MEASURING VENTILATION AND AIR INFILTRATION IN BUILDINGS - SWEDEN

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ABSTRACT

"When you can measure what you are talking about and express it in numbers you know something about it"
Lord Kelvin (1824-1907)

Measuring air flows and tightness of ventilation ductwork is compulsory in Sweden but not measuring air infiltration or building tightness which normally is done only in some research projects. Instead building tightness is regarded to be covered by compulsory construction guidelines. Tightness of a buildings envelope (external walls, roof and floor) is required for two reasons: to reduce dampness problems and to reduce the use of heating energy of the building. This aim and direction of the Swedish building authorities today is different from earlier codes as shown below.

During the 1980's several studies reported health problems from emissions in badly ventilated dwellings. This resulted in in a new Swedish law requiring compulsory inspection of ventilation systems – the **OVK** commissioning system that is described shortly in the paper.

The quality of ventilation systems in Sweden is also governed by another unique scheme – **AMA** - General Material and Workmanship Specifications. It has been in use since 1950 and is a tool for the customer to specify his demands on a new building and its installations. AMA contains e.g. requirements for tightness tests of ventilation ductwork, methods for measuring and adjusting airflows shortly described in the paper.

KEYWORDS

AMA, OVK, SBN, BBR, Ductwork tightness, Infiltration

SWEDISH REQUIREMENTS FOR AIR FLOWS AND INFILTRATION

Measuring air flows and tightness of ventilation ductwork is compulsory in Sweden but not measuring air infiltration or building tightness which normally is done only in some research projects. Instead building tightness is regarded to be covered by compulsory construction guidelines. Tightness of a buildings envelope (external walls, roof and floor) is required for two reasons: to reduce dampness problems and to reduce the use of heating energy of the building. This aim and direction of the Swedish building authorities today is different from earlier codes as shown below.

The quality of ventilation systems in Sweden is also governed by another unique scheme – **AMA** - General Material and Workmanship Specifications. It has been in use since 1950 and is a tool for the customer to specify his demands on a new building and its installations. AMA contains e.g. requirements for tightness tests of ventilation ductwork, methods for measuring and adjusting airflows shortly described in the paper.

Defective and badly maintained ventilation systems and insufficient airflows were found in studies during the 1980's to be main reasons for sick buildings. This resulted in a new Swedish law 1991 requiring compulsory inspection of ventilation systems – the **OVK** commissioning system – with aim to control and improve the function of ventilation installations. The ordinance requires that the ventilation in most types of buildings has to be controlled before the installations are taken into operation and then regularly at recurrent inspections.

The first global oil crises 1972-73 with rapidly increasing energy prices often led to a change of systems from oil-based to electric heating and from natural ventilation to mechanical extract in a vast majority of residential buildings in Sweden. As a follow-up the Swedish authorities raised the demands on thermal insulation and tightness for new buildings in order to reduce the oil import.

Swedish building codes for ventilation changed from detailed to functional demands

The Swedish building codes have changed from detailed requirements of e.g. building tightness and airflows for different types of buildings and premises to functional demands.

This change came gradually from 1988 when the (detailed) regulations, recommendations and directions in the Swedish Building Code, **SBN**, published by the earlier authority, Statens planverk (The National Board of Physical Planning and Building) was replaced by the mandatory provisions and general recommendations in Building Regulations (**BBR**) from the new authority Boverket (The Swedish National Board of Housing, Building and Planning) where the provisions are in the form of functional requirements, referring to standards when applicable.

In Sweden residential buildings are required to provide an acceptable air quality. The Swedish national environmental legislation states that: “In the year 2020 all buildings shall be healthy and have a good indoor environment”.
One of the intermediate goals within the frame of good indoor climate is that: “All buildings where people stay often or during a longer time shall 2015 at the latest have been proven to have a functioning ventilation system”.

MEASURING VENTILATION AS REQUIRED IN SWEDISH BUILDING CODES

The airflows to be measured have changed during the years

The reason for requiring correct airflows in ventilation systems has varied during the past years. During the 1930’s up till the oil crisis 1973/74 the main demand was to supply enough air to dilute the pollutants produced by the people in the premises – the dimensioning rules were based on the work done by Yaglou during the 1930’s and formed the basis for authority demands for general ventilation in new buildings. Energy was cheap and there was no special reason to economize with air.

The oil crisis changed this – drastically increasing prices and shortage of oil lead to reduced airflows. The old Swedish building code was replaced by SBN with special and detailed demands for maximum supply and exhaust airflows for different buildings, premises and production facilities.

