VENTILATION TECHNOLOGIES IN URBAN AREAS

19TH ANNUAL AIVC CONFERENCE
OSLO, NORWAY, 28-30 SEPTEMBER, 1998

Ventilation Reliability – an Evaluation Tool for Domestic Ventilation

Svein H. Ruud

Johnny Kronvall

Swedish National Testing and
Research Institute
P.O.Box 857
S-501 15 BORÅS
Sweden

J&W BAS
Slagthuset
S-211 20 MALMÖ
Sweden

Synopsis

Pre-assessing the reliability of ventilation systems is a difficult task and no simple methods have existed. This paper presents a tool for estimating the reliability of domestic ventilation systems. In general, ventilation reliability means the probability that the chosen ventilation system performs in an acceptable way for a certain building, in a certain climate, between scheduled maintenance measures. The tool presented consists of two different sub-tools: one for reliability as indicated by air flow rate stability as a function of situational factors and another for reliability as indicated by performance over time i. e. systems and components reliability.

Four different ventilation strategies have been analysed; natural window airing, passive stack ventilation, mechanical exhaust ventilation and mechanical exhaust and supply ventilation. The use of the tool involves specifications of the dwelling, the occupancy, the ventilation system etc. and the tool presents the consequences of the choices made, in a qualitative way on a five-grade scale from excellent to very bad reliability.

Introduction

Basic principles of a method for estimating the reliability of mechanical ventilation systems have been outlined (Kronvall, 1996) and further developed (Kronvall & Ruud, 1997). The concept of these analyses has been based on general methods for system safety analysis. The reliability analyses have now also been extended to other ventilation systems than mechanical ones, and another anlalysis component – flow rate stability has been added.

This final tool estimates the ventilation reliability for a dwelling. In general, the ventilation reliability means the probability that the chosen ventilation system performs in an acceptable way for a certain building, in a certain climate, between scheduled maintenance measures. Of real concern is the reliability of the indoor air quality. For practical reasons the tool presented consists of two different tools:

1. for reliability as indicated by air flow rate stability as a function of situational factors
2. for reliability as indicated by performance over time i. e. systems and components reliability.

Furthermore, the reliability as indicated by perceived indoor air quality can be analysed using the IAQ tool prepared in another part of the annex work. (Månsson ed., 1998).

The tool for airflow rate stability is based on the assumption that the ventilation flow rate in the bedrooms should exceed 4 l/s per person.

The tool for systems and components reliability is based on certain assumptions concerning mean life times, standard deviation of mean life times and maintenance intervals. If other assumptions are of interest, then an advanced computer based tool is available. In this advanced tool, the assumptions, mentioned above could be changed, see Main background report.

The paper forms part of the Swedish contribution to the work of IEA-Annex 27 "Evaluation and Demonstration of Domestic Ventilation Systems". The final report from the whole annex work (Månsson,ed., 1998) will be available by the end of 1998.

Input Parameters

Building parameters

Three climates are taken into account: Nice, London, and Ottawa corresponding to mild, moderate and cold situations.

Three types of dwellings are considered:

- A four main rooms (three bedrooms) apartment located on ground floor in a four-storey building (called D4a ground).
- A four main rooms apartment located on the top floor in a four-storey building (called D4a top).
- A four main rooms detached single family house (called D4c)

Two different leakage values. n_{50} can have the following values:

- 1 or 5 air changes per hour at 50 Pa, for the apartments D4a
- 2.5 or 10 air changes per hour at 50 Pa, for the house D4c

Ventilation system description

The ventilation systems are identified by four basic systems. (Natural window airing **NWA**, passive stack ventilation **PSV**, mechanical exhaust only **MEO**, mechanical exhaust and supply **MSE**). Those systems can then be combined with local fans in bathroom/toilet and/or kitchen and window opening patterns (closed, or climate depending).

WINDOWS OPENING (AIRING)

Bedroom windows can be opened during weekdays from 8 to 12 o'clock, depending on the weather conditions.

