 30 - 100 Pa, small deviation) or too leaky (difficult to create a measurable pressure difference). Simultaneously, the test can show whether the ventilating system is properly adjusted or not.

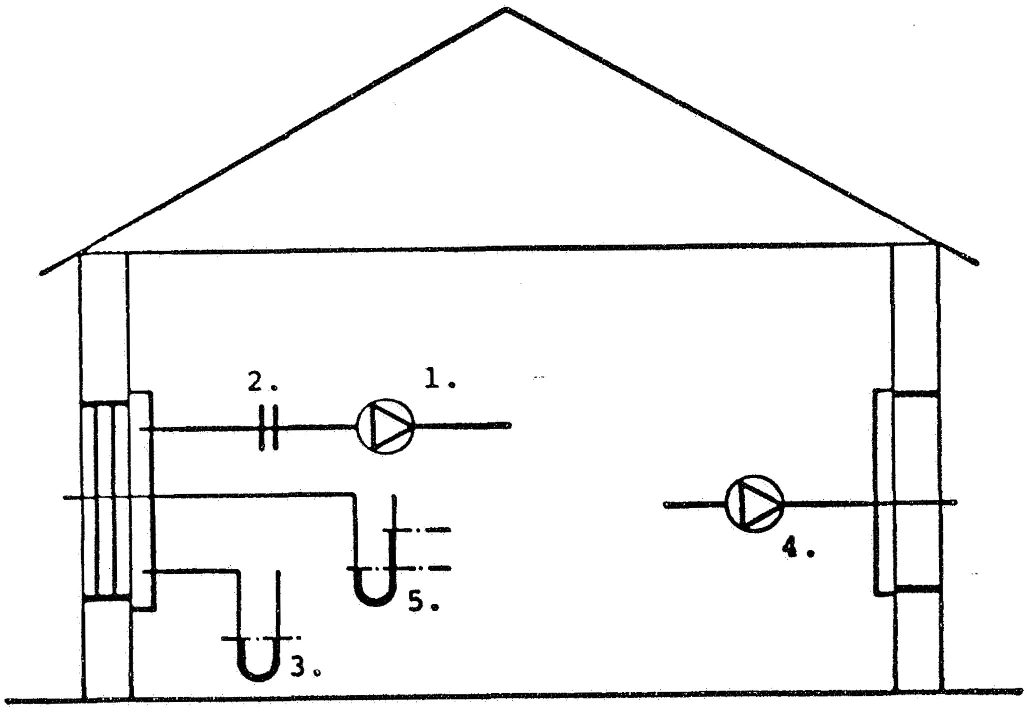
4.2 A statistical procedure in measuring local airtightness

Figure 1 indicates the equipment for measuring local air leakages by the collector chamber method /4/. The method is used for field measurements and it is the only way to get quantitative information about infiltration through structures,and especially structural joints. The method is highly accurate if the outdoor conditions are steady during the measurements. It is almost impossible to obtain the same pressure in the chamber and in the room if the wind is fluctuating.

The collector chamber method has been successfully utilized for quality control testing in actual buildings. This procedure was found necessary for testing the results of an experimental window sealing project ordered by the National Board of Public Buildings. Thirty-three similar openable double-paned windows were chosen for test objects. Nine window-sealing companies were then given the opportunity to show the quality of their workmanship by re-sealing a few windows each. High deviations in the airtightness were observed both between various test groups and within each group.

Because of the high number of structural joints in a high-rise building, it has been necessary for practical purposes, such as inspecting, to develop a statistical analysis for evaluating the local leakages (or the quality of workmanship in structural joints) with a minimum of measurements, see table 3. The measuring procedure is likely to remain very slow, and the practical applications of the method may be limited to case of complaint or for testing rooms in which an almost absolute airtightness is required. Even so, the existence of the method is important for the user of the building.