With the new code, **BBR**, these demands were changed from detailed into functional demands.

Airflows – functional requirements in BBR

<u>6:21 General</u>
Buildings and their installations shall be designed to ensure they can provide the conditions for good air quality in rooms where people are present other than occasionally. The requirements for indoor air quality shall be determined on the basis of the room's intended use. The air must not contain pollutants in a concentration resulting in negative health effects or unpleasant odours.

<u>6:25 Ventilation</u>
Ventilation systems shall be designed to ensure the required outdoor air flow can be supplied to the building. They shall also be able to carry off hazardous substances, moisture, annoying odours and emissions from people and emissions from building materials, as well as pollutants from activities in the building.
General recommendation
When designing ventilation flows in buildings, the environmental impact aspects of occupants, activities, added moisture, and emissions from materials, ground and water should be considered.
The installations should be designed in such a way that calibration, testing, inspection, supervision, servicing and exchange can be easily effected and adequate efficiency maintained.

<u>6:251 Ventilation flow</u>
Ventilation systems shall be designed for a minimum outdoor air flow corresponding to 0.35 l/s per m^2 floor area. When in use, rooms shall be able to have a continuous air exchange.
In residential buildings where the ventilation can be controlled separately for each dwelling, the ventilation system is allowed to be designed with presence and demand control systems. However, the flow of outdoor air

must not be lower than 0.10 l/s per m^2 of floor area when the dwelling is unoccupied and 0.35 l/s per m^2 of floor area when the dwelling is occupied.
General recommendation
The requirements for ventilation flow should be verified by calculation and measurement.
When designing outdoor air flow, account should be taken of the fact that the flow could be reduced due to dirt in ventilation ducts, changes in differential pressure over filters, etc.
For buildings other than residential buildings, the ventilation system may be designed so that a reduction of supply airflow, in multiple stages, continuously, or by intermittent operation, is possible when the building is unoccupied.
General recommendation
After a period of reduced air flow, normal air flow should be provided at least for a period of such length as is required to achieve a complete exchange of the volume of air in the room before it is reused.
The reduction of the ventilation air flow is not allowed to cause adverse health effects. Nor shall the reduction be allowed to bring about damage to the building or its installations due to moisture etc.

<u>6:254 Installations</u>
Ventilation installations shall be situated and designed in such a way that they are accessible for maintenance and cleaning purposes. Main and connect ducts shall have stationary measure outlets for flow measuring.
General recommendation
For the appropriate design of duct systems and cleaning hatches, see SS-EN 12097.

<u>6:255 Airtightness</u>
Pressure conditions between supply air and extract air installations shall be adapted to the airtightness of the installation, to ensure that transfer of extract air to the supply air does not occur.
General recommendation
To prevent pollutants from returning through heat exchangers where air can shift from the extract air side to the supply air side, the pressure level should be higher on the supply air side than on the extract air side.
The building envelope should have adequate airtightness in relation to the selected ventilation system to ensure good functionality and for adjusting airflow in individual rooms. The airtightness of the building envelope should also be ensured with regard to the risk of damage due to moisture. Rules on airtightness of a building's envelope are contained in Section 6:531.
Measurements of leakage in sheet metal ducts can be made in accordance with SS-EN 12237. Additional information on airtightness testing of ventilation ducts are contained in Formas publication Metoder för mätning av luftflöden i ventilationsinstallationer (Methods for measuring air flow in ventilation installations) (T9:2007) and instructions in **AMA** VVS & Kyl 09 and SS-EN 15727.

<u>Summary of Swedish ventilation requirements</u>: Functional requirements providing conditions for good air quality should be verified by calculation and measurement. The installations should be designed in such a way that calibration, testing, inspection, supervision, servicing and exchange can be easily effected and adequate efficiency maintained. Airflow and ductwork tightness measurement, and accepted methods, as stated in **AMA.**

AIR INFILTRATION IN BUILDINGS

Air Infiltration – detailed requirements in SBN

In the last edition, **SBN** 1980 edition 2, maximum air infiltration in buildings were stated as maximum accepted air leakage (in m^3/m^2,h) for different building types: "For premises intended (designed) to be heated above +10°C a maximum air leakage as stated in column 33:3 (see below) is accepted".

