Malmö Real Estate Research Conference 2021 - May 6th-7th, 2021

Title:

Ventilation in Sweden – state of the art

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Abstract

The National Board of Housing, Building and Planning (Boverket) has initialized a compilation of knowledge about the current situation in Swedish ventilation. The purpose being to summarize an as broad and correct understanding as possible of who the industry is, what rules that applies, where there are knowledge centres and what development needs are required to be supported for the industry. Ventilation systems has developed from simple to high-tech sensor-controlled with the main task of removing unwanted airborne substances (e.g. odours) and excess heat, in an energy efficient way.

Data was collected from stakeholders dealing with ventilation and indoor climate. A group of knowledgably consultants and scientists have collected information, analysed different aspects of ventilation, and presents the results in a report available in Swedish.

Ventilation situation in residential buildings varies from other types of buildings that house widely differing businesses. Different types of activities place different demands on the buildings' air quality, thermal comfort, etc. For the operation of a building, it is important to clarify the conditions and requirements that determine needed airflow. Quite small, oversights and mistakes can ruin the possibilities for the ventilation system's to function properly.

The main outcome of the project is the presentation of the state-of-the-art position of ventilation in Sweden. Ventilation is a vital part of the building's system and the prerequisites for correct ventilation function. Seemingly, banal user behaviours can have a major impact on the control of the indoor climate.

Regulations and rules that govern and apply for ventilation and indoor climate comes from a number of international, national organisations. More than ten Swedish authorities define regulations influencing ventilation. This affects how measurement and verification of indoor climate and ventilation can take place with different methods and instruments depending on which properties are studied.

The survey contributes to the dissemination of knowledge about the industry, stakeholders, technology, systems, construction, controls, operation and maintenance as well as research and development.

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1 Introduction

Good indoor air quality is an important health factor. This applies in all types of buildings with different needs for air exchange. Over the years, ventilation has evolved from natural ventilation to high-tech, sensor-controlled mechanical systems with the main task of removing unwanted airborne substances (e.g. odours) and excess heat. The first ventilation systems were installed to ventilate and heat rooms, according to the thermal principle that warm air rises upwards, creating a suppression that sucks in fresh air. Today's mechanical ventilation systems are high-tech and sensor-controlled and important not only for indoor air quality but for energy use in buildings.

In 1992, the Swedish Parliament and government introduced rules and requirements regarding inspection of ventilation systems in public environments. The reason for this was that in many homes, schools, and other premises, there was in many cases insufficient ventilation, which led to poorer indoor environment. This name of this inspection scheme in Sweden is OVK (Mandatory Ventilation Inspection).

In 2020, a Nordic collaboration project launched an investigation of possibilities with regulatory harmonisation in the field of mechanical ventilation. A first part of this work is to compile Swedish regulations and knowledge regarding ventilation. In 2020, work also started to develop the building regulations for ventilation. In the new forthcoming regulations, the "industry" will have a clearer responsibility and the Swedish National Board of Housing, Building and Planning's rules will be designed as more straight-forward functional requirements with less detailed control.

The knowledge compilation should give a clearer picture of which regulations govern and are applicable operators/stakeholders involved in the design, installation, and inspection and testing of ventilation systems in various ways; literature, industry standards, and regulations for the ventilation sector; training in the ventilation sector.

The full report (Ekberg, Hjelmer, Kempe, Ruud & Persson 2021) is available online.

2 Ventilation – part of the building as a system

Regardless of the type of building, ventilation has the same basic purpose: to provide air exchange so that polluted, moist and warm air is transported out and replaced by cleaner tempered air. Clean and moderately temperate air is added to areas/spaces where people are staying, such as in study rooms, living rooms and bedrooms. The air is distributed to the areas/rooms that produce the most moisture and odours such as toilets, kitchens, or spaces where the requirements for the quality of the air are not very high, such as storage rooms or other rooms that are used infrequently and then only briefly. Then the air is transported out again. The intention is that air is supplied and removed via designated openings (outdoor air vents or supply air diffusers and exhaust air diffusers and cooker hoods, etc.).

2.1 Proper airflow

The current regulations can be summarised very briefly by the fact that dwellings should have an outdoor airflow of at least 0.35 l/s per m^2 floor area. Commercial buildings should be ventilated at least with additional 7 l/s per person. These figures refer to the size of the so-called hygiene airflow, i.e. the minimum airflow required to remove disruptive substances from indoor air. In buildings with high level of pollution generation or where ventilation is also used for comfort cooling, significantly higher airflows may be needed.