Supply air

NWA 2 cases of purpose provided openings:

- **no :** **0 cm^2**
- **yes :** **410 cm^2** (80 cm^2 in each habitable room. 30 cm^2 in each of the toilet, bath, kitchen)

PSV 2 cases of purpose provided openings:

- **no :** **100 cm^2**
- **yes :** **400 cm^2** (80 cm^2 in each bedroom and 160 cm^2 in the living-room)

MEO 2 cases of purpose provided openings:

- **no :** **0 cm^2**
- **yes :** **100 cm^2** (20 cm^2 in each bedroom and 40 cm^2 in the living-room)

MSE 3 cases of supply flow rates:

- **15 l/s** (3 l/s in each bedroom and 6 l/s in the living-room)
- **30 l/s** (6 l/s in each bedroom and 12 l/s in the living-room)
- **45 l/s** (9 l/s in each bedroom and 18 l/s in the living-room)

EXHAUST FLOW RATES AND STACKS

NWA No vertical duct

PSV A passive stack ducted ventilation system is installed in the kitchen, bathroom and toilet.

MEO and MSE The mechanical exhaust flow rate is given for three levels.

- 15 l/s (7.5 l/s in the kitchen 5 l/s in the bath and 2.5 l/s in the toilet)
- 30 l/s (15 l/s in the kitchen 10 l/s in the bath and 5 l/s in the toilet)
- 45 l/s (22.5 l/s in the kitchen 15 l/s in the bath and 7.5 l/s in the toilet)

Heat exchanger efficiency for MSE is 50 %

LOCAL ADDITIONAL EXHAUST FANS

No no local fan

Yes 2 local fans as follows:

- Kitchen hood: Running time 1 h/day, at 17.00 - 18.00 o'clock. Flow rate 100 l/s
- Bathroom fan: Running time 2 h/day. **Weekdays** 6.00 - 8.00 o'clock and weekends at 9.00 - 11.00 Flow rate 25 l/s.

TECHNICAL QUALITY OF VENTILATION SYSTEMS

Poor system: Low cost equipment is chosen in order to minimise the initial cost. Low attention to future maintenance and life cycle cost.

Average system: Relatively good quality standard equipment chosen according to good engineering practice. Some attention on minimising future maintenance and life cycle cost, but still rather high attention on minimising the investment cost.

Best Practice: The best available high quality equipment is carefully chosen. High attention on minimising future maintenance and life cycle cost. Less attention on reducing the investment cost.

Note: All the components of each system are assumed to be equally poor or good, i.e. there are no single especially weak (or strong) component. (To see the influence of an unevenly designed system we refer to the use of the advanced tool, which has been used when developing the simplified tool. See "Main background report".)

Maintenance levels

High: Maintenance is performed approximately 50-100 % more intense (often) than normal practice for the actual type of system.

Medium: Maintenance is performed with an intensity according to normal practice for the actual type of system.

Low: Maintenance is performed approximately 30-50 % less intense (often) than normal practice for the actual type of system.

Note: For each maintenance level, the maintenance interval of each component is assumed to be equally intense, i.e. there is no single maintenance interval for any component that is especially short or long. (To see the influence of an uneven maintenance scheme we refer to the use of the advanced tool. See "Main background report".) It should also be noted that if the chosen maintenance level does not correspond to the suggested level in the output of the LCC-tool, then the calculated LCC does not apply for the chosen level.