Table 1 (SBN 33:3) - Maximum accepted air leakage (in m^3/m^2,h)

Building part	Pressure difference Pa	Building with height in floors		
		1 - 2	3 – 8	>8
Exterior wall	50	0.4	0.2	0.2
Exterior window and door (referring to the tightness of the chink between the frame and the window sash and door leaf respectively	50	0.4	0.2	0.2
	50	1.7	1.7	1.7
	300	5.6	5.6	5.6
Roof and floor towards the outside or towards a ventilated space	50	0-2	0.1	0.1

During the late 1970's a majority of the existing buildings were tightened to reduce the need for heating energy (the easiest way to do this was to tighten leaking window frames). This however often led to critically reduced air flows in buildings with natural supply and exhaust (S-system). In buildings with natural supply and mechanical exhaust (F-system) the increased under pressure in the rooms often resulted in noise problems.

Building tightness, when measured, is controlled with blower door but only for smaller buildings, type one-family houses and not for e.g. office buildings. The author has been involved in tightness tests of two large buildings where the supply air fans were used for pressurizing the buildings : (1): the R2 Reactor Hall at Studsvik where the large reactor hall for safety reasons was pressure and tightness tested at 1000 Pa!; and (2): the Fries office building at Växiö which was constructed to obtain a high degree of tightness, the windows were e.g. mounted in projecting frames being part of the concrete exterior walls (covered on the outside with mineral wool and grouted brick).

Air Infiltration – functional requirements in BBR

In **BBR** maximum air infiltration in buildings have been replaced by functional requirements, referring to reducing the risk for damage due to damp in the building structure (6:95) or to reduce the maximum use of energy for buildings (9:21 – dwellings; 9:31 – premises):

6:255 Airtightness
Pressure conditions between supply air and extract air installations shall be adapted to the airtightness of the installation, to ensure that transfer of extract air to the supply air does not occur.
General recommendation
To prevent pollutants from returning through heat exchangers where air can shift from the extract air side to the supply air side, the pressure level should be higher on the supply air side than on the extract air side.
The building envelope should have adequate airtightness in relation to the selected ventilation system to ensure good functionality and for adjusting airflow in individual rooms. The airtightness of the building envelope should also be ensured with regard to the risk of damage due to moisture. Rules on airtightness of a building's envelope are contained in Section 6:531.
Measurements of leakage in sheet metal ducts can be made in accordance with SS-EN 12237. Additional information on airtightness testing of ventilation ducts are contained in Formas publication T9:2007, see above, and instructions in AMA VVS & Kyl 09 and SS-EN 15727.

6:531 Airtightness
General recommendation
To prevent damage due to convection of moisture, the parts of the building that separate spaces with different climatic conditions should have as high airtightness as possible. In most buildings, the risk of convection of moisture is greatest in the building's upper parts, i.e. where internal excess pressure may be prevalent.
Particular care should be taken to ensure airtightness where the environmental impact of moisture is great such as in public baths or where temperature differences are particularly great.
Airtightness can affect the moisture level, thermal comfort, ventilation and a building's heat loss.
A method for determining air leakage is contained in SS-EN 13829. When determining air leakage, it should also be investigated whether the air leakage is concentrated to a particular structural element. If this is the case, there is a risk of moisture damage.

6:95 Damp
Buildings should be designed so that moisture does not cause damages, bad smell or hygienic nuisances or microbial growth that can affect the health of people.

The air tightness of a building shall be such that convection of moist air does not lead to that the highest accepted moisture pickup of the material is exceeded.

9:21 and 9:31 Building envelope tightness with reference to energy use
The building envelope shall be so air tight that the requirements on specific energy use of the building and installed electric power for heating purposes are fulfilled.

9:4 Alternative requirements on the energy use of the building
As an alternative to the requirements for buildings given in Clauses 9:2 and 9:3,
where
- the floor area A_{temp} does not exceed 100 m^2,
- the window and door area A_f does not exceed 0.20 A_{temp} and
- there is no requirement for cooling,
the following requirements relating to the thermal insulation of the building, the
airtightness of the building envelope and heat recovery may be applied.
…

The building envelope shall be of sufficient tightness to ensure that the average air leakage rate at a pressure difference of ± 50 Pa does not exceed 0.61 l/s m2. In relation to this, the area A_{om} shall be applied. *(BFS 2006:12)*
General recommendation
A method for determining air leakage rate is given in SS-EN 13 829. *(BFS 2006:12)*

A common question put to Boverket: "Why are there no quantified demand values stated for the building envelope tightness in chapters 9:21 and 9:31?" was answered as follows:
"There is an all-embracing functional demand on the energy use of the building. This demand can be fulfilled in many ways, e.g. with more or less heat insulation, different technical installations and a more or less airtight building envelope.