In the 1990s, attempts were made to determine the required airflow, taking into account the emission from the sources of air pollution present in a building (building materials, furnishings, people, chemicals, external exhaust gases, etc.). However, this approach proved to be not working in practice, for a number of reasons. On the one hand, the generated pollutants have very different effects on human comfort (perceived air quality), and on the other hand, the relationship between concentration and experience is reasonably well known only in exceptional cases. In addition, data on the source strength of most of the different sources of pollution are missing.

Today, the way of working to determine the required hygiene flow for general ventilation is instead standardized. The principle normally applied is that the choice of building and interior materials is quality assured in order to limit indoor pollution generation. Furthermore, if the pollution generation of the activity is limited, the idea is that the standard airflows referred to in the preceding subparagraph are sufficient from an air hygiene point of view. Whether they will actually be sufficient over time depends on a number of factors, such as user behaviour, indoor moisture generation and possible contamination of the ductwork.

The background to the standard values
In rooms where people dwell, a characteristic "human smell" arises caused by substances emitted by each human being. Pettenkofer (1858) showed that the concentration of carbon dioxide is proportional to the intensity of the human smell. He concluded that a carbon dioxide concentration of about 1,000 ppm constituted a limit for acceptable human smells in populated rooms. This concentration corresponds to an airflow of approximately 8 l/s per person. During the 20th century, several studies have been carried out on this theme and 7 l/s per person has become established as a comfort limit regarding human smell.

In the 1940s, Rydberg and Arnell (1949) conducted measurements in a large number of naturally ventilated homes. The average of the measurements was 0.5 air turnover per hour. At 2.5 m room height, 0.5 air turnover per hour is equal to 0.35 l/s per m^2 floor area. Today's flat-rate value is thus a conversion of a kind of typical value of air exchange in Swedish housing in the 1940s. The value became established as a reasonable basic flow for mechanical ventilation of housing. The current airflow is also an approximate upper limit that should not be significantly exceeded so that the risk of draught does not become unacceptable in rooms ventilated by the supply of untreated (unheated) outdoor air, i.e. for natural and exhaust air ventilation systems

2.2 Ventilation operating times

In dwellings, the ventilation system may be designed so that it is possible to reduce the supply airflow when no one is in the building, but the airflow must never be completely switched off. It is permissible to reduce airflows or intermittent operation of ventilation in commercial buildings as long as there are no health risks or damage to the building and its installations caused by e.g. moisture.

In certain types of commercial buildings, it may be necessary for the ventilation system to be kept in continuous operation even when no operation is in progress; for example, in commercial buildings with processes generating moisture and/or air pollution, which could otherwise be spread through the ductwork to rooms where they are not normally generated, or in buildings with large emissions from building materials. In buildings with a very airtight climate screen, regardless of the size of internal emissions, it may be inappropriate to have completely switched off ventilation. However, in less airtight buildings it can work because they often get a certain basic ventilation via "natural ventilation" depending on wind and thermal drivers.

The issue of limiting the possibilities to periodically reduce or turn off ventilation has been raised in connection with the viral pandemic (Covid-19) that spread in 2020 and is still ongoing in 2021. Research on this issue, and other issues related to the spread of infection indoors, is followed, among other things, by the Nordic Ventilation Group.[1]

2.3 State and quality of supply air

In order to avoid the addition of air pollutants or air at unnecessarily high temperatures to a building, the location and design of outdoor air intakes and intake chambers must be appropriate. Outdoor air intakes should be positioned in such a way as to minimize the impact of exhaust gases and other sources of pollution. This takes into account altitude above ground, direction and distance from traffic, vent openings, aeration of wastewater pipes, cooling towers and chimneys.

The outdoor air usually needs to be filtered, partly to prevent dust collection on surfaces in the air-handling unit. This is especially important when it comes to maintaining high efficiency of heat transfer components, such as heat recyclers. Filters are also needed to reduce the presence of pollen and pollen allergens indoors. In order to protect human health in places exposed to traffic exhaust or other combustion-related pollutants, filters are needed that can distinguish small combustion particles, such as soot from diesel exhaust.