Other situations

The tool was produced based on a four room dwelling. For other cases, it is possible to use the tool if it is considered that one bedroom is added or deleted (nevertheless, a one main room dwelling should not be taken into account). The results are then less precise, but the ranking would remain quite the same. If these changes must be made, the following adjustments could be applied:

- n_{50} : no change, as n_{50} is related to the dwelling volume
- Airing : no change
- Supply air devices : the bedroom(s) added or deleted are equipped as defined in 2.2.2
- Mechanical airflow: add or subtract 3, 6 or 9 l/s for each bedroom. Split the total exhaust airflow in kitchen, bathroom and toilet using weights of 3:2:1.
- Additional fan : no change

Output Data

The output from the tool is given as qualitative ratings with the following interpretations:

+ +	**Excellent reliability**
+	**Good reliability**
0	**Fair reliability**
-	**Poor reliability**
- -	**Very poor reliability**

Evaluation Tool

In Tables 1, 2 and 3 are given the reliability as indicated by situational factors (flow rate stability)

Table 1 Reliability flow rate stability. Climate ***NIce***

System	Airing	Inlet	Exhaust	Extra	Dwelling					
		area	fan flow	fan	Apartment				House	
			rate		D4a top		D4a ground		D4c	
					n50		n50		n50	
					1	5	1	5	2.5	10
NWA	No	0		N	- -	-	- -	-	- -	- -
				Y	- -	-	- -	-	- -	- -
		410		N	0	0	0	0	-	0
				Y	0	+	0	0	-	0
	Yes	0		N	-	0	-	0	-	-
				Y	-	0	-	0	- -	-
		410		N	+	+	0	0	0	0
				Y	0	+	0	+	0	0
PSV	No	100		N	+	+	0	+	0	0
				Y	+	+	0	+	0	0
		400		N	+	+	+	+	+	+
				Y	+	+	+	+	+	+
MEO		0	15	N	- -	0	- -	0	- -	0
				Y	- -	0	- -	0	- -	0
			45	N	0	+	0	+	-	0
				Y	0	+	0	+	-	0
		100	15	N	-	0	0	0	0	0
				Y	0	+	0	0	0	0
			45	N	+	+	0	+	0	0
				Y	+	+	+	+	0	0
MSE			15	N	0	+	0	+	0	+
				Y	0	+	0	+	0	+
			30	N	++	++	++	++	++	++
				Y	++	++	++	++	++	++
			45	N	++	++	++	++	++	++
				Y	++	++	++	++	++	++

Table 2 Reliability flow rate stability. Climate **London**

System	Airing	Inlet area	Exhaust fan flow rate	Extra fan	Dwelling					
					Apartment				House	
					D4a top		D4a ground		D4c	
					n50		n50		n50	
					1	5	1	5	2.5	10
NWA	No	0		N	-	-	-	-	- -	-
				Y	- -	-	- -	-	- -	-
		410		N	0	+	0	0	0	0
				Y	0	+	0	0	0	0
	Yes	0		N	0	0	0	0	-	0
				Y	-	0	-	0	-	0
		410		N	+	+	0	+	0	0
				Y	+	+	0	+	0	+
PSV	No	100		N	+	+	0	0	-	0
				Y	+	+	0	0	-	0
		400		N	+	+	+	+	0	0
				Y	+	+	+	+	0	0
MEO		0	15	N	- -	0	- -	0	- -	0
				Y	- -	0	- -	0	-	0
			45	N	0	+	0	+	-	0
				Y	0	+	0	+	-	0
		100	15	N	0	+	0	0	0	0
				Y	0	+	0	0	0	0
			45	N	+	+	+	+	0	0
				Y	+	+	+	+	0	0
MSE			15	N	0	+	0	+	0	+
				Y	0	+	0	+	0	+
			30	N	++	++	++	++	++	++
				Y	++	++	++	++	++	++
			45	N	++	++	++	++	++	++
				Y	++	++	++	++	++	++