The building envelope needs to be so tight that the building can fulfil the energy use requirements for the whole building. Other relevant all-embracing demands to be fulfilled are installed electric power, ventilation, thermal comfort, moisture safety and noise. How tight the building envelope has to be is therefore something that has to be decided from case to case by the building proprietor/designer depending on the choice of ventilation systems, energy management solutions etc."

<u>Summary of Swedish air infiltration requirements</u>: Today there are no Swedish quantified building airtightness requirements except for small buildings (<100 m^2 A_{temp}).

MEASURING VENTILATION AS REQUIRED IN AMA

Practically all buildings and their installations in Sweden are performed according to the quality requirements in **AMA** specification guidelines (General Material and Workmanship Specifications). The AMA requirements are made valid when they are referred to in the contract between the owner and the contractor.

Starting more than 60 years back in time we have been using this probably quite unique quality assurance system in Sweden covering all aspects of building and installation technologies.

But requirements and demands can be worthless unless they are controlled. The AMA requirements thus also include demands for tightness testing of the ductwork and adjusting airflows in the building. The results of prescribed measurements have to be reported to the proprietor on standard protocol forms signed by the testing contractor.

AMA is a voluntary complementary to statutory rules, regulations and specified building standards laid down by the authorities. The statutory rules, e.g. in BBR, are normally mostly focussed on reducing the risk of injuries while AMA (not having to deal with that) is focussed on reducing damages and LCC-costs. Common interest areas for both are sustainability and low energy use.

Two of the AMA rules are relevant for measuring airflow and ductwork tightness: "Express your requirements in measurable terms and control that you have got it!" and the other: "The costs and risks for the contractor to fulfil the requirements in the contract should be possible to calculate".

<u>YTC.157 – Control of air handling systems</u>
Functions specified in the contract documents shall be controlled.
Before the control is made the control responsible shall make sure that the parts of other contracts that can have influence on the control are performed.

<u>Measurement uncertainty</u>
Extended measurement uncertainty is calculated as:

$$U = \sqrt{U_1^2 + U_2^2 + U_3^2 + \dots}$$

Where
U_1 = the extended measurement uncertainty of the measuring instrument, percent
U_2 = the extended measurement uncertainty of the measuring method, percent
U_3 = probable extended uncertainty when reading off the instrument, percent
In literature occurring term ***m***, probable measurement error is here the same thing as standard measurement uncertainty.

Values for these uncertainties are given in the report T9:2007 presented above and referred to in both BBR and AMA. Values are given for normally used measurement methods and instruments such as:
(Extract)
Methods for measuring in duct
Prandtlrör in duct with circular and rectangular cross section (Methods A11 and A12)
Fixed flow measurement (Methods A21 – A29)
Measuring airflow with tracer gas (Method A3)
Methods for measuring extract registers and air intake grilles
Hot-wire anemometer on rectangular grilles with the 4-point method (Method B1)
Pressure drop measurement with probe (Method B21)
Pressure drop measurement with fixed measuring connection (Method B22)

Tightness control of duct systems
Leak airflow shall primarily be measured at 400 Pa test pressure but can be measured at another pressure if found suitable due to control device and controlled surface area. The pressure shall not be lower than 200 Pa and not higher than 1 kPa. Duct with a larger circumference than 6.4 m shall however be controlled at 200 Pa.

The sum of measured leak airflow and measurement error shall not exceed the value for prescribed tightness class.

Leak airflow shall be measured with recommended method in Formas report T9:2007(see above), Metoder för mätning av luftflöden i ventilationsinstallationer (Method for measuring airflows in ventilation installations). Tightness control shall be made as spot test, each with approx. 25 m^2 duct exterior perimeter area. Controlled duct area shall for each test be at least 10 m^2 . Tightness control shall be made with either over- or under-pressure depending on the operation pressure.

Tightness control of type approved duct systems for prescribed tightness class shall be controlled in following manner: circular spiral wounded ducts shall be controlled to 10 percent of the total duct exterior perimeter area; other ducts to 20 percent.

If the prescribed tightness requirement is not fulfilled the control shall be extended to another duct part with the same percentage. If the requirement neither is fulfilled at this control, the control shall be extended to comprise all the ducts.
Tightness control of other types of ductwork shall comprise 100 percent of the total duct exterior perimeter area. The proprietor shall in each case give instructions on which ducts and units that shall be controlled. Tightness control shall be documented on AMA form YTC/5.

