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# Evaluation and Demonstration of Domestic Ventilation. State of the Art

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## Synopsis

The IEA Annex 27, "Evaluation and Demonstration of Domestic Ventilation Systems" is aiming at developing tools by using the most developed computer models and equations available including modul development. Before staring up all the simulations an in depth review of the variables influencing the evaluation of a ventilation system have been done and a report is to be published. All parameters are needed to be mapped so that realistic assumptions can be made for the simulation phase. In the review is also included the models that can be possible to use for simulations of indoor air quality, thermal comfort, water vapour content, giving the possibilities to calculate the life cycle cost.

In the review report is given facts about housing statistics, population densities, moving pattern. The residents' behaviour is given for time spent in the dwellings, airing pattern etc. The loads, that have to be dealt with, are given by reviewing the present results on particles, $NO_x$, VOCs. The AIVC TNs have been used for the chapters concerning standards and leakages in dwellings. Also emissions from radon, landfill spillage, garage, and combustion can be influenced by the ventilation system and that have also been dealt with.

## Background

The rate of outdoor air supply as well as comfort aspects associated with air distribution and the ability of the systems to remove pollutants are important factors to be considered at all stages in the building lifecycle. As distinct from a work place, residents can vary across a wide span from an allergic infant to a well trained sportsman, from active outgoing people to elderly confined to a life indoors.

During the lifetime of a building its dwelling occupational pattern vary. This results in a varying need for supply air to obtain acceptable indoor air climate and to avoid degradation of the fabric. Emissions from building materials are also time dependent. When the building is new or recently refurbished it may be necessary to dilute the emissions by extra outdoor air. In standards and codes the outdoor air needed in a dwelling is generally based on the maximum number of persons living in the dwelling, defined by the possible number of beds contained therein.

Dwellings represent about 25 - 30 % of all energy used in the OECD countries. In the near future domestic ventilation will represent 10 % of the total energy use. Thus even relatively small reductions in overall ventilation levels could represent significant savings in total energy use. Improvement of residential ventilation is of concern in both existing and future buildings. The functioning of the ventilation system may deteriorate at all stages of the building process and during the lifetime of the building. Research in the recent years and in particular the IEA annexes now makes it possible to formulate methods to evaluate domestic ventilation systems.

## Objectives

The objectives of A 27 are: **to** develop tools, for evaluating domestic ventilation systems; **to** validate the methods and tools with data obtained from measurements; **to** demonstrate and evaluate ventilation systems for different climates, building types, and use of the dwellings

The methods, tools, and systems are intended for existing and future residential buildings, that require heating. The target group is composed of standard and policy makers, developers in industry, and ventilation system designers.

With this general objectives the Annex is divided in three subtasks: 1. State of the Art, 2. Development and Validation of Evaluation Methods, and 3. Evaluation, Demonstration, and Application of Current and Innovative Ventilation Systems.

With the above objectives and scopes of the three subtasks the Annex started in April 1993 and has today nine participants: Canada, France, Italy, Japan, Netherlands, Sweden, UK, and USA. The specific objectives of the first subtask "State of the Art" are:

1. Give an overview of typical and frequently used systems,
2. Background and reasons for existing systems and standards,
3. Review existing evaluation methods.

# Introduction

With the State of the Art Review, Månsson (1995), it is possible to give realistic assumptions of the most frequently used ventilation systems, the design of the dwellings, how many residents there usually are, the behaviour, and the time spent in dwellings. This means that one aim has been to cover about 90 % of all possible cases, that are influencing the need of outdoor air supply. The usual levels of different pollutants in the dwellings are also given based on the review. The review report is based on and giving references to about 400 reports.

The content of the report is also the headings of the following text in this paper. However, it should be noted that the chapter "Statistical Data on Housing" and the subchapter "User Behaviour and Perception" under chapter "Evaluation Approach" was presented at the AIVC conference in Buxton, UK, 1994, see Månsson (1994).