Table 3 Reliability flow rate stability. Climate **Ottawa**

System	Airing	Inlet area	Exhaust fan flow rate	Extra fan	Dwelling					
					Apartment				House	
					D4a top		D4a ground		D4c	
					n50		n50		n50	
					1	5	1	5	2.5	10
NWA	No	0		N	-	0	-	0	-	0
				Y	-	0	-	0	-	0
		410		N	0	+	0	+	0	0
				Y	0	+	0	+	0	0
	Yes	0		N	0	0	0	0	0	0
				Y	0	0	0	0	0	0
		410		N	+	+	+	+	0	+
				Y	+	+	+	+	0	+
PSV	No	100		N	0	0	0	0	-	0
				Y	0	0	0	0	-	0
		400		N	+	+	0	0	0	0
				Y	+	+	0	0	0	0
MEO		0	15	N	- -	0	- -	0	-	0
				Y	- -	+	-	0	-	0
			45	N	0	+	0	+	-	0
				Y	+	+	0	+	0	0
		100	15	N	0	+	0	0	0	0
				Y	0	+	0	+	0	0
			45	N	+	+	+	+	0	0
				Y	+	++	+	+	0	0
MSE			15	N	0	+	0	+	0	+
				Y	0	+	0	+	0	+
			30	N	++	++	++	++	++	++
				Y	++	++	++	++	++	++
			45	N	++	++	++	++	++	++
				Y	++	++	++	++	++	++

Table 4 Reliability as indicated by performance over time is shown in the set of tables on this page

Apartments

Passive stack ventilation system			
Technical quality of system	Maintenance level		
	High	Medium	Low
Poor system	++	++	-
Average system	++	++	+
Best practice	++	++	++

Central exhaust ventilation			
Technical quality of system	Maintenance level		
	High	Medium	Low
Poor system	++	-	--
Average system	++	++	-
Best practice	++	++	+

Central supply and exhaust ventilation			
Technical quality of system	Maintenance level		
	High	Medium	Low
Poor system	+	--	--
Average system	++	+	--
Best practice	++	++	0

For natural window airing ventilation strategy, only openable windows, and sometimes natural supply air devices in the facades, constitute the ventilation system. For this
case, the score "++" could be used.

Single family houses

Passive stack ventilation system			
Technical quality of system	Maintenance level		
	High	Medium	Low
Poor system	++	+	-
Average system	++	++	+
Best practice	++	++	+

Central exhaust ventilation			
Technical quality of system	Maintenance level		
	High	Medium	Low
Poor system	++	-	--
Average system	++	++	-
Best practice	++	++	+

Central supply and exhaust ventilation			
Technical quality of system	Maintenance level		
	High	Medium	Low
Poor system	+	--	--
Average system	++	0	-
Best practice	++	++	-

For natural window airing ventilation strategy, only openable windows, and sometimes natural supply air devices in the facades, constitute the ventilation system. For this
case, the score "++" could be used.

Further Information

Reliability as indicated by situational factors

Computer simulations of outdoor air flow rates to individual rooms have been performed by means of a multi-zone air flow model.

The reliability as indicated by situational factors study is focused on the fraction of time of the total heating season when the **ventilation airflow rate is at or above a certain ventilation requirement.** The target value chosen for outdoor air ventilation flow rate is 4 litres per second per person in the bedrooms. This airflow rate chosen represents an internationally commonly used figure.

In order to establish quantitative relationships between building characteristics, ventilation strategies, climates etc. and the responding parameter, which is the air flow rates to the bedrooms, a procedure using fractional factorial design (174 combinations) and a statistical analysis was used.

In the simplified tool a qualitative value is given depending on the fraction of time when the air flow rates at or above the target value. This is 4 litres per second and person in the bedrooms, as an average for the bedrooms in the house/dwelling.

In order to assess the performance of different ventilation strategies etc., from a flow rate stability point of view, it is necessary to set up intervals for different classes, see table 5.

Table 5 Transformation from quantitative to qualitative values Flow rate stability

Fraction of time with acceptable flow rates	**0.50-1.00**	**0.25-0.50**	**0.12-0.25**	**0.06-0.12**	**0.00-0.06**
Assessment	**++**	**+**	**0**	**-**	**--**
Reliability Quality	**Excellent**	**Good**	**Fair**	**Poor**	**Very poor**

Reliability as indicated by performance over time

Mechanical ventilation systems are built up by a number of mechanical and electrical components, such as fan(s), electrical motor(s), damper(s), silencer(s), air terminal devices, system(s) for automatic control etc. The way that these components influence the performance of the system can of course be described in a fault-tree analysis. There are principally three different kinds of probabilities to estimate individual events.