2.4 Efficient ventilation of the entire residence zone

The ventilation system must be designed in such a way that the entire residence zone is ventilated at the intended airflows. In a general advice, BBR (Boverket 2020) refers to measurement, either of air exchange efficiency, or of local ventilation index. In many cases, however, it is sufficient to make an assessment of the design and location of the supply air diffuser and the temperature of the supply air in relation to the temperature of the room air. Normally, the supply air should be a few degrees colder than the room air in order to drop and mix. According to SWESIAQ (2017), the assessment of airflow in a room should primarily be based on an assessment of these factors, preferably together with simple checks with smoke indication.

2.5 The transportation path of air through the building

In practice, air will not always/completely follow the intended route through the building. Air can leak both in and out through the building's climate screen. Air can also leak between different parts of the building, e.g. between the basic construction/basement and living room or between the living room and attic. Through in-leakage, the stay zone can be added contaminants, e.g. in the form of exhaust gases from garages or radon and other contaminants from the basic construction. Through out-leakage, moist room air can be added to cold parts of the building structure, such as a cold attic, where condensation can cause the growth of microorganisms. Air leakage through the climate screen also means that part of the airflow

[1] http://www.scanvac.eu/nvg.html

does not pass through a possible heat recovery in the central air-handling unit, which impairs the energy performance of the building.

The extent of the leakage is affected by pressure differences over the different construction parts of the building. Malfunction of the ventilation system in the form of excessive imbalance between supply airflow and exhaust airflow can create pressure differences that cause disturbing air movements and noise in connection with doorways and contribute to a greater leakage through the construction of the building. The amount of the leakage also depends on how dense the construction is.

3 Ventilation in residential buildings

Ventilation in residential buildings should provide a good indoor climate and be quiet, draught-free, energy efficient and safe. Most often, residential buildings are heavily optimized to obtain as much living area as possible, which means that it can be problematic to find space for the ventilation system's ducts.

Major maintenance on the ventilation system is most often carried out in connection with major renovation of the building. Given that large parts of the duct systems are built into hard-to-reach shafts or poured in, it is important to do things right from the beginning. Otherwise, the owner need to manage the shortcomings for a very long time.

New energy-efficient and airtight residential buildings often have problems with under-pressure or overpressure in the apartments, due to shortcomings with adjustment and measuring of airflows. A better holistic approach is needed for a good function for residential buildings and their installation systems. The better the construction contractor is at building with high air tightness, the greater the challenge the ventilation contractor will have to create good function for e.g. cooker hoods/(cooker fans) (Kempe 2019, Kempe 2016).

When pressure differences occurs between apartments, there is a risk that small airflows go between apartments via electric pipes, network pipes, pipe-in-pipe systems or other leakage routes, which can spread odours between apartments.

Supply and exhaust air diffusers in dwellings need to be cleaned a couple of times every year. This has to be done without changing the setting of the diffusers, as this affects the properties and function of the unit. The ventilation system should be cleaned and checked at least about one year before the mandatory ventilation inspection (OVK). This means that the OVK inspection more accurately describes how the ventilation works between cleaning cycles (OVK inspections). The OVK inspection interval for residential buildings is 3 years for systems with supply air and 6 years system with only exhaust air ventilation.

4 Ventilation of commercial buildings

The facilities sector is highly diversified. Different types of buildings house very different activities. Different types of activities also places different demands on the indoor air quality of buildings, thermal comfort, etc. In addition, different activities can mean quite different loads on the indoor environment, in the form of heat, moisture and pollution.

Normally, different technical solutions can meet the requirements that have been set – provided that the design is carried out taking into account clearly formulated and verifiable functional requirements and knowledge of the building's and the business's conditions. It is important that the chosen solution is designed and dimensioned with a holistic view of the building and installation technology as a system. A common denominator is that, in addition to requirements for the quality of the indoor climate, there are always more or less stringent demands on efficient energy use.

The conditions are often very different for different types of commercial buildings. However, the ventilation system of the buildings can be made up of the similar components and subsystems.

There is always a subsystem for air treatment, one for control and a third for air distribution of ventilation air. The possibility to change the water content of the air, especially by moistening, is only built in when the business places special demands on moisture control, e.g. in museums, concert halls and special production and laboratory premises. The basic structure of ventilation systems and subsystems is illustrated schematically in Figure 1.