# Statistical Data on Housing

The 14 OECD countries studied have 700 million inhabitants, 280 million dwellings and a useful floor space of 32 000 million $m^2$. The variation is great and goes from 65 $m^2$/dwelling (Italy) to 152 $m^2$/dwelling (USA). There is also a great variation between the countries weather the dwelling is in a single family house or in a multi family building, see figure 1.

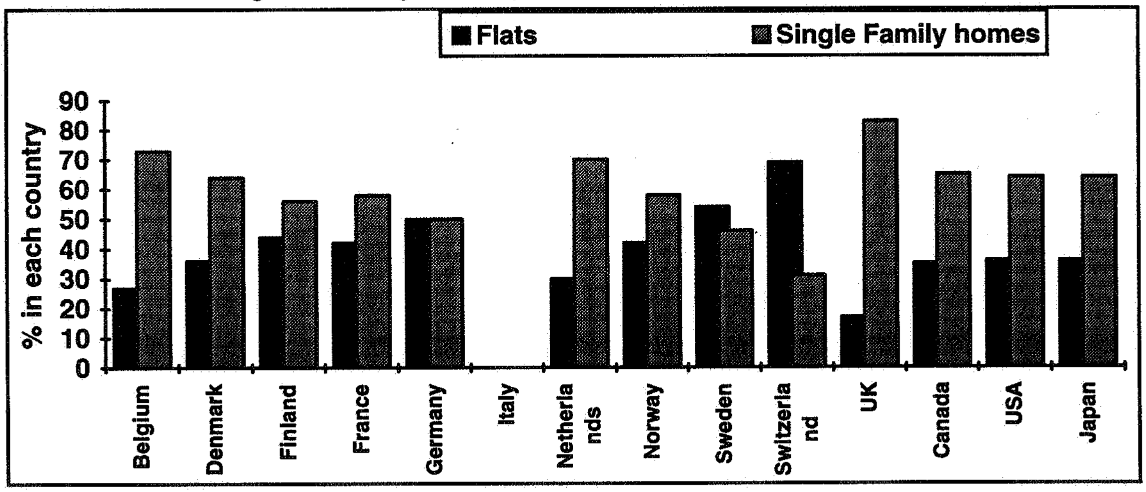


*Figure 1. Single family homes and flats, percentage (%).*

The number of persons/dwelling goes from 2.1 (Sweden) to 3.2 (Japan, Italy). Combined with the dwelling area it gives a floor space from 27 $m^2$/person (UK) to 61 $m^2$/person (USA). The crowdiness is defined by the number of persons/bedroom. From data can be seen that in 35 % - 50 % of all dwellings, there is less than 1 person/bedroom and in nearly all (90 - 95 %) less than 2 persons/dwelling. Moving frequency studies show, that after 35 years of age the family has settled and will remain living in that dwelling.

A very important trend is that the number of one-person household is increasing. Today it goes from 20 % to 40 %. The trend has been observed during the last 45 years in all countries. A majority of the households have only two persons, except Japan (40 %). In the future it can be expected that we will have even more 1- and 2-person households as the number of persons older than 60 years during the next 40 years is growing from about 20 % to 30 % of the population.

## Ventilation Performance

In order to get an overview of the most frequently used ventilation systems and how they perform, a survey has been done giving the ventilation rate and tightness reported from different measurement campaigns. As expected the most used system in existing dwellings is natural ventilation, see table 1. However, in new constructions a fan is always installed either for local exhaust or for general exhaust with a fan running all the time, see table 2.