Fixed probabilities These probabilities are, in principle, not depending on time. Power failure for example can be estimated if you can acquire data on how many hours per year you can expect power failure from the Electricity Company.

Time-depending probabilities These are depending on in which state, i.e. at what time you analyse the problem. The failure intensity for mechanical components, for example, is not the same as long as the component is fairly new compared to when it grows older. Another example is duct fouling with its consequences of gradually lower flow rates.

More or less unknown probabilities In the context of ventilation performance, typical examples are events based on user influence. These probabilities are very little known, not only because people are different, but also that the design of the ventilation system influences the behaviour.

By connecting component models in a fault-tree scheme, the analysis can be extended to a system level. An example of a fault-tree for a mechanical exhaust ventilation system is given in figure 1.

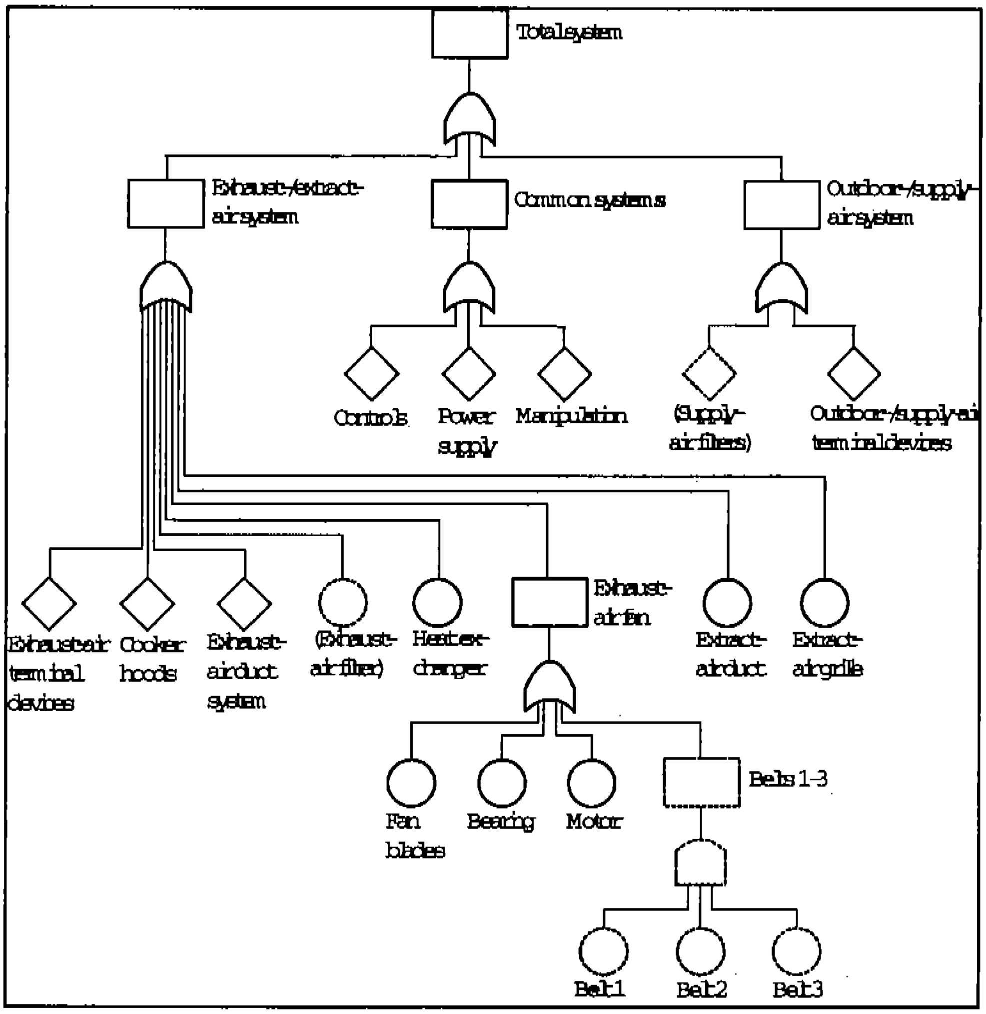

Figure 1 Fault tree for a central mechanical exhaust ventilation system

A simplified model for describing the influence of maintenance has also been incorporated into each component model. It assumes that after each maintenance occasion, the component is "as good as new".