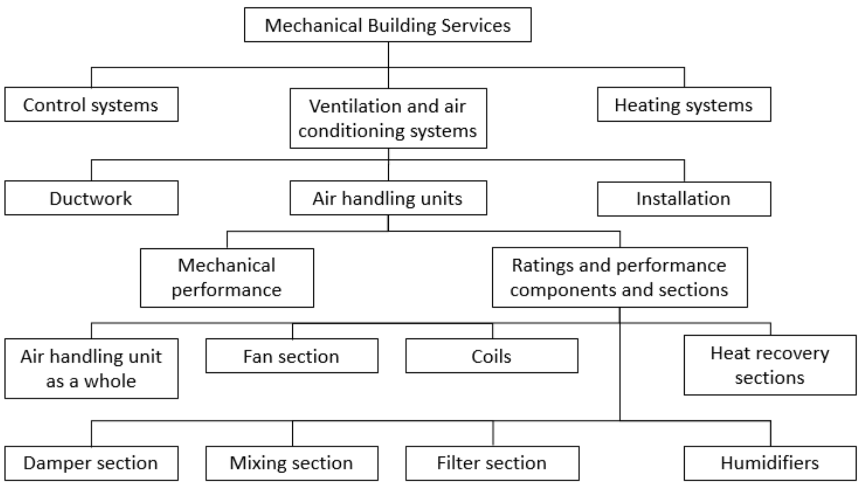

Figure 1. Different parts of Mechanical Building Services (SS-EN 13053:2019 (E))

5 Ventilation and indoor climate requirements (regulations) and inspections

Most regulatory frameworks from public authorities set minimum requirements that must never be undercut. The minimum requirements are set so that ill-health or injury is not at risk. In many cases, the minimum requirements are misunderstood as 'desirable' values. There are several examples of undesirable complications when minimum requirements from several regulatory systems and regulations are combined. In practice, it is often compound requirements (for example, for better comfort) that control the necessary level.

Table 1 compiles some rules and advice regarding ventilation in connection with the Planning and Building Act (PBL), the Environmental Code, the Work Environment Act and the Act on Protection against Accidents.

Table 1. Some rules and advice on ventilation

	Legislation				
	Planning and Building Act, PBL (2010:900)	**Environmental Code (1998:808)**	**Accident Protection Act (2003:778)**	**Work Environment Act (1977:1160)**	**Air quality regulation (2010:477) (Environmental Code/ Form of Government)**
Responsible authority	The National Board of Housing, Building and Planning	Public Health Agency of Sweden/ National Board of Health and Welfare	The Swedish Civil Contingencies Agency (MSB)	The Swedish Work Environment Authority	The Swedish Environmental Protection Agency

Local/ regional supervisory authority	Municipal Building Board City Planning Office	Municipal Environment Board Environmental management	Municipal councils	Regional Health and Safety Inspection	Municipal Environment Board Swedish Environmental Protection Agency
When and where?	New building, extension and refurbishment, OVK	General purpose housing and premises*	Sweeping and fire protection	Workplaces and schools, not preschools with regard to children	Quality of outdoor air

6 Measure and verify indoor climate and ventilation

Measurement and verification of indoor climate and ventilation can be done using different methods and instruments depending on the buildings you are studying. Indoor climate refers not only to thermal comfort, but also to air quality and sound environment that directly or indirectly is affected by the type of ventilation and its function. The different main groups of properties that can be measured and verified linked to ventilation are:

- Airflows
- Air exchange and ventilation efficiency
- Thermal climate
- Sound environment
- Ambient air quality
- Overall function
- Experienced indoor climate using surveys
- Inspection of the cleanliness in ventilation systems

After each subchapter the number of standards etc is noted.

6.1 Airflows

Airflows in ventilation systems can be measured and verified using a number of instruments and methods, most of which are described in standard SS-EN 16211:2015 Air treatment - Field methods for measuring airflows. **Fixed measuring devices** in ducts, supply air or exhaust air diffusers are usually based on some type of strangulation that creates a differential pressure. By measuring the pressure difference and a value of the k-factor known for the measuring instrument, the airflow can be calculated with relatively good accuracy. However, this assumes that the measuring instrument has been placed according to the installation instructions, for example with sufficient straights before and after the measuring instrument.