***Table 1. Distribution of ventilation systems in the existing dwelling stock***

| **Country** | **Single family houses** | | | | | **Multi family houses** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ***Natural*** | | | ***Mechanical*** | | ***Natural*** | | | ***Mechanical*** | |
| | Adventitious | Stack (S) | S+Kitchen hood | Exhaust | Supply+ Exhaust | Adventitious | Stack (S) | S+Kitchen hood | Exhaust | Supply+ Exhaust |
| Belgium | 100 | | | | | 95 | 5 | | | |
| Canada | | 15 | 85 | | | | | | | |
| Denmark | | 50 | | 48 | 2 | | 50 | | 50 | |
| France | 40 | 15 | 20 | 22 | 3 | 40 | 20 | 10 | 30 | |
| Italy | 80 | | 10 | 10 | | 75 | | | 25 | |
| Netherlands | | 62 | | 38 | | | 37 | | 63 | |
| Norway | | | 80 | 15 | 5 | | 60 | | 30 | 10 |
| Sweden | | 12 | 63 | 14 | 11 | | 40 | | 44 | 16 |
| Switzerland | 70 | | 30 | | | 40 | | 60 | | |
| UK | | 95 | 5 | | | | 100 | | | |
| USA | 60 | | | 40 | | | | | | |

***Table 2. Distribution of ventilation systems in the new constructed dwellings***

| **Country** | **Single family houses** | | | | **Multi family houses** | | | |
|---|---|---|---|---|---|---|---|---|
| | ***Natural*** | | ***Mechanical*** | | ***Natural*** | | ***Mechanical*** | |
| | Local exhaust | S+local exhaust | Exhaust | Supply+ Exhaust | Local exhaust | S+local exh | Exhaust | Supply+ Exhaust |
| Canada | | | | 100 | | | | |
| France | | 20 | 75 | 5 | 1 | | 99 | |
| Italy | 80 | | 20 | | 90 | | 10 | |
| Netherlands | | 20 | 80 | | | 20 | 80 | |
| Sweden | | | 80 | 20 | | | 20 | 80 |
| UK | 100 | | | | 100 | | | |
| USA | 90 | 10 | | | 90 | 10 | | |

From various reports are given results of the ventilation rate in dwellings measured with active or passive methods. In table 3 is given the results from countries or regions with a need for heating during a part of the year. The air change rate is usually lower in single family houses than in multi family buildings. From Orme et al (1994) can be seen that the air tightness goes from 1 $h^{-1}$ ($_n50$) to 30 $h^{-1}$ ($_n50$) and with average values from 3 to 14 $h^{-1}$ ($_n50$).

***Table 3. Ventilation in dwellings***

| Country | No of dwell.s | Year of constr | Method p or a | Single family houses $h^{-1}$ | Single family houses l/s,p | Single family houses l/s,m$^2$ | Single family houses system | Multi family buildings $h^{-1}$ | Multi family buildings l/s,p | Multi family buildings l/s,m$^2$ | Multi family buildings system |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Belgium | 17<br>many | 1980 | a | 0.5<br>0.75 | | | N | | | | |
| Canada | 40 | | | 0.2-0.6 | | | | | | | |
| Denmark | 200<br>?<br>150 | 1930-60<br>>1982 | p<br><br>p | <br><br>0.35 | | | | 0.4 | 8 | 0.27<br>0.6 | N<br>E |
| Finland | 242 | -1982<br><br><br>all | p | 0.40<br>0.42<br>0.45<br>0.45 | | | | 0.62<br>0.64<br>0.60<br>0.64 | | | N<br>E<br>SE |
| Germany | | all | | 0.8 | | | | 0.8 | | | |
| Japan | 10 | 1984 | p | 0 -0.7 | | | | | | | |
| Netherlands | | | | | | 40 l/dw | | | | | |
| Norway | | <1951<br>51-65<br>>65 | | 0.5<br>0.4<br>0.3 | | | | | | | |
| Sweden | ≈2000 | all | p | 0.34<br>0.36<br>0.43 | 12<br>12<br>14 | 0.23<br>0.24<br>0.29 | N<br>E<br>SE | 0.49<br>0.58<br>0.60 | 12<br>14<br>16 | 0.33<br>0.39<br>0.40 | N<br>E<br>SE |
| Switzerland | 5 | mv1980s<br>mv1980<br>all | a<br>a | <br><br>0.7 | | | | 0.5[1]<br>0.1[2]<br>0.7 | 11 | | N<br>N |
| USA, NY<br>Cal, L.A.<br>Georgia<br>All states<br>North states | 30<br>640<br>22<br>500<br>? | <br><br><br>all<br>all | p<br>p [3]<br>p<br>a<br>a | 0.2<br>0.6<br>0.1-6<br>0.83<br><0.2 | | | | | | | |

p=passive & a=active tracer gas method, 1) closed & 2)opened bedroom doors 3) measured in January
N=natural, E=mechanical exhaust, SE=mechanical supply and exhaust