For each type of system, three different quality standards have been defined and combined with three different levels of maintenance level. This means a matrix with a total of nine different combinations for each ventilation system. Relevant data have been collected from published and orally transferred empirical experiences from maintenance people and other researchers working with reliability or related matters.

The result of each combination in the matrixes with life time and maintenance intervals can be presented in figures showing the estimated reliability for the system as a function of time. The result is further evaluated by calculating the mean and minimum value of the reliability for a time span of 30 years. An example is shown in figure 2. The result for each system applied in both single-family houses and multi family buildings can be summarised in a matrix.

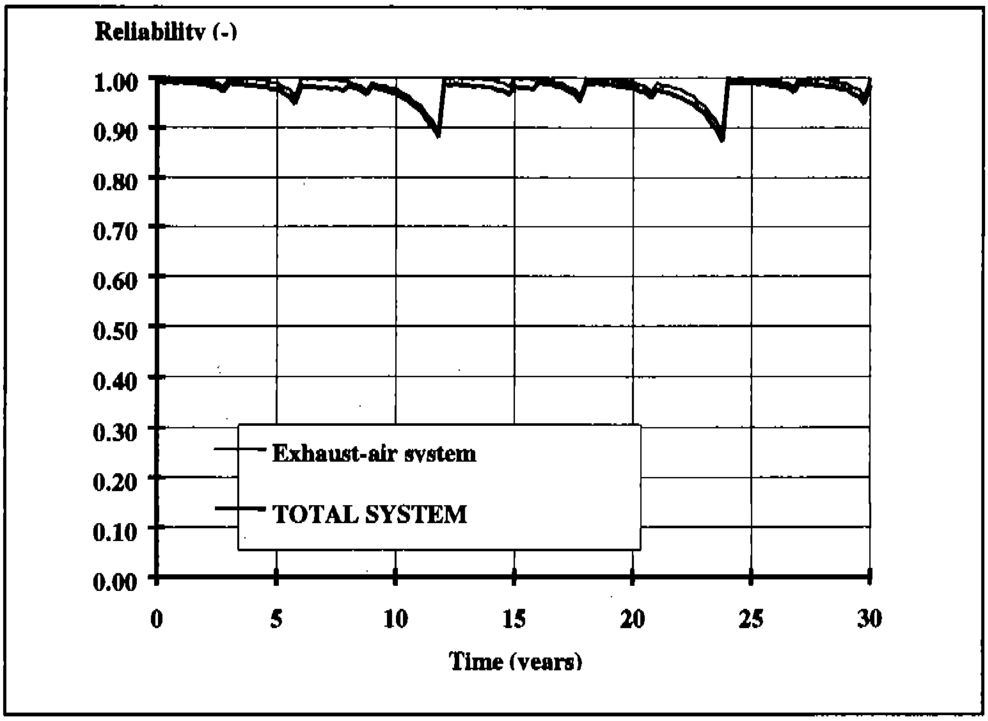

Figure 2 ***The variation of reliability over a 30 year period for a multi-family building with exhaust ventilation at an average system performance with medium maintenance***

The resulting mean and minimum values (of the reliability for a time span of thirty years) given in the matrixes is then finally evaluated and transferred into a single classification system, the qualitative tool. The interpretation from mean and minimum values to qualitative values are given in table 6.