Totally 2 Swedish Standard, 1 Nordtest methods and 2 reports noted

6.2 Air exchange and ventilation efficiency

Measuring and verifying how much air is supplied and removed in a building or area/space, is one thing for which different methods can be used. Another thing is how well a supply airflow is distributed in the ventilated space and how well ventilation can take care of internally generated air pollutants.

There are three different concepts of efficiency that can be measured and verified using different methods, all based on the dosing of a trace gas and measuring its concentration. One concept is *air exchange efficiency*, which is a measure in the range of 0–100 % on how efficiently the air in the room is replaced on average or, in other words, a measure of how good the ventilation system is at spreading the supply air to different parts of the ventilated space.

The second concept is *ventilation efficiency,* which is a measure of how good the ventilation system is at removing internally generated air pollutants. It is defined as the ratio of the concentration in the exhaust air to the mean concentration in the room, expressed as a percentage.

The third concept is *the local ventilation index,* which is a measure of how good the ventilation system is at removing an internally generated air pollution with respect to a local point in the room. Defined as the ratio between the concentration of an exhaust air pollutant and the concentration of the same pollutant in the stay zone, expressed as a percentage.

Totally 1 Swedish Standard and 6 Nordtest methods noted

6.3 Thermal climate

Perceived thermal comfort depends not only on the air temperature, but also on humidity, air speed and the temperature of surrounding surfaces. Even the variation of the air temperature in the stay zone affects the perceived thermal comfort. Of course, upholstery and physical activity also has great impact on perceived thermal comfort.

In addition, age and gender have an impact. But equally old people of the same sex experience different thermal comfort (or discomfort) with the same attire and activity. It is therefore impossible to set a thermal climate that makes every one of the larger numbers of people present experience good thermal comfort.

There are a number of measurements that need to be collected in order to assess the thermal climate of a stay zone. There are three different ways to calculate and describe experience and dissatisfaction with the thermal environment:

1. *Predicted Mean Vote (PMV)* which on a 7-degree scale describes how one is expected to experience the thermal climate
2. *Predicted Percentage Dissatisfied (PPD)*, which is expected percentage dissatisfied with the thermal climate.
3. *Local Thermal Discomfort (DR)* is usually calculated as a draft rate *(DR)* that is expected to be dissatisfied due to air temperature, air speed and turbulence.
   A *Percentage Dissatisfied (PD) value* can be calculated that indicates the expected percentage dissatisfied.

Totally 3 Swedish standards and 1 ANSI standard noted

6.4 Sound environment

Measurement and verification of the indoor sound environment connected to the ventilation system is in principle linked to three different types of noise sources:

1. Sound generation that occurs in the ventilation system itself;
   (a) mainly from fans, but also from damper motors and circulation pumps in refrigeration/heating batteries
   (b) self-sound generation in duct parts, dampers, fixed gauge, supply and exhaust air diffusers, etc.
2. Transfer of sound between spaces (rooms, offices or apartments) via the ventilation ducts.
3. Outdoor noise brought in via outdoor air vents in exhaust air ventilated buildings, mainly in residential areas.

Field measurement is appropriate with a calibrated sound pressure meter with known measurement uncertainty, which with different weighting filters (usually dBA and dBC) can measure the sound pressure level both in total and in different octave bands. It is important that measurement takes place in particularly sensitive spaces such as bedrooms.

Totally 8 Swedish Standard and 1 report noted

6.5 Ambient air quality

Indoor (and outdoor) air pollution occurs in the form of particulate matter and gases. Particles occur in different sizes and the sources can be both outdoors and indoors. Long-distance transport of smaller particles from other countries can at times form a large part of measured particle levels in Sweden.

The type of ventilation system and the filters used can have a major impact on the presence of small particles indoors. Instruments are available to measure particle size distribution in air from approximately 5 nm to several hundred µm. There are a number of different techniques for measuring particles and measuring instruments for particles available from very simple and inexpensive to very expensive and advanced depending on what and how accurately they can measure.

Totally 9 Swedish standards noted

6.6 Overall functionality

Both during commissioning and subsequent operation, the ventilation system should be measured and verified that it has good functionality and meets the requirements. One issue is to assure is that internal or external re-airing does not occur. That the system maintains the correct pressure balance, especially important around a rotating heat exchanger. It is also important that the heat exchanger meet the specified performance.