New systems that are on its way into the market or under testing are also briefly described. A trend is to install demand related systems and components, which make it possible to use the supplied air more efficient. Humidity is the most common controlling parameter, but also others are under development. A system under development is to use a timer to direct the constant flow of outdoor air to different rooms at various time, when the rooms are occupied. The location of the supply devices have always been a matter of experiments. Today also displacement ventilation is tested in dwellings. Various improvement measures of natural ventilation systems are under development in particular for existing dwellings. Such systems might be the improvement of the stack effect by small exhaust fans controlled by humidity, timer, pressure difference etc. Also improvemet of the trickle ventilator, usually located in the window frame or casement, so the opening is varied depending on the wind velocity, humidity, or temperature.

## Standards

Indoor climate have been discussed almost as long as man built the first dwelling. Documented comments and recommendations were given in the ancient societies Egypt, Greece, and Rome. But a more detailed study started at first in the 19th century by distinguishing between undesireble unvoluntary and acceptance of voluntary exposure of pollutants. Today there are different ideas of how to give a standard for ventilation. It is or has been based on:

1. Outdoor environment
2. Hazardous air pollutants
3. Work place emissions
4. Causing chronic effects
5. Associated with threshold values
6. Specific pollutants/indicators ($CO_2$, particles, total hydro carbons)
7. Irritant properties of chemicals
8. Odour criterion

Standards are mostly based on perceived body odour and some specific pollutants. Moisture seems to be forgotten in the discussion of giving a ventilation standard in dwellings. All flow rates are based on the maximum number of residents defined by the number of beds possible to furnish all the bedrooms with.

## Pollutant Loads

The main purpose with a review of pollutants, that may occur indoors, is to give information on normal levels and the range. The loads can be emissions of three categories : ① Constant (more than a few days), ② Variable, or ③ Outside sources. Some pollutants are given when the house is constructed or refurbished and others are unavoidable or linked to the living in a dwelling. Other pollutants are possible to avoid e.g. tobacco smoke.

### Moisture

The water vapour content has very seldom been monitored in large investigations. A large study in Sweden reports average values of 38 % Relative Humidity (RH) in single family houses and 32 %RH in flats. This levels are out of the risk for house dust mites and mould growth. The comfort interval is reported to be 30 - 70 % RH (acceptable interval 20 - 90 % RH). It is recommended to have at least one month with RH < 45 - 50 % RH to avoid the growth of house dust mites and always try to keep it below 55 % RH (all figures as monthly average). Mould growth is avoided if the RH is kept below 75 % RH, weekly average.

### VOCs

Volatile Organic Compounds (VOCs) are always present indoors and the emission is depending both on resident's behaviour and on building materials. Numerous studies have been conducted both large surveys in many ordinary dwellings and in problem buildings. Sometimes it is not possible to distinguish between dwellings with smokers and non-smokers. Other influencing factors are sometimes also at hand. Different sampling and analysing methods are giving different results. There is also a great variation during the day and can be in the ratio 1:5. E.g. in Japan is 27 000 t of para-chlorobenzene produced every year and used for deodorants (and moth-balls) and released usually in small rooms. The hygenic limits for work places is 300 $mg/m^3$ 15 min and might be excedeed every day in some bathrooms or bedrooms. In table 4 is given some values indicating a range of 50 - 800 $\mu g/m^3$ and can easily reach over 10 000 μg/m³ in new houses. A level usually mentioned is 300 μg/m³ that should not be exceeded.