YTC.257 – Airflow measuring of adjustment in ventilation systems
(Extract)
Measuring of system total airflow shall be made at a filter pressure drop corresponding to the final filter pressure drop in system with pressure controlled fans. Other systems shall be flow adjusted with clean filters with correction for a flow increase of 3 percent.
Adjusting systems with more than one operation case shall be made at one of the operation cases and measured at both max and min airflow
Airflow measurement shall be made with recommended method in Formas report T9:2007(see above)
Measurement shall be made and reported in such a way that a new measurement is possible and should give the same result if the conditions are the same, e.g. at recurrent OVK inspections.

System types F (exhaust), FT (supply and exhaust) and FTX (supply and exhaust with heat recovery) shall be adjusted with closed doors and windows.

Adjustment of airflows
Adjustment of airflows shall be made to achieve the values given in the building documents.

Alternative 1. Proportionality method
The adjustment shall be made with a systematic step-by-step-method with successive measurements and adjustments of throttling device (dampers) in accordance with the working procedure described in Building Research Council’s report Injustering av luftflöden i ventilationsinstallationer, T12:1981 (Adjustment of airflows in ventilation installations).
If the contract documents do not indicate reference register and index register they shall be decided at the adjustment.

Alternative 2. Pre-set value method
The adjustment shall be made by adjusting registers and dampers according to the pressure drop calculation. Airflow measurements shall be made for control. Consideration shall be taken to thermal influence power (stack effect).

Records
Records over adjustment and airflow control shall be presented after adjustment and following control has been made. Instructions for accounting are given under YTC.157.

MEASUREMENT COSTS

Measurements and control of the ventilation systems before the building is taken into operation and then regularly at recurrent inspections in the future are necessary to guarantee that the building and its installations are working properly.
Compared to the initial cost for the building and its installations the costs for control and maintenance are negligible. REHVA Guidebook No. 06, Indoor Climate and Productivity in Offices, shows how to quantify the effects of indoor environment on office work and also how to include these effects in the calculation of building costs. Such calculations have not been performed previously, because very little data has been available. The quantitative relationships presented in the guidebook can be used to calculate the costs and benefits of running and operating the building.
The cost for obtaining and controlling ventilation system tightness for the specified tightness class (A – D) in the HVAC specification (referring to the requirements in the Swedish HVAC AMA) is included in tender price given by the contractor.
There are no values available for the specific cost for obtaining and controlling building tightness.
For ventilation ductwork it is necessary to require high quality ductwork, units and components that have a known tightness are adapted to each other to form a system with the required tightness. During commissioning the actual tightness should be measured by skilled personnel (if not totally, in parts of the total installation chosen by the building proprietor) and reported in prescribed forms.
Building tightness should primarily be obtained by choosing suitable window/wall construction, using plastic foil with long-time durability and checking that it is not perforated by e.g. electric installations.

OVK – COMPULSORY INSPECTION OF VENTILATION SYSTEMS

Many Swedish and Nordic studies during the 1980's showed that defective and badly maintained ventilation systems and insufficient airflows was a main reason for sick buildings.

This resulted in a new Swedish law 1991 requiring compulsory inspection of ventilation systems – the OVK commissioning system – with aim to control and improve the function of ventilation installations. The ordinance requires that the ventilation in most types of buildings has to be controlled before the installations are taken into operation and then regularly at recurrent inspections.

Table 2 - OVK inspection intervals for different buildings and ventilation systems

Type of building and ventilation system	Inspection intervals
Day nurseries, schools and hospitals	3 years
Block of flats and offices with FT-ventilation	3 years
Block of flats and offices with F-ventilation	6 years
Block of flats and offices with S-ventilation	6 years
One and two dwelling-houses with FT-ventilation	only first inspection (new buildings)

Boverket is responsible for this control system and for nation-wide authorization of the inspectors while local authorities control the observance of the law locally and report the result to Boverket.
The inspector records the inspection. The result of the OVK inspection, the certificate, is given to the owner with a copy sent to the local authority. A copy of the certificate shall be posted in full view in the building by the owner, e.g. at the building entrance or staircase.

CONCLUSIONS

Back to the citation on the first page: “When you can measure what you are talking about and express it in numbers you know something about it”.

You have to know what you are aiming at and express it in measurable units, be willing to pay the cost to arrive there and control that you have got what you have paid for. For this you need to use measurement methods with low measurement uncertainties.

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