FIG. 1



Measurements of the total air leakage of a window with collector chamber method

1. Adjusted fan
2. Air flow meter (orifice plate)
3. Pressure difference between collector chamber and indoor air (eletric manometer)
4. Auxiliary fan (adjustable)
5. Pressure difference across the structure

TABLE 3

Sampling plan for inspection of local tightness in building /4/

lot size N	sample size n
$\leq$ 15	3
16 - 25	4
26 - 50	5
51 - 90	7
91 - 150	10
151 - 280	15
281 - 400	20
401 - 500	25
501 - 1200	35
1201 - 3200	50
3201 - 10000	75

This statistical analysis has been applied also in estimating the airtightness of a new public building.

The building consisted of about 1000 office rooms; of these were about 70 chosen at random for measurements. The measurements were carried out in about three man-days (incl. preparations), the fans were run at both full capacity - giving about 1 ac/h at 150 Pa pressure difference - and half capacity, when the actual leakage factor at 50 Pa was about 0,5 ac/h, with only minor deviations between individual rooms.

5. DEVELOPMENT IN CONTROLLED SUPPLY AIR INTAKE THROUGH THE BUILDING ENVELOPE

To avoid the problems of uncontrolled air supply, there have been many efforts to develop systems and devices to control the supply air intake through the building envelope, both for new and existing buildings. The problems can be solved easily in new construction as various devices can be installed in walls, etc. In existing buildings, the installation of new equipment in the walls can usually be done only as part of a major retrofit project. One such possibility is to replace the windows with a better quality product.

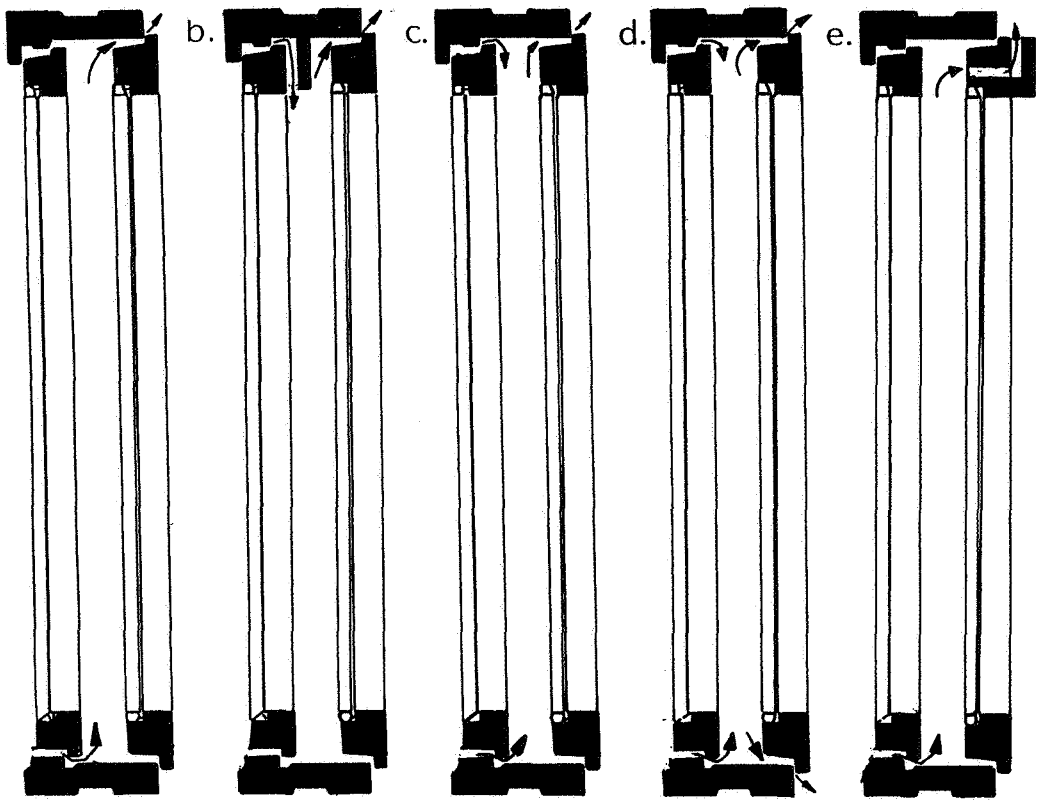
Supply Air Windows /5/. Among the several alternatives for the intake of outdoor air to a ventilated space is the supply air window which provides a designed path for the airflow. The window itself may be double or triple pane casement type window with various weatherstripping possibilities. The air may be taken in through the airspace between the window panes or through designed holes in the sash. Airflow through the window has in principle an opposite direction to the heatflow and the incoming air is heated by that heatflow in transmission at the window. This phenomenon is known in heat transfer text books as flow in porous material. The amount of heat transfer depends on the pattern of flow. The overall effect is an improvement in the energy balance of the indoor space. If the heat transfer from the room to the window is increased, that heatflow is used to warm up the incoming (ventilation) air and the heatflow from the exterior pane of the window is decreased.