*Table 4. Average concentration of VOC, 95 % confidence intervals [μ g/m³]*

| | Sweden | | Canada | UK | Germany | Switzerland |
|---|---|---|---|---|---|---|
| | Single family | Flats | Single family | All bldg types | Single family | New or refurbished flats |
| **No of dwellings** | 101 | 92 | 754 | 120 | 180 | 22 |
| **Analyse method** | Tenax, MS | Tenax, MS | OVM 3500, MS | Tenax, FID | Home-made FID | |
| **VOC conc** | 470 ± 180[1)] | 310 ± 40 | 4 - 11 | 110 | 90<br>45 - 886 | 13 000<br>700 - 35 600 |

**Particles**

High particle concentration is usually a matter of smoking or not indoors. Particles originating from outdoors is less than 10 % as long as the air change rate is kept below 1 $h^{-1}$. In table 5 is given values for average and peak situations. It must be noted that peak values are not very well studied.

*Table 5. Particle levels in homes, average and peak values.*

| | Average mg/m³ | | Peak mg/m³ |
|---|---|---|---|
| | Normal areas | Polluted areas | |
| Nonsmokers | 0.020 | 0.050 | 0.1 - 0.2 |
| Smokers | 0.10 - 0.20 | - | <1.0 |
| Standards Netherlands<br>USA federal<br>USA California | 0.070<br>0.150<br>0.050 | | |

**Bioeffluents and $CO_2$**

The tracergas for bioeffluents is $CO_2$ even if it is known that the compounds giving the bioeffluents are chemical unstable and is rapidly decomposed to less odorous compounds. The result is that the odour is vanishing faster than a result of the dilution. The perception of odour has two cases: 1. Visitors entering a room with people, 2. Occupants. Flow rate is usually not discussed in the perspective of the occupants' case. Studies with occupants' percep-tion have given very small differences of the perception of annoyance of 800 or 1500 ppm $CO_2$.

**$NO_x$**

In dwellings the pollutant can originate from unvented gasheaters, a stove (range), an oven, and domestic hot water heater(s). A pilot flame for easy access results in a constant $NO_x$ emission even if it is at a low level. In the future it is foreseen that more vented appliances are installed. Together with an increased number of installed kitchen hoods, better outdoor conditions and the use of outdoor vented appliances, the $NO_x$ levels can be expected to decrease during the next decade. Large monitoring and epidemiological studies have been finalised the last few years.

Sensitive individuals have been observed to feel annoyance at 100 μg/m³ $NO_2$. Measured values have been reported as high as 800 μg/m³ $NO_2$ as weekly average in kitchens. Peak values during cooking can be up at 2200 μg/m³ $NO_2$. However, it should be noted that the level originating from traffic can be in the range of 5 - 75 μg/m³ $NO_2$ measured in homes without any natural gas appliance, but mean values is often at 20 μg/m³ $NO_2$. As the energy used for domestic hot water can be up to 10 times the energy used for cooking the $NO_2$ level is consequently much higher. As a guidance the standards in dwellings are 60 μg/m³ in Japan, 100 μg/m³ in USA and Canada, and 300 μg/m³ in The Netherlands for 24 h level.

**Interaction with combustion. Radon and landfill spillage**
Open-flued natural draught combustion appliances are very sensitive to the pressure difference. In calm weather conditions spillage can be caused at a pressure difference of 4 - 5 Pa when the vent is cold. With a hot flue spillage can be the case at 10 - 20 Pa. When installing mechanical ventilation this must be observed. Also warning flags must be rised if there is a risk for radon in the ground under the house and in particular if the indoor is given an underpressure.

# Evaluation Approach

When evaluating ventilation systems the residents' behaviour must be taken into account. This must be made by assuming behaviour based on studies that might not be found in the ordinary technical reports. Usually it is market researches or sociological studies of smaller or larger groups. This assumptions will be used in simulation programs for evaluating the various systems.

**User behaviour**
This was presented last year at the AIVC conference, Månsson (1994), and here briefly summarised. In itself the discussion of how many persons/household is also a sort of behaviour. Assumptions must be made as close as possible to general behaviour.