Table 6 Transformation from quantitative to qualitative values Performance over time

	Minimum reliability									
Mean reliability	**0.90-1.00**	**0.80-0.89**	**0.70-0.79**	**0.60-0.69**	**0.50-0.59**	**0.40-0.49**	**0.30-0.39**	**0.20-0.29**	**0.10-0.19**	**0.00-0.09**
0.90-1.00	++	++	+	+	0	0	-	-	- -	- -
0.80-0.89		+	+	0	0	-	-	- -	- -	- -
0.70-0.79			0	0	-	-	- -	- -	- -	- -
0.60-0.69				-	-	- -	- -	- -	- -	- -
0.50-0.59					- -	- -	- -	- -	- -	- -
0.40-0.49						- -	- -	- -	- -	- -
0.30-0.39							- -	- -	- -	- -
0.20-0.29								- -	- -	- -
0.10-0.19									- -	- -

0.00-0.09										- -

The use of the advanced tool for systems and components factors involves the use of a computerised tool (spreadsheet) for MS-Excel, Version 5.0 or 7.0. The tool is available electronically (by e-mail with attached *.XLS files, or on diskette) from:

Mr. Svein Ruud, Swedish National Testing and Research Institute,
Mail: Box 857, SE-501 15 BORAAS, Sweden,
E-mail: svein.ruud@sp.se

Or

Dr. Johnny Kronvall, J&W BAS,
Mail: Slagthuset, SE-211 20 MALMOE, Sweden,
E-mail: johnny.kronvall@malmo.jacwid.se

In this advanced tool, it is possible to change the figures and use your own figures.

Conclusions

From the work performed, the following conclusions can be drawn:

Regarding flow rate stability

- The flow rate stability is very sensitive to the ventilation system chosen.
- Generally, the flow rate stability is better for mechanical systems than natural and passive ones
- It is easier to maintain stable flow rates in colder climates than in mild ones

Regarding performance over time

- The general concept of system safety analyses can be used in order to assess the performance over time for mechanical ventilation systems.
- There is a great lack of knowledge on basic reliability data for ventilation system components, e.g. life-times; only more or less "best guesses" can be used with the present knowledge.
- The reliability of a mechanical ventilation system is determined both by the technical quality of the system and the maintenance intensity.

Acknowledgements

This work was sponsored by the Swedish Council for Building Research under research contract no. 940309-6. The support is gratefully acknowledged.

References

Main background report

Kronvall, J., Ruud, S. et al., (1998) *Reliability of Domestic Ventilation Systems*, AB Jacobson & Widmark, Malmö, Sweden. http://www-epb.lbl.gov/annex27

Other related literature

Feustel, H. & Raynor-Hoosen, A., (1990) *COMIS Fundamentals*, Energy Performance of Buildings Group, Applied Science Division, Lawrence Berkeley Laboratories, Berkeley, USA.

Gröninger, B.P. and van Paasen, A.H.C. (1997) *Characteristics Values of Natural Ventilation and Air Conditioning*, Proceedings from the 18th AIVC Conference in Greece, AIVC, Coventry, UK, 1997.

Kronvall, J., (1996). *System Safety Analysis on the Performance of Mechanical Ventilation Systems*, Proceedings from the 17th AIVC Conference in Sweden, AIVC, Coventry, UK.

Kronvall, J. & Ruud, S., (1997). *System Safety Analysis on the Performance of Mechanical Ventilation Systems – the quantitative approach*, Proceedings from the 18th AIVC Conference in Greece, AIVC, Coventry, UK, 1997.

Myrefelt, S., (1996). *A Model for Feed-back of Experience on Operational Reliability in Indoor-climate and Ventilation systems* (In Swedish) Div. of Building Services Engineering, Royal Institute of Technology, Sweden.

Månsson, L.-G., (ed.) (1998), *Simplified Tools for Evaluation of Domestic Ventilation Systems. Hand Book.*, IEA, Energy Conservation in Buildings and Community Systems Programme, Annex 27. LGM-Consult, Stockholm, Sweden.