The critical parameter in the operation of a supply air window is the pressure difference at the window. It should be high enough to decrease the effects of the wind and outdoor temperature on the ventilation and low enough not to cause difficulties in the operation of doors and windows. The optimum pressure difference determined through practical experience seems to be 10 - 20 Pa. Another important parameter is the airflow through the window. It affects all the properties of the window. Airflow through the window is critical because of the thermal conditions in the indoor space. The main concern in practice is to find the maximum airflow through the window that does not cause thermal discomfort to the occupants. The most critical thermal comfort parameter is the draught. Laboratory tests has been made to find out the influences of the supply air window on thermal comfort. Previously, laboratory tests were carried out also to find temperature conditions, overall heat transfer coefficients and condensation risks for various types of supply air windows.

On the basis of these tests it seems that the most efficient airflow pattern is the one with outdoor air flowing to the window space through the bottom edge of the outer pane and to the rooms from the upper edge of the inner pane. The surface temperature of the inner pane is important in respect of condensation and thermal comfort. Reduced surface temperature is a drawback of the supply air window system.

The supply air windows, as described above must be considered as a "not good but much better than nothing" -solution. Its properties in use cannot be controlled as those of the supply air devices especially designed for the intake and diffucion of outdoor air. Such devices can, of course, be integrated into a window element, as shown in fig. 2.

FIG. 2



Various types of air flow arrangements for a supply air window. Alternative e represents a more controlled air diffusion arrangement .

6. INFORMATION FOR OCCUPANTS AND MAINTENANCE PERSONNEL IS ALSO NECESSARY

Standards for infiltration and airtightness, as well as for ventilation, will remain too theoretical if they are only controlled randomly and in new buildings only. Unfortunately, in Finland (and probably also in many other countries) many problems are caused by incorrect operation and maintenance of structures and HVAC systems.

Keeping structures and building services in good condition is often assumed to be unnecessary and expensive. People forget that the building must some day be totally renovated. High renovation costs are generally related to poor maintenance.

Concerning the airtightness, it is easy to find out if complaints about draught have increased; the condition of windows and window sealing can be seen with bare eyes. The maintenance must, of course, be done by skilled operators, especially in ventilation, but with a proper schedule many unnecessary repair costs can be avoided.

User information and training, including service instructions in product information are means for improving the quality of maintenance. The quality of information is continuously being developed in Finland.

For an ordinary inhabitant (=for everyone) we must point out the following:

- kitchen terminal devices, and kitchen hood filters should be cleaned according to the instructions. Request instructions if you do not have any.
- avoid unnecessary airing in wintertime. You are of course allowed to open your window - but please keep it open for a few minutes only at a time.
- report on difficulties in opening/closing windows
- report on problems with the ventilation system

7. CONCLUSIONS

Standards for airtightness and/or air infiltration will have a great importance in securing a good building practice. But they alone are not enough, because ventilation is also necessary. Good standards or regulations should thus be a combination of

- requirements for airtightness for the whole building envelope (excl. ventilation arrangements) for building details and structural joints
- requirements for sufficient and controlled ventilation, both supply and exhaust
- guidelines for airtightness, infiltration and ventilation measurements (in building inspection etc.)
- instructions for use and maintenance

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