***Presence in the dwelling and in individual rooms:***
Emploied men are away from the dwelling between 7 h to 17 h. In some countries it is more frequent, up to 60 %, to have lunch at home but not more 1 hour, whilst in other countries it si 40 %. Lowest frequence during a day is 20 %. The pattern for emploied women si similar but at a higher level at lunch and coming home 2 hours earlier. The housewives are away most frequently during a couple of hours in the morning and in the afternoon. Studies have also been made on the pattern of people at different ages. In the study of the time spent in the kitchen it was proportional to the area of the kitchen. A cultural habit is that the time in the kitchen is doubled in France compared to USA. This was valid both for housewives and women working also outside the home. Time spent on household work (cooking, cleaning, washing etc) is 3 - 4.5 h.

***Body washing***
One very important source for water vapour production is body washing. Some ideas of how much water vapour that is needed to be transported away, might be given by the use of water that goes from 150 to 260 l/person,day. Variation of hot water use is very high and can be in the ratio of 1:20. Most common is to take a shower. Studies in Europe indicates a frequency of once a day to 4 times a week and the duration seems to be about 10 min/shower.

***Window airing***
Todays knowledge of the behaviour can be summarised to be:
* The same daytime and at night
* Proportional to the outdoor temperature (higher when warmer)
* Proportional to the wind speed (lower with higher wind speed)
* Windows are not left opened when no person is present in the dwelling.
* Doubled when tobacco smoking is allowed in the dwellings. If smoking only takes place in the living room it is only in this room the opening is doubled.
* Regulating occationally high temperature, eg at parties.
* Regulating the temperature in general.

* Depending of the housewives' habits when making up the beds and cleaning the dwelling.
* Less when higher indoor temperature was prefered.
* Less amongst elderly people.
* No socio-economic correlation
* Increased when the room has direct solar radiation
* More when sunny than cloudy

**Energy models**
Simple heat loss calculations may be adequate for determining thermal liabilities if an appropriate balance point is chosen (usually 4 - 6 $^{o}$C below room temperature). Only those hours where the external ambient temperature is less than the balance point are included in the calculation. Of course fan energy must be included if mechanical systems are evaluated. Simplified calculations can be performed on an hourly basis, but using daily or weekly averages for temperatures and average net flow rates results in only minor loss of accuracy. It is about 1 - 3 % relative to thermal simulation results.

**Indoor Air Quality Models**
As the main aim with Annex 27 is to evaluate ventilation systems the influence of many variables must be able to be dynamically handled by the model. Examples of variables are:

1. External: temperature, wind velocity, sunshine, treeshading.
2. Building envelope: air tightness, unintentional cracks, intentional leakage paths
3. Internal: pollutants (average, resident depending, local), ventilation system, room location, doors opened or closed, room volume.

Only very few models take into account all variables. In all the multi zone models it is assumed to be complete mixing in each zone. If an individual room is to be investigated on the consequences of not having complete mixing it can be handled by the discussion of ventilation efficiency and the use of computational fluid dynamic models (CFD). In such case most often only one room is dealt with. Models can include adsorbtion and emission of different gaseous pollutants as well as the treatment of water vapour. The greatest problem is to find material data.

Orme (1995) shows that there is no great differences between four tested models. However, some models can only make simulations for a day. The comparison gave identical results or less than 1 % deviation between the average of the four models and an indivual one.
The conclusion is that it is not the model that is most important, but the careful selection of the input data.

**Thermal Comfort Model (Draught Equation)**
As the equation with its constants is an empiric equation a sensitivity analysis will show how small errors will influence the prediction of dissatisfied.