Placing of reference sensors, avoiding interference, calibration and verification during commissioning is important. This is important to enable the operation after final inspection. The same applies to sensors and function of ventilation units, VAV and DCV components, etc.

Totally 5 Swedish standards noted

6.7 Experienced indoor climate using surveys

To evaluate different aspects of the perceived indoor climate, there are several existing surveys to choose from. There is big difference between the different options regarding purpose, scope, how the questions are asked and how respondents are asked to submit their answers. Some surveys focus on the impact of the indoor climate on health, others on comfort and some surveys are focused on self-perceived work performance/productivity.

6.8 Inspection of the cleanliness of ventilation systems

Keeping the ventilation system clean can affect the indoor environment both directly and indirectly. It is important to regularly inspect and, if necessary, clean the different parts of the system. How often the cleanliness should be checked depends on the type of system, the part of the system, airflows, airspeeds and operating times, as well as internal and external loads in terms of presence, activity, traffic, etc. The purity requirement in the ventilated space also matters.

The ventilation system can roughly be divided into ducts, units and supply and exhaust air diffusers. The ducts can in turn be divided into supply air ducts, kitchen ducts and ordinary exhaust ducts. The ventilation unit can be anything from a single fan to a complex unit with many parts that need to be checked.

Totally 1 Swedish standard 4 Reports and noted

7 Guidelines for ventilation and indoor climate

An inventory was made regarding information, documents and guidelines available encompassing ventilation and indoor climate. The full report lists 188 documents, standards and guidelines with description.

The guidelines are aimed at different target groups, such as clients/developers, consultants, contractors, technical property managers, operational organisations, operations/health and safety managers, environmental and health inspectors. Table 2 presents the number of guidelines of different origin.

Table 2 – Number of guidelines divided in groups

Guideline from and about	**Number**
Authorities	12
Industry guidelines on indoor climate and ventilation	9
Industry guidelines specifically on ventilation	8
Industry guidelines for functional checks	4
Ventilation standards • Technical committees • Swedish standards • Nordtest methods	 9 19 7

In total, 52 Swedish standards were noted as relevant for ventilation. Seven of these were in Swedish language, the rest in English!

8 Stakeholders - ventilation in Sweden

In the full report totally 119 stakeholders and key industry players in Sweden were identified. Of them 47 are described with a brief summary of each stakeholder's field of work, see division into categories in table 3.

The listing is not complete and will need to be adjusted gradually, both in terms of which stakeholders are/should be included, and regarding the descriptive text.

Table 3 – Number of stakeholders in categories

Stakeholder	**Number**
Trade and interest groups and networks	21
Universities & University colleges	13
Research institutes	3
Research and development	5
Training organisation	5

9 Conclusion

In the work on this report, we have noted great complexity in requirements, the diversity of regulations for different purposes as well as knowledge collections in literature, standards, test instructions, industry recommendations, associations and networks. A description of the current situation must not be made too complex and complicated for it to be of benefit to industry and decision-makers at different levels of the ventilation industry. The state-of-the-art description can hopefully be improved through further studies where less relevant information can be identified while closing gaps. With a baseline "map" it is possible to build in terms of knowledge.

Nothing is stronger than the weakest link. In order to build energy-efficient and achieve set environmental and climate goals, the ventilation industry must operate throughout the chain, as well as compile knowledge from the installer level. The full report contains technical descriptions for the design stage, and not so much guidance for assembly, commissioning and adjustment. Further proposals for continuation:

- Consultation round to ensure timeliness in the knowledge overview.
- Create meeting place and ventilation dialogue.
- Investigate research and development needs.
- Update the state-of-the-art report.
- Customize information and different professions and stages of the construction process.

The following suggestions for extension of the report have been noted during a review period.

- Fire and safety connected to ventilation systems has to be further development.
- System relation between ventilation and energy use.
- Thermal comfort.
- Assessment of over-heating.
- Operation and maintenance of ventilation systems.
- Instruction for cleaning and maintaining ventilation systems.
- Control systems and alarms in ventilation systems.
- Inspection intervals, instructions and pitfalls.
- Differences in rules between residential and commercial buildings.
- Air quality.
- Understanding risks related to ventilation systems.

Discussions are underway on how to develop and improve the state-of-the-art report on Swedish ventilation.

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