**Draught Equation** $$PD = (34-t_i)\times(v-0.5)^{0.62}\times(3.14+0.37\times v\times T_u)$$

| | | |
|---|---|---|
| where | PD | Predicted dissatisfied in percentage (%) |
| | $t_i$ | Indoor room temperature ($^{o}$C) |
| | v | Air velocity (m/s) |
| | $T_u$ | Turbulence intencity in percentage (%) |

With a fault of 3 % of the constants the PD can deviate up to 20 %. For greater faults of about 10 - 15 % the result will deviating up to 100 %. Various anemometers for the measured turbulence intencity are reported to give a 10 % difference at 10 % turbulence intencity and a 30 % deviation at 30 % turbulence intencity. With such a large range of uncertainty it may cause problems to interprete the measured values as well as the formula above as uncertainty may arise in what type of anemometer, that was used when the data were collected.

If the aim is to have the PD-value of 15 % it might also be up to 30 % with the given measured values for air velocity, turbulence intencity and room air temperature. If the target is a PD-value of 10 % with the uncertainty it might also be PD=20%. The practical way to use the equation is to compare different solutions in the seletion phase. Another means can be to recommend how close to a device, external wall or a window a person can sit or stand. Thus the equation can be used as a quality index.

**Ventilation Efficiency**

All the various methods to express the ventilation efficiency criteria for service and habitable rooms are given, see table 6

| *Table 6. Ventilation efficieny criteria* | |
|---|---|
| **Service rooms** | **Habitable rooms** |
| Ventilation efficiency<br>Pollutant removal efficiency<br>Capture efficiency<br>Removal efficiency<br>Collection efficiency<br>Pollutant index<br>Room pollutant index | Nominal time constant<br>Air change time<br>Air change efficiency |

**Life Cycle Cost (LCC)**

In order to compare different systems economically investment and LCC calculation methods are described. The total LCC must include factors like initial investment, maintenance cost, replacement cost, operating cost (heating the supply air, electricity for fans), damages caused by bad ventilation (eg refurbishment caused by mould growth). The best way to calculate is to use the Net Present Value (NPV). As the housing sector is dealing with a very long time perspective it is usually not possible to use the simple payback method. Sometimes there are other factors to concider such as noise and noise reduction, when dwellings are close to heavy traffic. A sensitivity analysis will show the consequenses of minor changings in the assumptions and is recommended to be made, as predictions of the future always are uncertain. With this type of calculations taking into account both the direct investment and the cost of the consequences of inadequate choice of ventilation system it might be possible to change the view of a ventilation system **from a cost to an investment.**

**Noise**

Noise related to domestic ventilation systems can be divided into three main areas. Depending on which system, that the dwelling has, the consequences varies, see table 7. Noise reduction goes hand in hand with air tightness. A good single weatherstripped window in a facade of brickwork will reduce the noise even if the ventilation provision through the wall has no soundproofing (25 dB(A) compared to 21 dB(A) without). If there is no ventilation opening (eg.

*Table 7 Noise consequence*

| | Natural | Mechanical exhaust | Mechanical supply and exhaust |
|---|---|---|---|
| Outdoor noise | x | o | o |
| System Noise | - | x | x |
| Sound transmission | o | o | x |

mechanical supply and exhaust) the reduction is even more (29 dB(A) compared to 22 dB(A)). It should be noted that a stack can transmit noise from aircraft and elevated roads and this must be observed when the facades are well soundproofed.

In many countries the maximum allowed indoor noise level is 30 dB(A). Usually a fan in a single family house gives a noise level of 30 - 45 dB(A) in rooms without sound reduction in the ductwork. With a silencer it is cheap and easy to take action. Another matter to consider is the vibration from a fan unit and in particular if a heat recovery unit is installed. Cross-talk especially between flats is a problem, that is of particular concern in mechanical supply and exhaust systems. It can be brought about by the following ways:

- Through the ductwork
- Transfer openings (within the same dwelling)
- Duct transition

**Reliability**

The reliability of a ventilation system is how well it can provide a minimum air flow rate and keep it. How well a certain selected system can give a required flow rate in individual rooms during a year under certain weather conditions is exemplified in the paper presented at this conference by Kronvall, Blomsterberg (1995). Other very important factors are dust accumulation in ducts and other components and malfunction of system equipment.

The malfunction of equipment is a matter of collecting information of how long the life time is expected to be. With a technique of safety analysis either with "Event Tree Analysis" or "Fault Tree Analysis" this is treated.

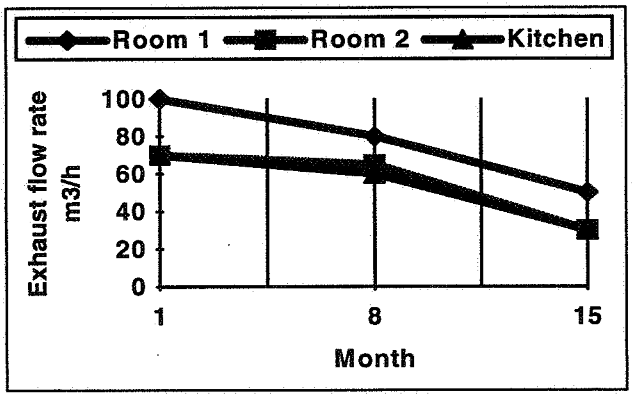


*Figure 2. Measured reduction of the air flow rate due to dust accumulation*

Dust accumulation gives a reduction of the flow rate, thus resulting in a risk for not keeping the required flow rate. If the dust can be calculated and the reduction of the flow estimated it is possible to give the duct cleaning intervals. In figure 2 is shown results of measured exhaust flow. A method to calculate has been developed by Wallin (1994) gave a flow rate reduction of about 20 % within 2 to 3 years. Another year without cleaning might result in a dramatic decrease of the flow rate to less than 50 %.

## Conclusions

Dealing with the housing sector and with residents means to deal with a great variation in technical status and behaviour. Cases are not always well defined as it usually are in work places eg. offices. In some areas there is a lack of data or only studied in one or two countries. However, there is enough data on technical status and on loads to formulate assumptions, see table 8, that is expected to cover most of the residential behaviour and systems. Reliable simulation programs for energy, noise, IAQ are developed using the most recent knowledge. Modeling of water vapour and sorption might need to be developed further. The draught equation has to be used with great care. Data are still the most crucial point.

| *Table 8. Assumptions for the simulations* |
|---|
| **Design assumptions** |
| 1. Example dwellings |
| 2. Ventilation systems |
| 3. Leakage values |
| **Residents' behaviour** |
| 4. Standard families |
| 5. Combination of families and type plans |
| 6. Time spent at home and in individual rooms |
| 7. Window airing pattern |
| 8. Internal door positions, indoor temperature |
| 9. Metabolism, water vapour production |
| 10. Criteria for house dust mites and mould growth |
| **Simulations** |
| Indoor air quality |
| Energy |
| Thermal comfort |
| Life Cycle cost |
| Noise |
| Reliability |

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## References

1. Månsson, L-G. **Annex 27 - Domestic Ventilation. Occupant Habits' Influence on Ventilation Need.** Proceedings 15th AIVC Conf. Buxton UK 1994. ISBN 0 946 075 79 4.
2. Månsson, L-G (ed). **Evaluation and Demonstration of Domestic Ventilation Systems. State of the Art.** Swedish Council for Building Research (to be printed autumn 1995).
3. Orme, M; Liddament, M; Wilson, A. **An Analysis and Data Summary of the AIVC's Numerical Database.** AIVC TN 44. ISBN 0 946 075 76 X
4. Orme, M. **Comparison of Multi-zone Air Flow Models.** AIVC, UK 1995 (to be published)
5. Kronvall, J; Blomsterberg, Å. **Performance of Passive Stack Ventilation in a Single-Family House. A Computational Simulation Study.** Proceedings 16th AIVC Conf. Palm Springs, USA, 1995.
6. Wallin, O. **Computer Simulation of Particle Deposition in Ventilation Duct Systems.** Bulletin no 31 Building Services Engineering, Royal institute of Technology, Stockholm Sweden, 1994. ISSN 0284 - 141X.